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Evaluation of Evacuation Safety in University Libraries Based on Pathfinder

Zechen Zhang*, Jaewook Lee**, Hasung Kong[1]***

**Graduate Student, 55338 Dept. of Fire and Safety Engineering, Woosuk Univ, 443 Samnye-ro, Samnye-eup, Wanju-gun, Jeonbuk state, Korea*
***Part-time Instructor, 32627 Division of Fire Safety, Mokwon Univ. 88 Doanbuk-ro, Seo-gu, Daejeon*
**** Professor, 55338 Dept. of Fire Protection and Disaster Prevention, Woosuk Univ, 443 Samnye-ro, Samnye-eup, Wanju-gun, Jeonbuk state, Korea*

*Corresponding Author E-mail: 119wsu@naver.com**

Abstract

In recent years, the frequent occurrence of fire accidents in university libraries has posed significant threats to the safety of students' lives and property, alongside negative social impacts. Accurately analyzing the factors affecting evacuation during library fires and proposing optimized measures for safe evacuation is thus crucial. This paper utilizes a specific university library as a case study, simulating fire evacuation scenarios using the Pathfinder software, to assess and validate evacuation strategies and propose relevant optimizations. Pathfinder, developed by Thunderhead Engineering in the United States, is an intuitive and straightforward personnel emergency evacuation assessment system, offering advanced visualization interfaces and 3D animation effects. This study aims to construct evacuation models and perform simulation analysis for the selected university library using Pathfinder. The library's structural layout, people flow characteristics, and the nature of fire and smoke spread are considered in the analysis. Additionally, evacuation scenarios involving different fire outbreak locations and the status of emergency exits are examined. The findings underscore the importance of effective evacuation in fire situations, highlighting how environmental conditions, individual characteristics, and behavioral patterns significantly influence evacuation efficiency. Through these investigations, the study enhances understanding and optimization of evacuation strategies in fire scenarios, thereby improving safety and efficiency. The research not only provides concrete and practical guidelines for building design, management, and emergency response planning in libraries but also offers valuable insights for the design and management of effective evacuation systems in buildings, crucial for ensuring occupant safety and minimizing loss of life in potential hazard situations

Key Words: *University Libraries, Evacuation Safety, Pathfinder Simulation, Safety Analysis, Fire Emergency.*

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Corresponding Author: 119wsu@naver.com
Tel:+82-063-290-1686, Fax: +82-063-290-1478
Author's affiliation:
55338 Dept. of Fire Protection and Disaster Prevention, Woosuk Univ, 443 Samnye-ro, Samnye-eup, Wanju-gun, Jeonbuk state, Korea

1. INTRODUCTION

In recent years, there has been a frequent occurrence of fire accidents. Fires in university libraries pose a threat to the safety of students' lives and property and can have negative social impacts [1]. Consequently, it is crucial to accurately analyze the factors affecting evacuation during library fires and propose optimized measures to ensure the safe evacuation of individuals. Experts both domestically and internationally have been conducting research on safe evacuation of individuals.

S.L. Ho et al. [2] considered factors influencing evacuation such as crowd assembly, subway delays, and congestion, and conducted evacuation simulations based on the Pathfinder software, proposing corresponding measures.

M. Farid et al. [3] suggested an evacuation safety framework that can be regionally optimized according to the evacuation safety of buildings and facilities.

S. Nur et al. [4] reviewed agent-based pedestrian evacuation literature to assess the current level of technology and determine directions for improvement.

Yan [5] discovered the behavioral characteristics of individuals during a fire through a large-scale survey and emergency evacuation training, indicating that gender, firefighting education, and training have the most significant impact on evacuation time.

Wang et al. [6] explored factors affecting individual evacuation by collecting information through surveys, encoding each variable using logistic regression models, and quantitatively analyzing sample data.

The results of these studies emphasize the importance of effective evacuation in fire situations. Various environmental conditions, individual characteristics, and behavioral patterns significantly influence evacuation efficiency. Through these studies, we can better understand and optimize evacuation strategies in fire situations, thereby enhancing safety and efficiency.

