BASIC CONCEPTS INTO METHODOLOGIES ON SYSTEMS APPROACH TO BUILDING FIRE SAFETY

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ABSTRACT

Methodologies on systems approach might be useful for the synthetic estimation of building fire safety. However, the meaning of their formula often seems obscure or irrational. This paper has a discussion on the characteristics of systems-structures applied to each method. For example, Gretener's method is basically composed by a divisional formula, which belongs to an emphatic expression with the ratio of hazard potential to safety countermeasures. The other discussions are on the point-making methods determining an effectiveness of fire facilities, with a tentative result of double effectiveness of sprinkler systems to heat detector equipments.

INTRODUCTION

There exist great deal of tools to assess building fire safety with the systemic point of view: i.e. probabilistic or stochastic estimation^[1], experts judgement, senario description etc.. However, in some cases, they might have been derived from obscure thinkings, which leads to discuss the basic meaning of their tools. With the viewpoint of taking stage-factors into systems-structure, the following problems have

been unsolved. Table-1 indicates the adopting status of stage-factors into fire safety systems.

- 1) Initial Stage : the risk-level of fire origin in fire management.
- 2) Growing Stage : the possibility of flashover-outbreak in a compartment.
- 3) Developed Stage : the severity of smoke and toxic gases to evacuee.

Table-1 The adopting situation of stage-factors in system-structures

Stage	methodologies of firesafety evaluation			
	probabilistic	Delphi	Multivariate	Senario
Initial	C	B	C	C
Growing	B	B	C	B
Developed	B	B	B	B
All	B	A	B	C

(A: better, B: good, C: not good)

Methodologies on systems approach are subject to be aimed at the establishment of systemic fire safety^[2]. A deterministic tool such as physical or chemical simulation is supposed to be more powerful for simple space-requirements, despite of a bit inflexibility. On the other hand, the advantage of a systemic method seems to exist in the possibility of solving problems on human factors or safety trade-off for large building complex^[3]. One of the main points in this paper is to discuss the basic concepts on the characteristics of systems-structure of building fire safety.

THE ANALYSIS OF THE CHARACTERISTICS FOR BRUSHING UP A FIRE SAFETY SYSTEM

The following characteristics should be equipped in a fire safety system.

- 1) It should be a typical application of scientific methodologies to engineering fields.

The reason : science should be exact and divisive, aimed at elucidating the truth of nature. Engineering might not need too much exactness, because of its applicability to social complexities, but it should be a reliable tool for social efficiency and comfortability.

- 2) It should be a structure based on the combination of several scientific methodologies.

The reason : engineering is essentially composed by man-machine system. Human behavior or recognition might be intuitively flexible or ambiguous, caused by the exact activities of human brain.

- 3) It should be a structure with flexibility and capability of transferring science to engineering.

The reason: a flexible system will include the following mathematical expression

- a) $E \cup E \neq \text{The whole}$

The gathering of parts of events cannot always compose the whole, and ambiguity is not equal to probabilistic randomness.

- b) $FP = \sum p(i) \times pp(i : j)$

where, FP : stochastic value of safety-feeling, $p(i)$: probability of i-event derived from mathematical formula, $pp(i : j)$: estimating ratio of i-feeling derived from personal safety feeling or consensus. Human feeling at the verdict of a certain safety-level seems similar to that of "i or around i at diceplay". If $i=3$,

$$\begin{aligned} FP(3) &= p(1)pp(1:3) + p(2)pp(2:3) + p(3)pp(3:3) + \\ &\quad \dots + p(5)pp(3:5) + p(6)pp(3:6) \\ &\doteq 1/6 \times 0.001 + 1/6 \times 0.1 + 1/6 \times 1 + \dots \\ &\quad + 1/6 \times 0.001 + 1/6 \times 0 \doteq 0.20 \end{aligned}$$

On the other hand, the appearance of 3 at diceplay is $1/6 (=0.17)$, which means stochastic value of safety feeling may be a bit swelling. Fig.-1 shows a curve based on human feeling to a certain safety-level(si).

Fig.1 An ambiguous concept on human feeling for a certain safety-level

- 4) It should be aimed at a method for evaluating human value.

The reason : final target of all sorts of safety

technologies is to eliminate unwanted loss of life. According to a social consensus, the value of human life can be expressed as time-increment function. However, the settlement of the function might be quite difficult. As shown in Fig.-2, if a present situation is at point M1, a change of situation from M1 to Mmin is preferable, because of the reduction of human-loss(A1 → A). On the contrary, a movement of situation from M2 to Mmin might be rejected because of the increase of human loss (A ← A2).

Fig.2 a concept on human-loss function relating to total-loss for firesafety

- 5) It should be a tough structure despite of taking unstable parameters.

