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Study on the relationship between disaster prevention awareness and fire safety management of commercial facilities

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ABSTRACT

For the real estate industry in Japan, the significance of facility management has been on the rise in recent years. Especially, the importance of fire safety management for facilities has grown as part of preparations for potential large-scale earthquakes. Fire safety management is regulated by the Fire Service Act and is established based on analyses of past facility fire incidents. However, in fact, facilities with inappropriate fire safety management can often be observed. The purpose of this research is, to target commercial facilities, investigate and analyze the causes of inappropriate fire safety management from the perspective of human error, and implement effective fire safety management. The hypothesis was constructed that the reality of fire safety management in commercial facilities is related to the disaster prevention awareness of managers and employees in commercial facilities. The hypothesis was examined through field surveys in commercial facilities and interviews with facility managers and is substantiated. With the aim of reducing human errors in fire safety management, the "Fire Safety Management Checklist" has been proposed, and its effectiveness has been confirmed.

KEYWORDS

Fire safety management; Human error; Disaster prevention awareness; Management quality

ARTICLE HISTORY

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Introduction

In the Japanese real estate industry, there has been a shift in uilding management approaches. In the past, it was "flow-oriented," involving frequent construction and capital circulation. However, with slower economic growth since the 1990s and environmental concerns, there's now a move towards "stock-oriented" management, focusing on long-term building use to reduce costs and environmental impact.

As the real estate industry shifts towards stock-oriented building management, there's a rising focus on facility management, which includes building maintenance, environmental solutions, and disaster prevention. Fire prevention and management within building maintenance have gained significant importance, especially due to the potential for significant damage in the event of a fire outbreak. Effective fire prevention and management countermeasures have proven to contain damage in building fires [1]. In Japan, the Fire Service Act has been revised to enhance fire safety management based on the analysis of fire causes, ensuring better safety practices.
In addition, it is necessary to be careful about earthquakes as a trigger for building fires in Japan. The probability of a magnitude 7 earthquake occurring beneath the capital for 30 years was estimated at around 70% (as of January 24, 2020) [2]. According to the earthquake damage estimation released by the Tokyo Metropolitan Government on May 25, 2022, if an earthquake directly hits the capital, 2,482 people, or about 40% of the expected maximum casualties of 6,148 people, are predicted to be victims of fire [3]. Based on this prediction, it emphasizes the need for further fire prevention programs in urban areas.

In recent years, the need for fire prevention countermeasures has grown, but there are still facilities with inadequate fire safety management due to low fire prevention awareness among facility managers. Article 8-2-4 of the Fire Service Act in Japan mandates that administrators of various facilities ensure unobstructed pathways in case of fires [4]. However, on observing several commercial facilities in a city, some facilities have managed to not place anything under fire shutters and around fire doors, while others have installed items such as shelves, signs, and digital signage in these areas. The differences in fire safety management among these facilities are due to differences in the compliance of facility managers with the Fire Service Act. These differences in compliance with the Fire Service Act are likely related to the disaster prevention awareness of facility managers and employees.

The purpose of this study is, to target commercial facilities, investigate the relationship between inadequate fire safety management and the disaster prevention awareness of facility managers and employees, and develop effective countermeasures. We conducted on-site observations and interviews with facility managers or employees at multiple commercial facilities. Based on them, we analyze the relationship between inadequate fire safety management and the disaster prevention awareness that induces human error. Furthermore, with the goal of ensuring compliance with the Fire Service Act, we propose countermeasures to enhance disaster prevention awareness and evaluate their effectiveness.

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Research on fire safety management

Research on fire safety management is categorized into two types: ones based on the analysis of past disasters and others using predictive technology such as simulation. In recent years, the importance of fire prevention and safety management has been widely recognized worldwide, and many studies based on the analysis of past disasters have been reported [5-8].

As a representative example, Shao et al. investigated 17 fire incidents that occurred in Taiwan over the past 20 years [5]. They extracted critical factors contributing to these fires and proposed their utilization in fire prevention activities by firefighting agencies. Omar et al. conducted a literature review to identify significant factors influencing fire incidents in high-rise residential buildings [8]. They defined three categories of factors, including management factors, human factors, and technical factors. For each category, they examined and proposed corresponding preventive countermeasures.

As an example of the application of predictive technology, Ginting evaluated the fire safety management at the Millennium ICT Center in Medan, Indonesia, with Arena simulation to estimate evacuation times and other factors [9]. Sun and Turkan proposed a Building Information Model (BIM)-based Simulation Framework [10]. This framework utilizes simulations for evacuation during disaster incidents to identify factors influencing evacuation performance. Based on the identified factors, they demonstrated that by improving fire safety management, it is possible to minimize both casualties and fatalities, as well as property losses resulting from fires.