This paper will use a specific university library as a case study, assuming the location of fire outbreak and the status of safety door opening and closing within the library, and simulate the evacuation of people in the event of a fire using the Pathfinder simulation software. The results of the simulation will be evaluated to verify the design's validity, and based on this, relevant optimization measures will be proposed.

2. MAIN BODY

Pathfinder is an intuitive and simple personnel emergency evacuation assessment system developed by Thunderhead Engineering in the United States. This software provides an advanced visualization user interface, equipped with 3D animation effects. The built-in character library includes various setting options, offering more realism and superior graphic effects compared to other simulators of the same type. Additionally, it features complete 3D triangular grid design capabilities [7]. These realistic representations of people provide users with a tangible sense of reality. Pathfinder supports standard graphic cards, allowing for smooth real-time animation simulations of thousands of people, thereby providing more scientific data in modeling and simulation analysis [8].

2.1 Building Overview

The library in question comprises five floors, with a total floor area of 25,900 m2. The library has an

overall rectangular shape, with each floor having a height of 4 meters. Each floor features large reading rooms, which are the primary congregation points for people. The structure from the first to the fifth floor is similar. The fire prevention design is equipped with a first-class fire resistance rating.

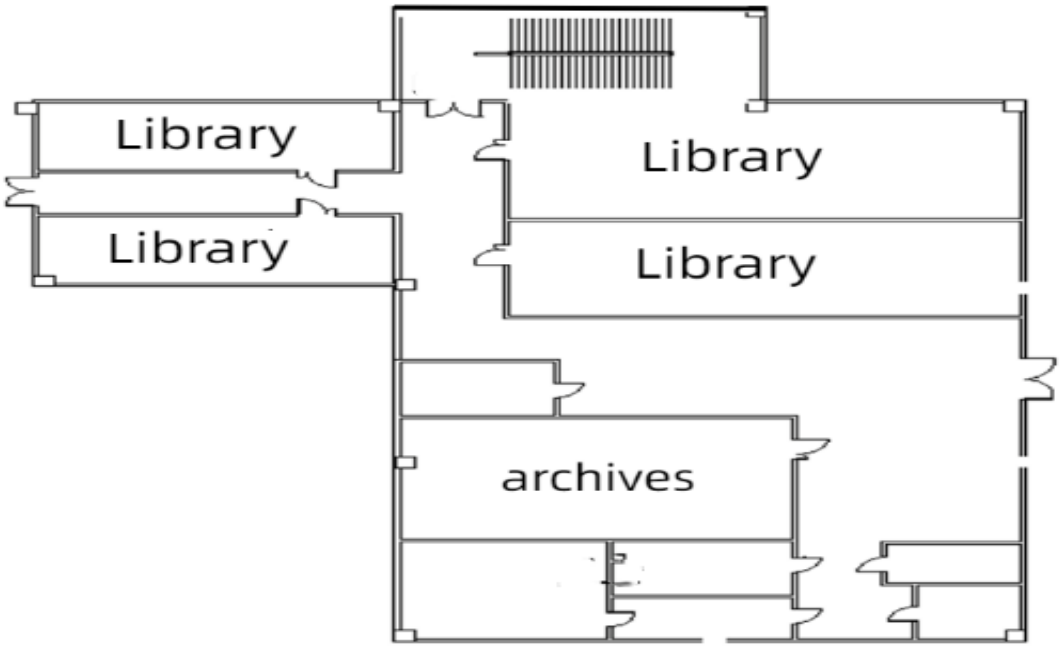

Figure 1. Blueprint

2.2 Construction of Evacuation Model and Simulation Analysis Based on Pathfinder

Pathfinder supports two movement simulation modes. In Steering mode, doors do not restrict people's movement, and a reasonable distance is maintained between individuals. SEPE (Social Force and Path Efficiency) mode is an important function used in personnel evacuation simulations. SEPE mode combines the concepts of 'Social Force' and 'Path Efficiency' to model human behavior in a way that resembles real-life situations. As the library's structure and flow of people indicate, it covers a large area with a reasonable level of people flow during peak hours. During emergency evacuations, doors have a minor impact and the likelihood of congestion is low, making SEPE mode applicable in certain modules. However, considering the critical aspects of this design, Steering mode can better model real scenarios during personnel evacuation. Additionally, it is necessary to analyze the characteristics of fire and smoke spread in the library before constructing relevant scenario modeling. The library, being rectangular overall, with reading rooms on each floor prone to fire, allows the fire to spread throughout, increasing its range. The rectangular structure also significantly reduces the time it takes for smoke to spread to other areas on the same floor. Therefore, the spread of fire and smoke in areas prone to fire is rapid and widespread, with a high intensity of fire. Moreover, evacuation scenario modeling results may vary significantly if a fire occurs on different floor.