The reason : for determining a safety-level, blanks of formula should be filled with some fixed values often derived from statistical or Delphi estimation. Fire accidents are to occur as probabilistic phenomena, but almost quite different, so the values of factors from statistical analysis are subject to be unstable.

- 6) It should be a dynamic structure considering the reduction of reliability of factors.

The reason: for building fire safety, No.3 curve is often adopted, because of mental sensitivity to survival as shown in Fig.-3

Fig.3 Preferable reliability of fire barrier as a function of time

THE CLASSIFICATION OF MATHEMATICAL FORMULAS FOR THE EVALUATION OF BUILDING FIRE SAFETY

The structures of an evaluation method for building fire safety are classified in four basic types of mathematical formulas. According to the methodologies shown in table-1, a senario analysis is a method for determining a certain risk or safety level by writing carefully a detail process through an accident^[5]. The other four methods like tree, Delphi and multivariate analysis have more or less some sorts of mathematical formulas.

- 1) Type-1: Additive style

A basic example for fire analysis:

$$TL = (FB + EF + FE + FD + IC + MC) + HL + DL + IDL$$

Where, TL : total loss, and fire investment cost (FB : compartmentation, EF : escape facilities, FE : fire equipment, FD : fire department, IC : insurance cost, MC : maintenance cost), HL : human loss, DL : direct loss, IDL : indirect loss.

$$EFP1 = APL + PPL + HCL \div PD + PSp + RML$$

where EFP1 : effectiveness of fire protection, APL : active protection level, PPL : passive protection level, HCL : human correspondence level, PD : performance of doors, PSp : performance of sprinkler systems, RML : risk management level.

Edinburgh point scheme^[4,6,7] and Tokyo-metro matrix figure method^[8] partly belong to this type.

2) Type-2 : Multiplicative Style

This style is often used for an event tree analysis. A basic example is as follows.

$$PD = FR \times MF \times ML, \quad FR = S \times I \times P$$

Where, PD : performance of a door, (FR : fire resistivity, MF : mechanical function, ML : management level) of the door ; S : stability, I : insulation level, P : flame or smoke penetration level.

NBS Occupancy Risk Analysis^[9,10] and Decision Tree Analysis^[11,12,13,14] partly belong to this type.

3) Type-3 : Divisional Style

This is preferable for presenting the efficiency of countermeasures against fire damages. A basic example is in the following.

$$HP = LD/LC$$

Where, HP : hazard potential, LD : level of danger, LC : level of countermeasures. Gretener's method and other following methods^[15,16] mainly belong to this type.

4) Type-4 : Vector Style

This type has been little used for fire safety fields, because system-elements have more or less relationship with each other.

$$EFP2 = \left((APL)^2 + (PPL)^2 + (HCL)^2 \right)^{1/2}$$

where, the above nomenclatures have been mentioned at Type-1.

Point-making method in Tokyo-metro Matrix Figure Analysis⁽⁸⁾ belong to this type.

5) Type-5 : Mixed Style

The above four types are usually in a system structure. Network method for evaluating hazard potential of an existing building^[17] NBS method for health care facilities and E.R.I.C. method belong to this type.

THE COMPARATIVE CHARACTERISTICS OF EACH EVALUATION FORMULA

General expressions of each style are in the following,

$$\text{Type-1: } T1 = \sum w_i \times x_i$$

$$\text{Type-2: } T2 = \prod x_i^{w_i}$$

$$\text{Type-3: } T3 = \prod x_i^{w_i} / \prod x_j^{w_j}$$

$$\text{Type-4: } T4 = \left(\sum (w_i \times x_i)^2 \right)^{1/2}$$

Where, x_i :value of factor- i , w_i :weight of factor- i

For explicating the characteristics of each formula, if $i=2$, the peak or bottom will appear in Type-2 or 4 curve,

$$\text{at } x1 = x2 = T1/(w1 + w2) \text{ for Type-2}$$

$$\text{at } x1 = T1/(2w1), x2 = T1/(2w2) \text{ for Type-4}$$

and, moreover, in case of $w1 = w2 = 1$, each curve is shown in the Figure-4, which is to indicate the below-mentioned meaning.

As for Type-1 formula, each value of factors would supplement the other factors.

As for Type-2, the peak appears at the middle point, and $T2$ -value is 0 at the end point of each $x1$ or $x2$, which means this formula would

represent a balance style under constant $T1$.

As for Type-3, value of $T3$ is increasing to infinite at $x1$ or $x2=0$, which means $T3$ curve would be emphatic, comparing with the other curves.

As for Type-4, $T4$ becomes minimum at the point of $x1=x2$, and on the contrary, the maximum appears at the end of each $x1$ or $x2$, which means Type-4 curve would give an individuality (fig-4), and the characteristics of each formula discussed here are summarized in Table-2.

