A Study on Improvement of Fire Protection Systems based on Failure Characteristics accodrding to Yearly Variation in Old Commercial Buildings

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Abstract

Background: Safety assessment of fire protection system is very important. Especially, Fire Protection system is central to minimizing damage to human lives and property. They're not in demand at normal times but are definitely needed in times of fire or other disasters. Concerns of performance loss or failure owing to yearly variation remain but the nature of fire protection system challenges users from detecting equipment failure or defects early on. **Methods:** This study sets a certain inspection score to defect probability, which is calculated by quantitative defect probability arising from yearly variation in fire protection systems by part of fire protection systems observed by time and use the score as the basis to determine replacement and inspection of parts. This study also aims at suggesting hazard calculation associated with aging based on criticality and yearly variation of fire protection systems. This method can realize active and quantitative management and the old fire protection system. **Findings:** Presented in this study Performance Assessment Tool allows a more effective replacement and inspection of firefighting equipment in structures and eventually calculate hazard of firefighting equipment. **Improvements:** For improvements of this study, data on defect rate of fire protection systems should be recorded to deliver higher reliability and aging of fire protection systems reliable management.

Keywords: Failure Characteristics Characteristic, Fire Protection System, Old Commercial Building, Yearly Variation

1. Introduction

Objective of fire protection systems is to keep off fire or other kinds of disasters in advance or keep damage to minimum. It should be readily able to do its job in all cases in response to changes in the surrounding environment. Any inconvenience associated with fire protection systems is hardly recognized by users as they are not used all the time and a rather long period until disuse or renewal makes it difficult to predict defects arising from yearly variation or environmental changes. All structures in Korea are subject to legal and periodical inspection, which varies by size and structures' purpose, but their performance until the next inspection cycle is not fully guaranteed since their repair and replacement are determined only by checking how well they work during inspection. Small and medium-sized structures shall ensure performance guarantee of fire protection systems through supervisor's safety control activities. There is a need to introduce replacement cycle standard that accounts for greater yearly variation and environmental changes in order to secure reliability. Put in another way, fire protection systems should be guaranteed of their performance at all times and quantitative analysis method should be applied during replacement and inspection period. Based on this understanding, this study aims to propose performance diagnosis methodology for fire protection systems by examining quantitative defect ratio owing to yearly variation from the year a particular structure is completed and determining criticality of each equipment and part.

2. Operation of Fire Protection Systems and Methodology

2.1 Operation of Fire Protection Systems

Study on the fire protection systems analysis has been studied continuously from the past. Typically, the NFPA has been presented to the scientific concept of fire safety systems¹. Fire safety systems research until recently has become a study on the reasonable quantification method of fire safety systems² and evaluation methods³. But performance improvement of fire protection systems has more to do with improvement in physical/functional performance loss of equipment and system than with performance loss arising from economic and environmental aging. This suggests the importance of performance guarantee. It is, therefore, highly important to develop an effective maintenance solution to ensure they properly perform during fire by inspecting and replacing equipment at the right time.



Rapid combustion of the combustible material
Delay of access to the scene (illegal parking)
Arrival on the field delays (traffic jams)
Long distance Fire Station
Insufficient Function of Fire compartment
Narrow distance between the neighboring buildings
Congestion wooden buildings
Weather (dry, strong winds, etc.)
Etc
Uaknown
Reporting delay
Duct becomes the passage of smoke

Figure 1. The cause of greater combustion during fire accidents in Korea (2011~2015).

An analysis into identifying cause of greater combustion during fire accidents in Korea over the last five years ($2011 \sim 2015$) points to rapid combustion of combustible materials as the primary culprit⁴. This indicates failure by fire protection systems to put out fire in the early stage, which is their most important job (Figure 1).

Figure 2 presents operation status of major fire protection systems in the last five years⁴. There are still many cases of fire protection systems and system not working properly at times of fire accidents when they are most direly needed. In particular, fire alarm system and automatic fire detection system fail to work in over 25% of the cases.





2.2 Performance Diagnosis Methodology

Performance of fire protection systems shall therefore be guaranteed at all costs yet they're not being properly replaced and repaired as they are not always in use. Hence, this study aims at proposing supervisor-led performance diagnosis to support proper replacement and repair of fire protection systems and solutions for improvement. To this end, the basis in this study is elements of performance loss owing to yearly variation of fire protection systems. Aging of fire protection systems has many causes that include quality issues, surrounding environment and construction capabilities but it is impossible to classify and analyze all causes of aging. Recognizing such limitations, this study limited aging of fire protection systems caused by yearly variation to defect rate of fire protection systems applied to actual buildings. In other words, performance diagnosis of fire protection systems proposed in this study classifies each fire protection systems by equipment and part. It also encourages proactive control by users and supervisors, particularly firefighting safety supervisors and building owners, based on defect rate of fire protection systems by yearly variation and criticality by equipment and part.

