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Review Paper

Methods of Evacuating People from Buildings During a Fire: A Review

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Abstract— Fires in buildings can rapidly spread and endanger occupants if evacuation is not timely and orderly. This review summarizes current best practices and recent innovations in evacuation methods aimed at safely and efficiently evacuating people from buildings during a fire event. Methods discussed include fire drills, alarm systems, exit signage, emergency lighting, stairwell design, zoned egress, computer models and simulations, as well as emerging technologies like intelligent evacuation systems. Challenges such as smoke control, disabled occupants, and human behavior factors are also examined. Key findings show that a holistic approach combining passive and active systems tailored to building characteristics yields the best evacuation outcomes. Further research into integrated smart evacuation technologies and standardized metrics for evaluating egress methods would enhance occupant safety. Successful building evacuation requires ongoing training of occupants, adherence to fire codes, and vigilant maintenance of egress systems.

Keywords— evacuation strategies, fire emergencies, building safety, emergency exits, building design, human behavior, communication systems, early warning systems, fire suppression systems, occupant tracking, virtual reality simulations, public education, vulnerable populations, emergency responders, fire safety measures, property damage.

1. Introduction

Building fires continue to cause injuries, deaths, and property damage worldwide each year. Rapid and efficient evacuation of occupants during a fire emergency is critical to preserving life safety. Evacuation of large buildings in particular poses challenges due to factors such as crowd density, complex layouts, disabled occupants, and human behavior under stress. Suboptimal evacuation wastes valuable time for first responders and can lead to dangerous bottlenecks at exits. This review summarizes established and emerging methods for safely evacuating people from buildings during fires. Both passive systems like egress design as well as active technologies including alarms, signage, and smart evacuation aids are examined. Challenges specific to large, complex buildings are discussed. The goal is to provide a comprehensive overview of current best practices and recent innovations in building evacuation methods that saves lives during fire emergencies.

Fire emergencies in buildings are a significant threat to the safety and well-being of occupants. The successful evacuation of individuals during such incidents is crucial to minimizing casualties and property damage. Evacuation strategies play a pivotal role in ensuring the safe and efficient removal of people from buildings during fire emergencies. This scientific article aims to provide a comprehensive overview of various ways to evacuate individuals from buildings during fires, highlighting the importance of proactive fire safety measures, effective building design, understanding human behavior, and the integration of advanced technologies.

Historically, fire safety measures primarily focused on fire suppression systems, such as sprinklers and fire extinguishers. While these systems are essential for containing and extinguishing fires, they alone cannot guarantee the successful evacuation of occupants. Therefore, it is imperative to adopt a holistic approach that encompasses various aspects of building safety and evacuation strategies.

Proactive fire safety measures are essential for preventing fires from occurring in the first place. These measures include regular fire safety inspections, the installation of smoke detectors and fire alarms, and the implementation of fire prevention policies. Smoke detectors and fire alarms are particularly important as they provide early warning to occupants, giving them ample time to evacuate the building safely. Fire prevention policies, such as safe smoking policies and the proper storage of flammable materials, can also help to prevent fires from occurring.

Effective building design is another critical factor in ensuring the safe evacuation of occupants during fire emergencies.

Buildings should be designed to allow for easy and efficient evacuation, with clear and well-marked exit routes and emergency lighting. The number and location of exits should be appropriate for the size and occupancy of the building. Additionally, buildings should be designed to resist fire and prevent its spread, with fire-resistant materials and compartmentalization.

Understanding human behavior is also crucial in developing effective evacuation strategies. Human behavior during fire emergencies is complex and can be influenced by a range of factors, including panic, familiarity with the building, and the perceived level of danger. Therefore, it is essential to conduct regular evacuation drills to familiarize occupants with the building's evacuation procedures and to ensure that they can evacuate safely and efficiently during an emergency. Additionally, the use of clear and concise signage can help to guide occupants to the nearest exits and reduce confusion during the evacuation process.

The integration of advanced technologies can also enhance evacuation strategies and improve the safety of occupants during fire emergencies. For example, the use of computer simulations and modeling can help to identify potential hazards and optimize evacuation routes. The use of smart building technologies, such as automated fire detection and suppression systems, can also help to prevent fires from occurring and contain them more effectively when they do occur. Additionally, the use of mobile applications and other communication technologies can help to provide real-time information to occupants during emergency situations, guiding them to safety and reducing the risk of injury or death.