2.3 Estimation of Occupancy and Building Modeling

First, a planar model consisting of single lines in Pathfinder's 2D view is created based on the architectural

design blueprints of a specific university library, as shown in

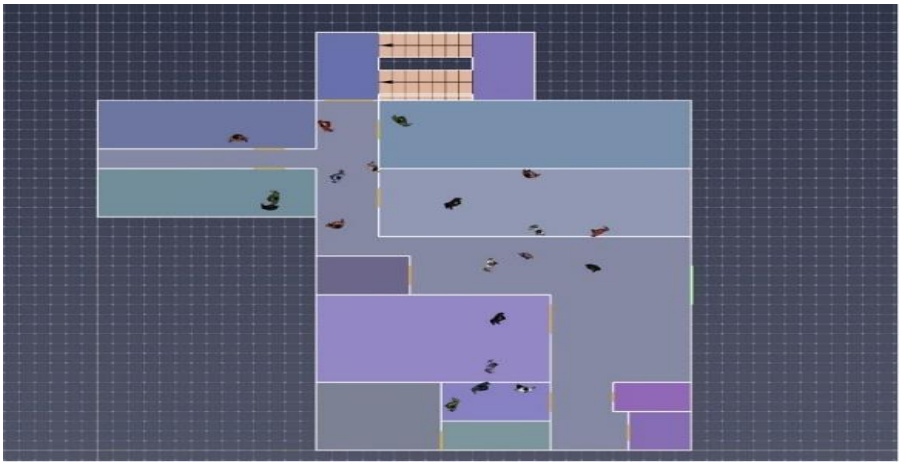

Figure 2. 3D Floor Plan

Figure 1. Based on the previous steps, the evacuation floors are combined to construct the overall frame of the 3D structure of the simulation model, as shown in Figure 2.

Figure 3. 3D Effect Diagram

2.4 Inputting Occupants and Character Modeling

The behavioral characteristics of people are crucial factors that influence evacuation during a fire incident in Pathfinder software, directly determining evacuation time and efficiency. Therefore, selecting parameters based on the behavioral characteristics of people is vital for the accuracy and realism of the evacuation simulation results.

(1) The total number of evacuees is 1,400, randomly assigned, with characters having a shoulder width of 50.0 cm and an average height of 1.7 m, among other standard settings.

(2) The composition of the population is relatively simple, assuming normal behavioral capabilities and ignoring individual differences. The ratio of the population is 60% male and 40% female.

(3) The average walking speed of the population is 1.2 m/s, and the average evacuation speed during evacuation is set at 2 m/s. Additionally, the response acceleration and duration are set, and characters are randomly placed within the area. The individual behavioral patterns using Steering mode are shown in Table 1。

Table 1. Parameter Settings

category	Explanation
Number of Evacuees	1,400
Assignment of Occupants	Random
Average Height	1.7 m
Population Composition - Male Ratio	60%
Population Composition - Female Ratio	40%
Average Walking Speed	1.2 m/s
Average Evacuation Speed	2 m/s
Response Acceleration and Duration	Set
Distribution of Characters in the Area	Random
Behavioral Model	Steering Mode

3. SITUATION MODELING

We simulate scenarios involving different fire outbreak locations and the status of emergency exits being open or closed, setting up the following situation:

Table 2. Scenario Settings

Scenario	Fire Outbreak Floors	Internal Staircase Emergency Exit	Remarks
Scenario 1	2nd and 3rd Floors	Closed	Evacuation via internal staircase
Scenario 2	4td and 5td Floors	Closed	Evacuation via internal staircase
Scenario 3	4td and 5td Floors	Open	All emergency exits available for evacuation