As mentioned, existing research on fire safety management has predominantly focused on the analysis of past disasters and the utilization of predictive techniques. However, there is a lack of existing research that has conducted fieldwork-based surveys on real facilities and analyzed them with a specific focus on the disaster prevention awareness of facility managers and employees.

Research on human error

A decrease in disaster prevention awareness leads to human errors, such as the occurrence of oversights by facility managers and negligence by employees. First, regarding the definition of human error, it has been addressed by many researchers. For example, Reason defined human error as "a generic term to encompass all these occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures connote be attributed to the intervention of some chance agency" [11]. Strauch defined it as "an action or decision that results in one or more unintended negative outcomes" [12].

Many studies have been conducted on human error across various industries and subjects [13-17]. Edmondson analyzed healthcare operations and found that in teams with a psychologically safe and open culture, the reporting rate of human error was higher [13]. This environment promoted learning behaviors and correlated with better team performance. Ouache et al. developed a framework for quantitatively assessing human error factors that can lead to fires in urban areas and predicting their impact [17]. They applied this framework to evaluate seven cities in the Canadian province of British Columbia and confirmed its effectiveness. There are numerous studies that analyze and categorize challenges from the perspective of human error, and the scope of research in this area continues to expand. However, based on the investigation of existing research, it appears that there is a lack of studies that have analyzed fire safety management from the perspective of human error. Therefore, in this study, we aim to analyze fire safety management in facility management, focusing on human error and exploring effective countermeasures.

Construction of Hypothesis

Problem analysis

As mentioned above in the background, there are commercial facilities that implement proper fire safety management and those that do not. For instance, some facilities take precautions to prevent obstructions beneath fire shutters or around fire doors, while others install items such as product shelves, signs, or digital signage in these areas.

We analyze the causes of such inadequate fire safety management from the perspective of human error. We classify human error as shown in Table 1 [13]. Firstly, the occurrence of human error can be broadly categorized into two groups: those arising from unintentional actions and those arising from intentional actions.

Table 1. Classification of human error [13].

	Classification	Definition
Unintended	Slip	Attentional failure
	Lapse	Memory loss
Intended	Mistake	Rule-based mistake
	Violation	Routine violations

Human errors stemming from unintentional actions can be categorized as slips and lapses. Slip occurs due to inattention, where individuals unconsciously obstruct fire safety measures due to carelessness. Lapse is caused by memory lapses and mistakes in fire safety management despite having the necessary knowledge, often due to factors like poor communication.

Human errors resulting from intentional actions can be classified as mistakes and violations. Mistake occurs due to inattention and misunderstanding, leading to incorrect management decisions because of a lack of understanding regarding fire safety equipment. Violation involves intentionally engaging in incorrect management practices.

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The inadequate fire safety management is caused by these four types of human errors as described. Therefore, the prevention of human error is effective in eliminating inadequate fire safety management in facilities.

Hypothesis

To prevent human error in fire safety management, improving disaster prevention awareness through education and regular management is effective. In commercial facilities where human errors tend to occur in fire safety management, it is possible that the facility managers understand the meaning and purpose of fire safety equipment, but there may be insufficient education provided to the employees of tenants in the facilities. Additionally, even if tenant employees understand the meaning and purpose of fire safety equipment, there might be an inadequate system for conducting regular checks. In other words, facilities with inadequate fire safety management may have low disaster prevention awareness, which can lead to human errors. To clarify this relationship and consider effective countermeasures against inadequate fire safety management, this study sets the following hypothesis regarding the reality of fire safety management in commercial facilities.

Hypothesis: Fire safety management in commercial facilities is related to the disaster prevention awareness of both facility managers and employees.

Verification of Hypothesis

Verification target

To verify the hypothesis set in the previous section, a survey was conducted on seven large commercial facilities located in Kanazawa Ward, Yokohama City, Kanagawa Prefecture. Here, large commercial facilities refer to facilities with a capacity of 1,000 people or more. The targeted commercial facilities are listed in Table 2. The surveyed facilities include one station building, two shopping centers, three general merchandise stores, and one shopping mall.

Table 2. List of target commercial facilities.

No.	Facility ID	Classification	Capacity (people)
1	SB-A	Station building	1,000
2	SC-A	Shopping center	5,000
3	SC-B	Shopping center	8,000
4	GMS-A	General merchandise store	6,000
5	GMS-B	General merchandise store	7,000
6	GMS-C	General merchandise store	4,000
7	SM-A	Shopping mall	7,000

Verification method

The hypothesis was verified for the seven commercial facilities with the procedure shown in Table 3. We provide explanations for each step.

Step 1: Fact-finding survey by on-site observation

We visited the seven commercial facilities and conducted on-site observations to count the number of instances where they were not in compliance with the fire safety management specified in Article 8-2-4 of the Fire Service Act. Specifically, we counted the number of inadequate fire safety management by observing the presence of obstructions along the fire compartment boundary lines, the presence of obstructions around fire doors, and the condition of evacuation route clearance.