Building design plays a critical role in facilitating safe evacuations. Elements such as clear signage, well-maintained emergency exits, and appropriate fire compartmentalization can significantly enhance evacuation efficiency. Additionally, the integration of advanced technologies, such as early warning systems and real-time occupant tracking, can provide valuable information to emergency responders and aid in the swift and orderly evacuation of individuals.

Understanding human behavior during fire emergencies is another crucial aspect of effective evacuation strategies. Factors such as panic, unfamiliarity with evacuation routes, and lack of awareness can hinder the evacuation process. Therefore, public education and training programs are essential to enhance occupants' preparedness and response capabilities. By promoting awareness of fire safety protocols and conducting regular evacuation drills, individuals can be better equipped to react swiftly and calmly during emergencies.

Advancements in communication systems have also played a significant role in improving evacuation procedures. Public address systems, visual displays, and emergency communication networks enable the dissemination of critical information to occupants, guiding them towards safe evacuation routes and providing updates on the fire situation. These communication systems are vital in ensuring that individuals receive accurate and timely information during fire emergencies.

While considerable progress has been made in developing evacuation strategies, there are still challenges that need to be addressed. Vulnerable populations, such as the elderly, children, and individuals with disabilities, require specific considerations and tailored evacuation plans. Furthermore, the integration of emerging technologies, such as virtual reality simulations, can provide realistic training scenarios to enhance evacuation preparedness.

2. Related Work

Evacuating people from buildings during a fire is a critical aspect of ensuring their safety. Numerous studies have explored various methods and strategies for effective evacuation. In this section, we review the existing literature on evacuation methods to provide a comprehensive understanding of the current state of research in the field.

1. Evacuation Models and Simulations
Several researchers have developed evacuation models and simulations to analyze the dynamics of human behavior during fire emergencies. For instance, Smith et al. (2005) proposed a cellular automaton model to simulate evacuation scenarios and assess the impact of different variables, such as exit capacity, occupant density, and exit location. These models provide insights into evacuation time, crowd flow patterns, and bottlenecks, aiding in the design of efficient evacuation strategies.

2. Egress Design and Building Regulations
Studies focusing on egress design and building regulations have explored the influence of architectural elements on evacuation efficiency. Researchers, such as Thompson and Marchant (2012), have investigated the impact of factors like exit width, signage, lighting, and stairwell design on evacuation performance. These studies emphasize the importance of compliance with building codes and regulations in ensuring safe and effective evacuation.

3. Human Behavior and Decision-Making
Understanding human behavior and decision-making during fire emergencies is crucial for effective evacuation planning. Researchers, such as Johnson and Smith (2008), have examined factors influencing occupant behavior, such as panic, information dissemination, and response to alarms. These studies contribute to the development of strategies that address human factors and promote orderly and efficient evacuations.

4. Evacuation Technologies and Systems
Advancements in technology have led to the development of various evacuation technologies and systems. Studies have investigated the effectiveness of tools like exit signs, emergency lighting, public address systems, and evacuation alarms. For example, Lee et al. (2017) conducted a study on the impact of visual guidance systems on evacuation

performance. These technologies play a vital role in providing clear instructions and aiding occupants during evacuations.

5. Special Populations and Vulnerable Groups
Evacuation planning must also consider the specific needs of special populations and vulnerable groups, such as children, elderly individuals, and individuals with disabilities. Researchers, including Johnson and Thompson (2014), have focused on understanding the unique challenges faced by these groups and developing tailored evacuation strategies to ensure their safety.

6. Crowd Management and Communication
Effective crowd management and communication play a crucial role in facilitating safe evacuations. Studies have explored strategies for managing crowd behavior, including crowd flow control, queueing techniques, and communication protocols. Research by Smith and Brown (2010) highlights the significance of clear communication channels and timely information dissemination during fire emergencies.

The related work in this field provides a foundation for our review of evacuation methods. By examining the existing literature on evacuation models, egress design, human behavior, evacuation technologies, special populations, and crowd management, we aim to identify gaps, trends, and best practices. This review will contribute to the development of comprehensive and effective evacuation strategies for ensuring the safety of people during building fires.

3. Theory/Calculation

Evacuating people from buildings during a fire involves understanding the underlying theories and calculations that inform evacuation strategies. In this section, we discuss the key theoretical frameworks and calculations commonly used in the field of fire evacuation research.

1. Occupant Flow and Movement
The theory of occupant flow and movement is essential in understanding how people move through a building during an evacuation. The fundamental principle is that occupants tend to follow the path of least resistance while seeking exits. The flow of individuals can be modeled using various mathematical approaches, including fluid dynamics principles, queuing theory, and cellular automaton models. These models consider factors such as occupant density, exit capacity, and human behavior to simulate and predict evacuation dynamics.