Fig.4 The characteristics of each formula at a certain $T1$

Table-2 A Basic formula for evaluating building fire safety

Type	Formula	Characteristics	Example
1	$\sum w_i \cdot x_i$	Supplimental	Edinburgh Point Scheme
2	$\prod x_i^{w_i}$	balancing	and-gate (NBS, NFPA, WPI)
3	$\prod x_i^{w_i} / \prod x_j^{w_j}$	emphatic	Gretener's Method
4	$(\sum (w_i \cdot x_i)^2)^{1/2}$	individual	Tokyo-metro's point
5	mixed	mixed	E.R.I.C. Method, NBS-Health Care

THE DETERMINATION OF THE VALUE AND WEIGHT OF EVALUATION FACTORS

Among several stochastic tools, a pair comparison method is often applicable for the determination of a factor-weight^[18]. For determining the points of fire facilities as factors to prevent flashover, this method is adopted here and the preliminaries are in the following.

1) Suggested factors :

A : Sprinkler system, B : Portable extinguisher, C : Heat detector equipment

2) Points by five experts, asked "Which is useful (A or B), (B or C), (C or A)?" : if useful, give 2 points; if the same, 1 point; if not, 0 point.

The result of χ^2 -analysis : $\chi^2 (2, 1\%) = 4.5 < 6.2$;
Variance analysis : $F(2, 13, 1\%) = 6.93 < 7.75$ as shown in Table-3.

Table-3 Points by experts, χ^2 -and F-analysis

	x1	x2	x3	x4	x5	total	avg	df	df ²	df ² /avg	V1row	V2error
A	4	2	3	4	3	16	10(3.2)	6	36	3.6	6.2	2.8
B	1	2	0	0	2	5	10(1)	-5	25	2.5		4 9.6/(15-3)
C	1	2	3	2	1	9	10(1.8)	-1	1	0.1		2.8 =0.8

$$V1row/V2error = 6.2/0.8 = 7.75$$

Results : in the case, a Presumed Point of each factor : (16,5,9)=(0.53,0.17,0.3) with 99% reliability.

At the second, a quantitative method applied here is for determining effectiveness of the before-mentioned fire facilities (A : sprinkler, C : heat detector) against flashover in case of four office fires with similar scales (Table-4).

Table-4 The effectiveness of fire facilities against flashover

office	heat detectors		sprinklers		flashover	
	well	bad	well	bad	no	yes
Y1	*		*		*	
Y2	*		*			*
Y3		*	*		*	
Y4		*		*		*
point	p11	p12	p21	p22		
(Result:	1	2	5	3	) A/C=8/3=2.67	

The process to the determination of points :
Variance of no flashover(Vnf) and flashover(Vf) cases,

$$Vnf, Vf = \frac{(NF-M)^2 + (F-M)^2}{2} \\ = \frac{(p21-p22)^2}{16}$$

Variance of all cases,

$$Va = \frac{(p11+p21-M)^2 + (p11+p21-M)^2 \\ + (p12+p21-M)^2 + (p12+p22-M)^2}{4}$$

where,

$$NF = \frac{(p11+p21) + (p12+p21)}{2},$$

$$F = \frac{(p11+p21) + (p12+p22)}{2},$$

$$M = \frac{(NF+F)}{2}$$

The most suitable value of each pij can be obtained at the maximum of the correlative ratio :
 $R = Vnf, Vf/Va$

that is, $\partial R / \partial pij = 0$

$$\therefore 2(p11-p12) = (p22-p21), \quad R = 1/2$$

Then, each point(p11,p12,p21,p22) might be determined as (1,2,5,3) for a suitable appraisal.

As for the difference of effectiveness between sprinkler system and heat detector equipment, a pair comparison method gives us $15/9 = 1.78$, and quantitative method $8/3 = 2.67$

From the two brief results, it seems that sprinkler system would have about double reliabilities comparing with heat detector equipment against flashover. However, more detailed investigations must be necessary, because other factors such as fuel-conditions, compartmentation, fire or risk management are not negligible^[19,20,21].

CONCLUSIONS

For identifying the effectiveness of systemic tools adopted for evaluating building fire safety, the characteristics of systems-structure were analyzed here through discussing the adoption of human-value and the durable reliability of system factors. Each system is usually composed by mathematical formulas. However, the meaning of their formulas have not discussed in detail before this paper. Several analyses on their formulas were carried out here with the significant result on the classification of formulas, i.e. Additive-, Multiplicative-, Divisive-, and Vector-Style, whose meanings were firstly named as supplemental-, balancing-, emphatic- and individual-Style.

The other thoughts on point-making methods for a system factor, were discussed in this paper, aimed at the establishment of some effective tools for supporting expert-judgement or Delphi method. For this purpose, the effectiveness of fire facilities were examined, with a brief result of double difference between sprinkler system and heat detector equipment.

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