4. ANALYSIS OF EVACUATION TIME SEQUENCES

According to the evacuation theory proposed by Marchant, the total evacuation process of pedestrians in the event of a fire is temporally related to the spread of the fire [11]:

- Tp: Time taken for pedestrians to detect the fire, i.e., the time from the onset of the fire to the activation of the fire alarm, statistically 60 seconds,

- Tr: Pedestrian response time,

- Ta: Time taken for actions after personnel response,

- Ts: Time taken for pedestrians to evacuate the building and reach a safe point outside,

- Tf: Available safe evacuation time (also

known as the permitted evacuation time) Tr+Ta, pre-evacuation time, i.e., the response time from fire identification to the start of evacuation preparations by the personnel. The response time Tc is 120 seconds, as per statistical data (see reference 1).

[Tc=Tr+Ta.Tp+Tr+Ta] (1)

- The start time of evacuation after the fire Tst is shown in equation (2): [Tst=tp+Tc] (2)

- The Required Safe Egress Time (RSET) is shown in equation (3): [RSET=Tst+αTs] (3).

In the formula, α is the safety factor (usually set to 1.5, considering the uncertainty factors during the movement of personnel through closed stairwells, external stair entrances, and exits leading directly to the first floor or directly outside).

The condition for all pedestrians in the library to evacuate successfully is as follows (equation 4):

[Tp + Tr + Ta + Ts ≤ Tf] (4), i.e., RSET ≤ ASET [12]. The expected td + tPRE is 25 + 35 = 60 seconds. Based on knowledge of smoke and fire, ASET is set to 300 seconds [13].

4.1 Results and Analysis of Evacuation Simulation

After setting the necessary parameters for the above simulation, we can start the dynamic simulation process. Based on the results of the Pathfinder simulation analysis, the total evacuation time for each floor in the three scenarios is statistically presented in Table 3.

Table 3. Evacuation time for all personnel by scenario

	1st Floor	2st Floor	3st Floor	4st Floor	5st Floor
Scenario 1	**196s**	**145s**	**132s**	**104s**	**31s**
Scenario 2	**176s**	**162s**	**140s**	**125s**	**40s**
Scenario 3	**164s**	**145s**	**130s**	**116s**	**40s**

In Scenario 1, the total evacuation time for all personnel on the 5th floor is 31 seconds, on the 4th floor is 104 seconds, on the 3rd floor is 132 seconds, on the 2nd floor is 145 seconds, and on the 1st floor is 196 seconds. Combining the above results, the evacuation simulation conducted under the conditions of Scenario 1 is the sum of the personnel evacuation time of 253 seconds and the set response time plus an uncertain factor of 60 seconds [14]. The total RSET is 313 seconds, which exceeds the expected ASET time of 300 seconds, indicating that evacuation under these conditions is extremely risky.