Table 3. Procedure of verification.

Step No.	Process
1	Fact-finding survey by on-site observation
2	Interview survey for facility managers or employees
3	Quantification of fire safety management and disaster prevention awareness
4	Hypothesis verification

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In this research, we conducted two on-site observations. The first one took place from June 7th to June 14th, 2022. We visited the seven commercial facilities and conducted approximately one-hour rounds, counting the number of inadequate fire safety management. The second one was executed from September 16, 2022 to September 19, 2022. We visited the same seven commercial facilities and conducted approximately one-hour rounds.

Step 2: Interview survey for facility managers or employees

We asked the following two questions to the managers or employees in the seven commercial facilities.
<Q1>: The presence or absence of disaster prevention education for employees in commercial facilities was questioned.
<Q2>: The presence or absence of regular fire safety management checks conducted by employees in commercial facilities was questioned. In cases where such checks are conducted, the frequency of the checks is verified.

Step 3: Quantification of fire safety management and disaster prevention awareness

To establish an indicator representing the level of fire safety management, we introduce the number of inadequate fire safety management in a facility, M, as follows:

$$\boldsymbol{M = \frac{1}{N}\sum_{i=1}^{N} m_i}\,. \tag{1}$$

Here, m_i represents the number of inadequate fire safety management discovered during the i-th on-site observation. N is the number of on-site observations conducted for the targeted facilities. In this study, we set N=2.
To represent the disaster prevention awareness of facility managers and employees, we introduce the disaster prevention awareness index, D, as follows:

$$\boldsymbol{D = \alpha E + \beta \frac{C}{CI}}\,. \tag{2}$$

Here, E is a binary variable representing the presence or absence of disaster prevention education, taking the value 1 if education is present and 0 if absent. C is a binary variable representing the presence or absence of regular fire safety management checks, taking the value 1 if such checks are conducted and 0 if not. CI represents the number of days between regular fire safety management checks. For example, if the checks are performed daily, CI=1; if weekly, CI=7; and if monthly, CI=30. α and β are coefficients that weigh for E and C, respectively. In this study, we set $\alpha = \beta = 1$.

The disaster prevention awareness index D is calculated for each facility using the results of the step 2. A higher value indicates a higher level of disaster prevention awareness.

Step 4: Hypothesis verification

To verify the hypothesis proposed in above, we conducted an analysis using Pearson's correlation coefficient to examine the correlation between the number of inadequate fire safety management M and the disaster prevention awareness index D.

Results

Firstly, in step 1, we conducted two on-site observations to investigate the number of inadequate fire safety management. In the station building SB-A, during the first observation, there were 4 instances of items such as merchandise wagons and signs being placed on the shutter line that separates the store area from the aisles. In the second observation, this number increased to 5 instances. If the shutters cannot be closed in a fire, heat and smoke may fill the aisles, making evacuation difficult.

At the shopping center SC-A, there were designated areas around the fire doors marked with yellow guidelines indicating that items should not be placed there. During the first observation, there were 5 instances of items being placed in these designated areas, and this number remained the same during the second observation. Fire doors are designed as an evacuation route in a fire, and placing items around them may obstruct the passage and impede evacuation. At the shopping center SC-B, there were yellow guidelines on the floor to indicate the shutter line. However, during the first observation, there were 5 instances of items being placed on these guidelines, and this number remained the same during the second observation.

At the general merchandise store GMS-A, there were yellow guidelines on the floor indicating the areas around the fire shutter lines and fire doors where items should not be placed. In both observations, there were no instances of items being placed in these designated areas. At the general merchandise store GMS-B, there were guidelines indicating that items should not be placed around the fire shutter lines and fire doors. During the first observation, one instance was found where shopping baskets for customers were placed near a fire door. In the second observation, two instances were found where items were placed on the fire shutter lines. At the general merchandise store GMS-C, during the first observation, there were no instances of items being placed near the fire shutters or fire doors. During the second observation, one instance was found where items were placed on the fire shutter line. At the shopping mall SM-A, during both the first and second observations, there were no instances of items being placed near the fire shutters or fire doors.

Next, we conducted a survey about disaster prevention awareness in Step 2. At the SB-A, the responses were as follows; <Q1>: Disaster prevention education was not conducted. <Q2>: Regular fire safety management checks by employees were not conducted.