Figure 3 shows concept of fire protection systems performance diagnosis proposed in the study.

3. Performance Diagnosis Method of Fire Protection Systems

3.1 Performance Diagnosis Method of Fire Protection Systems

Performance diagnosis of aging fire protection systems proposed in this study grants a certain diagnosis score to defects rate of each part in fire protection systems that occurs with time variance based on quantitative defect rate associated with yearly variation of fire protection

Fire protection systems	Parts	Defect function formula using trend curve	R2 value (Coefficient of determination)	Key inspection points		
Automatic fire detection	Receiver(P type)	f(x) = 0.46692x	0.47	Spare charging equipment, line, short circuit		
equipment	Alarm(sound) system	f(x) = 0.30653x	0.95	Volume, tone		
	Transmitter	f(x) = 0.70013x	0.72	Touch button, lamp		
	Smoke detector*	f(x) = 0.97249x	0.85	Status of operation/installation		
	Thermal detector*	f(x) = 0.42888x	0.76	Status of operation/installation		
Water-based fire extinguishing equipment	Wiring, power	f(x) = 0.21796x	0.71	Wiring, short circuit		
	Pipeline**	f(x) = 0.73235x	0.87	Pipeline damage, corrosion		
	Valve	f(x) = 0.47535x	0.66	Status of operation, corrosion		
	Pump performance	f(x) = 0.53393x	0.87	Defect by pump performance test value		
	Water source/water tank**	f(x) = 0.81082x	0.61	Valve status, water gauge		
Sprinkler System	Head	f(x) = 1.0179x	0.98	Head status, performance		
	Water flow device	f(x) = 0.73714x	0.63	Water flow device, power switch solenoid, status of water gauge		
	Control panel	f(x) = 0.52286x	0.71	Status of supervisory control panel, power control panel		
Indoor fire hydrant equipment	Control panel	f(x) = 1.0058x	0.78	Status of signal lamp/switch, emergency power conversion		
	Fire hydrant box	f(x) = 0.31229x	0.58	Status of fire extinguishing hose, signal lamp		
Fire extinguisher***	Status, operation	f(x) = 0.93287x	0.68	Status of power, fire extinguishing agent, exterior		
Evacuation exit light	Light source	f(x) = 0.90714x	0.66	Lighting of light source (two-wire, three-wire)		
	Emergency power	f(x) = 0.74848x	0.77	Emergency power status		
	Inspection switch	f(x) = 0.89357x	0.75	Fuse status		
Defect on placement distance and detection area size are excluded						

Table 1. Defect rate of each part caused by yearly variation

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Anti-freeze defect is excluded Defect on unit capacity, installation distance, adaptability, signal and status of supervision is excluded



Figure 3. The concept of performance improvement in fire protection equipment.



Figure 4. Defect-function of the of fire protection system according to of use in building.

systems. The score is then used as the basis to determine replacement and inspection of parts of fire protection systems. Defect rate of each part is calculated as defect rate of each fire protection systems and hazard rate of fire protection systems in a structure is presented numerically in accordance with criticality of fire protection systems. This is one of the methodologies to support effective performance improvement by comparing each firefighting-equipment and driving performance improvement of each part. Defect rate caused by yearly variation is based on Na's study⁵ results.

Figure 4 is a diagram of scoring method in fire protection systems performance diagnosis. It is based on defect rate of each fire protection systems and internal part caused by yearly variation, which was empirically researched and analyzed in Na's study⁵. Elapsed time (from installation period to examination period of fire protection systems and parts) is supervisor's input variance.

Define Linear trend curve in which defect rate of each part caused by yearly variation as shown in Table 1 is set at section 0 is used to functionalize for performance diagnosis method. Also, defect rate of each part is put in as data. Defect rate data examined in Na's study⁴ that has nothing to do with yearly variation is excluded. Aside from receiver based on defect rate trend curve, coefficient of determination (R²) in all functional formulas is above 0.5, an indication of defect rate increase in proportion to yearly variation. However, not all fire protection systems in structures have defects in their parts in a certain year as suggested in function by yearly variation in Table 1. Instead, defect rate from the function is used as a data to effectively support information related to replacement and inspection to the supervisor. By entering variance of elapsed time of all fire protection systems and parts in the structures, the supervisor can forecast probability of defect at the time of examination.

In addition, inspection and replacement are graded into four stages according to defect rate in order to assist supervisor with the right decision-making on performance improvement and effective maintenance. Highest grade (grade 4) by part means part replacement in which each part in the fire protection systems as described above has reached above 120% in use years or has a defect rate above 20%. Lowest grade (grade 1) means continuous use of parts in which its use years reached 30% and defect rate is less than 5%. Guidelines in inspection and replacement by each grade are defined in Table 2.