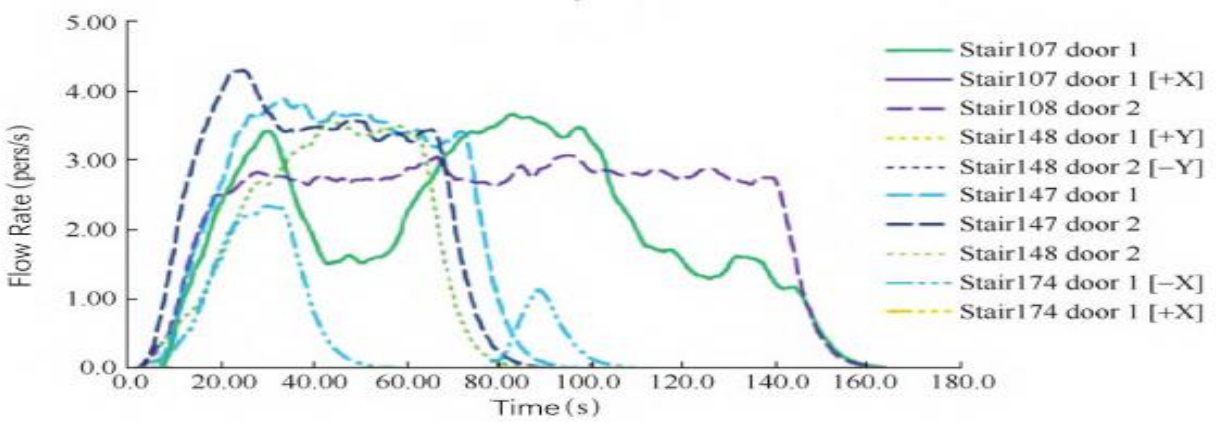

Figure 4. Fire Door Flow Rate

In Scenario 2, the total evacuation time for all personnel on the 5th floor is 40 seconds, on the 4th floor is 125 seconds, on the 3rd floor is 140 seconds, on the 2nd floor is 162 seconds, and on the 1st floor, the total evacuation time is 176 seconds. Combining the results, the evacuation simulation conducted under the conditions of Scenario 2 is the sum of the personnel evacuation time of 196 seconds and the set response time plus an uncertain factor of 60 seconds [14]. The total RSET is 256 seconds, which is less than the expected ASET time of 300 seconds. Evacuation in this scenario is relatively safe, but there are still many hidden dangers.

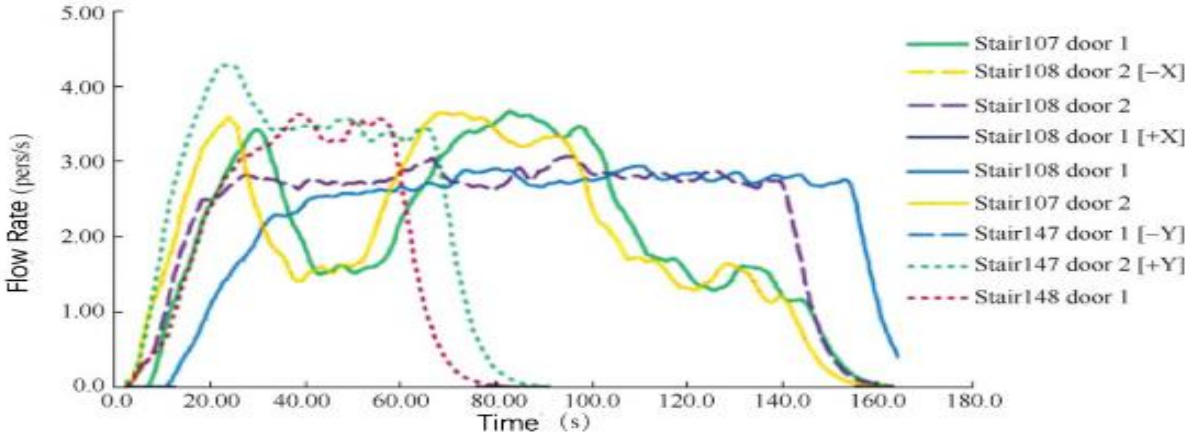

Figure 5. Fire Door Flow Rate

In Scenario 3, the total evacuation time for all personnel on the 5th floor is 40 seconds, on the 4th floor is 116 seconds, on the 3rd floor is 130 seconds, on the 2nd floor is 145 seconds, and on the 1st floor is 164 seconds. Based on these results, the evacuation simulation conducted under the conditions of Scenario 3, which includes a personnel evacuation time of 164 seconds and an uncertain factor of 60 seconds [14], results in a total RSET of 224 seconds. This is less than the expected ASET time of 300 seconds, indicating that evacuation under these conditions is safe. The fact that all exits were open and there was no extreme congestion during the initial stages of the fire evacuation is clear. Scenario 3 represents the required design plan for this evacuation design, and the feasibility and effectiveness of the design were further verified through software simulation methods.