At the SC-A, the responses were as follows; <Q1>: Disaster prevention education was not conducted. <Q2>: Regular fire safety management checks by employees were conducted, with a frequency of 30 days. At the SC-B, the responses were as follows; <Q1>: Disaster prevention education was not conducted. <Q2>: Regular fire safety management checks by employees were not conducted. At the GMS-A, the responses were as follows; <Q1>: Disaster prevention education was conducted. <Q2>: Regular fire safety management checks by employees were conducted, with a frequency of 1 day. At the GMS-B, the responses were as follows; <Q1>: Disaster prevention education was conducted. <Q2>: Regular fire safety management checks by employees were conducted, with a frequency of 1 day. At the GMS-C, the responses were as follows; <Q1>: Disaster prevention education was not conducted. <Q2>: Regular fire safety management checks by employees were conducted, with a

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frequency of 1 day. At the SM-A, the responses were as follows; <Q1>: Disaster prevention education was conducted. <Q2>: Regular fire safety management checks by employees were conducted, with a frequency of 1 day.

With the results of step 1 and step 2, we calculated the number of inadequate fire safety management and the disaster prevention awareness index for each commercial facility in the step 3. The results are shown in Table 4.

Table 4. Results of on-site observations and interview survey.

Facility ID	Number of inadequate fire safety management: M	Disaster prevention awareness index: D
SB-A	4.5	0
SC-A	5	0.03
SC-B	5	0
GMS-A	0	2
GMS-B	1.5	2
GMS-C	1	1
SM-A	0	2

Based on the results shown in Table 4, we conducted an analysis of the correlation between the number of inadequate fire safety management M and the disaster prevention awareness index D for commercial facilities in Step 4. The results showed a correlation coefficient r=-0.93 with p-value=0.002 ($p < 0.01$), indicating a strong negative correlation between M and D. This result supports the hypothesis that "fire safety management in commercial facilities is related to the disaster prevention awareness of both facility managers and employees".

Discussion

The verification presented in the previous section confirmed the hypothesis that "fire safety management in commercial facilities is related to the disaster prevention awareness of both facility managers and employees". However, it was observed that, despite conducting disaster prevention education and regular fire safety management checks, some facilities still had instances of inadequate fire safety management. To improve the level of fire safety management in all commercial facilities, it is necessary to implement countermeasures to enhance the management quality for disaster prevention awareness.

Based on the cases of inadequate fire safety management identified in the field surveys, we believe that we can improve the quality of disaster prevention awareness management by incorporating these cases into educational content and regular fire safety management checklists. Therefore, we have developed a "fire safety management checklist," as shown in Figure 1.

Fire Safety Management Checklist

Check	No.	Check Point	Potential Consequences caused by Inadequate Management
	1	There is nothing under the fire shutter.	Fire propagation occurs.
	2	There is nothing around the fire door.	Fire propagation occurs.
	3	There are no obstructions on the evacuation route.	Evacuation is not possible.
	4	Emergency exit lights are not hidden by objects	Evacuation is not possible.

Examples of obstacles that should be noted:
shelving units for merchandise, bulletin boards, menu signs, desks, chairs, Carts, shopping baskets.
cardboard boxes, etc.

Figure 1. Fire Safety Management Checklist.

Facility managers or employees of commercial facilities can use this checklist to identify the presence or absence of the four types of inappropriate cases observed during the field surveys. Additionally, we have improved the convenience of on-site checks by providing examples of items to check on this checklist.

We discussed the "fire safety management checklist" with the fire department staff and received the following feedback: "This checklist is useful for fire safety managers. It's simple and easy to use. It also provides information on why management is necessary and what items need to be checked, making it user-friendly. It would be even better if there was a mechanism to add or remove management items based on management performance."

With this feedback, we have qualitatively confirmed the effectiveness of the checklist.

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Conclusions

In recent years, the Japanese real estate industry has seen a growing emphasis on building management, particularly due to the increased awareness of fire prevention and management, considering the potential for major earthquakes. Although the Fire Service Act regulates fire prevention and management, we can find that the actual implementation in commercial facilities does not comply with it. This study centered on commercial facilities and aimed to investigate and analyze the causes of inadequate fire safety management, primarily focusing on human errors, and to introduce effective fire safety management strategies.

The hypothesis that fire prevention management in commercial facilities is related to the facility's disaster prevention awareness was established. This confirmation was achieved through on-site surveys and interviews with managers and employees of seven commercial facilities. We introduced a disaster prevention awareness coefficient based on the interview findings to gauge the disaster prevention awareness of facility personnel. Analysis using Pearson's correlation coefficient revealed a significant and strong negative correlation between the number of inadequate fire safety management areas in commercial facilities and this disaster prevention awareness coefficient, thus substantiating the initial hypothesis. Furthermore, with the aim of improving fire safety management in facilities, we proposed the "fire safety management checklist" based on the findings from the on-site surveys. We also received feedback from firefighters, which confirmed its effectiveness. In the future study, we plan to quantitatively evaluate the proposed "fire safety management checklist." Furthermore, we will consider extending this research to facilities with different purposes beyond commercial facilities.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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