Supervisors can determine when to replace and inspect parts of fire protection systems based on elapsed period of each part. Performance diagnosis as proposed in the study relies on variance of elapsed period of fire

	Grade 1	Grade 2	Grade 3	Grade 4
Defect probability	Less than 5%	5~10%	11~19%	More than 20%
Life span[3]	Life span × within 30%	Life span × within 60%	Life span × within 90%	Life span × above 120%
Replacement and inspection	Continuous use	Inspection subject (high sustainability)	Inspection subject (High replacement probability)	Replacement subject

Table 2. Performance improvement standard set in accordance with the fire protection systems faulty grade

protection systems components to automatically calculate defect probability of fire protection systems and grade them accordingly. This grading system enables supervisor to figure out which parts need to be replaced and inspected. Furthermore, an automated system makes it easier to effectively respond to replacement and inspection. Figure 5 proposes guidelines for replacement and sustained use by tapping into results of performance diagnosis.

Sprinkler System	Average failure rate 8.28875125		More than 5 points 4 ~ 5 points 3 ~ 4 points Less than 3 points	Replacement subject Inspection subject(High replacement probability) Inspection subject(High sustainability) Continuous use	
Parts	Use period	Failure probability	Point (E1)	Useful life	
Head	16	16.2864	4	20	
Water flow device	15	11.0571	3.75	20	
Control panel	18	9.41148	4.5	20	
Wiring & Power	10	2.1796	3.333333333	15	
Pipeline(carbon steel pipe)	15	10.98525	3	25	
Valve	10	4.7535	2.5	20	
Pump	10	4.3393	2.5	20	
Water source/water tank	9	7.29738	2.25	20	

Automatic fire detection equipment	Average failure rate 10.2335		More than 5 points 4 ~ 5 points 3 ~ 4 points	Replacement subject Inspection subject/High replacement probability) Inspection subject(High sustainability)	
Parts	Use neriod	Failure probability	Less than 3 points	Continuous use	
Receiver(P type)	10	4.6692	1	20	
Alarm(sound) system	20	6.1306	2	20	
Transmitter	25	17.50325	3	20	
Smoke detector	13	12.64237	2	10	
Thermal detector	16	10.22208	2	15	

Figure 5. Examples of automated diagnostic performance of the fire protection systems.

3.2 Calculation of Risk in Structures with Fire Protection Systems

Performance diagnosis of each system equals average defect probability of each part, which is calculated with formula (1).

F_{system} : firefighting system

f : defect probability of parts making up firefighting system

n : number of parts making up firefighting system

Degree of hazard of fire protection systems applied to structures can be determined by defect probability. Degree of hazard associated with fire protection systems in structures can be scored based on criticality and performance matrix examined in Na's study⁶. In other words, each system is scored according to defect probability and criticality of system applied to structures, which is then translated into performance diagnosis score. Aggregate of score for each system in fire protection systems can be calculated as hazard score through performance diagnosis of fire protection systems.

This enables effective replacement and inspection of fire protection systems in aging structures. Moreover, degree of hazard for performance of aging fire protection systems calculated quantitatively will be hopefully used as a great tool for maintenance and effective diagnosis for performance improvement

		Weighting of Fire safety Properties						
		High		Low				
		System A	system B	System ^C	SystemD	SystemD		
probability of failur	Very large (Grade 4)	Severe 5 Point	Severe 5 Point	High 4 Point	Moderate 3 Point	Mild 2 Point		
	Large (Grade 3)	Severe 5 Point	High 4 Point	Moderate 3 Point	Mild 2 Point	Low 1 Point		
	Medium (Grade 2)	High 4 Point	Moderate 3 Point	Mild 2 Point	Low 1 Point	Low 1 Point		
e	Small (Grade 3)	Moderate 3 Point	Mild 2 Point	Low 1 Point	Low 1 Point	Low 1 Point		

Figure 6. Risk matrix according to the importance and probability of failure of the fire-fighting facilities.

4. Conclusion

This study proposed supervisor-driven performance diagnosis method to fire protection systems in structures based on results from existing studies. This is an automated solution suggesting when to inspect each part of the fire protection systems, which can be regarded as an objective and concrete performance improvement tool to support supervisors to decide on what and when to replace or inspect or on the order of replacement. This way, limitations of performance improvement methods associated with previous inspections can be cleared. Therefore, the methodology proposed in this study can be put to use for a more effective and proactive management of fire protection systems in structures. In addition, data on defect rate of fire protection systems should be recorded to deliver higher reliability and aging of fire protection systems arising from time variance should also be

monitored by building detailed data to come up with a methodology that ensures reliable management.

5. Acknowledgement

This research was supported by the Fire Fighting Safety & 119 Rescue Technology Research and Development Program funded by the Ministry of Public Safety and Security (MPSS- Fire-Safety-2015-75).

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