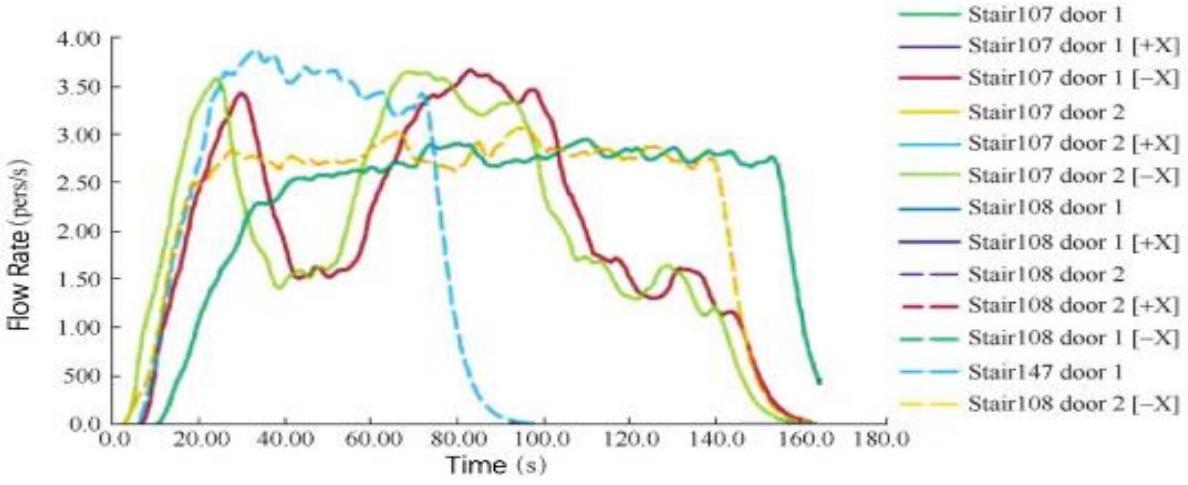

Figure 6. Fire Door Flow Rate

From the analysis of Scenarios 1, 2, and 3, the following conclusions can be drawn regarding the importance of the fire outbreak location:

It is evident that the evacuation time varies significantly depending on the floor where the fire occurs. For instance, Scenario 3, where the fire breaks out in the upper floors, results in a shorter evacuation time compared to other floors. There are considerable differences in the evacuation time for each floor, which are influenced by factors such as the building's design, evacuation routes, and population density.

- If the total Required Safe Egress Time (RSET) exceeds the Available Safe Egress Time (ASET), as in Scenario 1, the evacuation is considered to be in a dangerous state. On the other hand, if the RSET is shorter than the ASET (as in Scenarios 2 and 3), the evacuation is deemed relatively safe.

Evacuation simulation for predicting and planning the evacuation time for each floor is crucial in minimizing loss of life during a fire. Longer preparation times can improve the overall efficiency of evacuation. Adequate preparation and training for evacuation play a vital role in reducing evacuation time. Such analyses provide essential insights necessary for improving fire safety design, evacuation planning, and emergency response strategies.

5. CONCLUSION

The evacuation simulations performed in this study provide significant insights into minimizing loss of life during a fire. Through various scenarios, it was found that evacuation time is influenced by factors such as the floor where the fire occurs, building design, evacuation routes, and population density. Notably, in cases where a fire breaks out in upper floors (Scenario 3), the evacuation time is relatively shorter compared to other floors, highlighting considerations for building design and evacuation route planning. According to the analysis of the simulation results, situations where the total Required Safe Egress Time (RSET) exceeds the Available Safe Egress Time (ASET) (Scenario 1) can be dangerous, whereas if the RSET is shorter than the ASET (Scenarios 2 and 3), the evacuation is considered relatively safe.

These findings emphasize the need for improvement in evacuation routes and strategies, as well as the importance of evacuation training and preparedness. In particular, the significance of optimizing evacuation preparation time and conducting sufficient training to prepare for real situations was highlighted, increasing evacuation efficiency. Additionally, predictions made through evacuation simulations can be a vital reference for designing fire safety and emergency response strategies in buildings.

Overall, this study provides concrete and practical guidelines for designing and establishing response strategies to enhance fire safety in buildings. The design and management of an effective evacuation system play a critical role in ensuring the safety of building occupants and minimizing loss of life in potential hazard situations. Therefore, the results of this study can be a valuable reference for future building design, management, and emergency response planning.

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