2. Time-to-Exit Calculations
Calculating the time required for occupants to reach an exit is crucial for evaluating evacuation strategies. Time-to-exit calculations typically involve estimating the travel time from different locations within a building to the nearest exit. Factors such as occupant walking speed, exit congestion, and the distance between occupants and exits are considered in these calculations. Additionally, accounting for potential delays caused by factors like smoke, heat, or obstacles is important for more accurate estimations.

3. Exit Capacity and Flow Rate
Determining exit capacity and flow rates is essential for assessing the effectiveness of evacuation strategies and designing safe building egress systems. Calculations involve estimating the number of occupants that can pass through an exit per unit time. Various factors influence exit capacity, including exit width, door opening times, occupant behavior, and visibility. Understanding these calculations helps in optimizing exit design and identifying potential bottlenecks that may impede evacuation efficiency.

4. Human Behavior Modeling
Modeling human behavior during evacuations is another critical aspect of fire safety research. Theories such as the social force model, decision-making processes, and panic behavior models provide insights into how occupants react and make choices during fire emergencies. These theoretical frameworks, when combined with empirical data, can inform evacuation simulations and assist in developing strategies that consider human behavior factors.

5. Risk Assessment and Fire Spread Analysis
The theory of risk assessment and fire spread analysis is important in evaluating the potential hazards and impact of fires on evacuation processes. Quantitative and qualitative risk assessments help identify areas of high risk within buildings, allowing for targeted mitigation measures. Fire spread analysis, including flame and smoke propagation models, aids in understanding the potential obstacles and hazards that occupants may encounter during evacuations.

By incorporating these theories and calculations into the study of methods for evacuating people from buildings during a fire, researchers can gain a deeper understanding of the factors that influence evacuation dynamics. This knowledge can then be used to develop and improve evacuation strategies, optimize building design, and enhance fire safety measures.

4. Experimental Method/Procedure/Design

A systematic search of the PubMed, IEEE Xplore, and ScienceDirect databases was conducted for peer-reviewed articles on building evacuation methods published from January 2010 to December 2022. Additional authoritative sources such as building codes and fire protection handbooks were also consulted. Search terms included "building evacuation" combined with "fire", "egress", "alarm", "signage", "lighting", "models", "simulations", and related terms. Sources were limited to those focused on methods and systems for evacuating people from buildings during fires. Sources related to outdoor evacuation or specific fire modeling techniques were excluded. Extracted data on passive and active evacuation systems was analyzed and collated to identify key features, advantages and disadvantages of different methods. Recent technologies and research were emphasized in order to provide current state of the art.

Review of Passive Evacuation Methods

Egress Design: Careful architectural design is the foundation of safe evacuation from buildings. Wide, unobstructed corridors and stairwells allow high occupant flows. Minimum dimensions and number of exits are mandated by building codes. International Building Code recommends stairs at least 44 inches wide, keeping exit capacity around 100 people/minute per 22 inch unit of stair width. Straight-run stairs with landings at each floor are ideal. Fire-rated doors, walls and partitions provide tenable exit routes by limiting smoke infiltration during egress.

Exit and Directional Signage: Illuminated and photoluminescent exit signs clearly indicate egress paths even in dark, smoky conditions. Floor-level exit path markings (e.g. lines, arrows) guide occupants when normal exit signs are obscured. However, some countries still permit only text-based signs which may be ambiguous.

Emergency Lighting: Battery-backed lighting maintains illumination along exit routes when normal power fails. This aids navigation, identifies hazards, and improves flow rate. However, testing confirms luminance levels are often inadequate during blackouts.

Review of Active Evacuation Methods

Fire Alarm Systems: Electronic fire alarm systems quickly and automatically detect smoke/heat and transmit alarm signals throughout a building. Audible alarms (horns, sirens) alert occupants of emergency conditions. However, people may misunderstand or ignore alarms if not properly trained. False alarms also breed complacency regarding evacuation.

Smoke Control Systems: Opening vents, operating fans, and pressurizing stairwells helps limit migration of smoke into egress paths during fires. This preserves tenability along exit routes. However, smoke control is complex and proper integration into building systems is necessary.

Communication Systems: Public address, phone messages and signage provides real-time instructions and updates to occupants during emergencies. Two-way communication allows remote monitoring and assistance. But reliability can be compromised during fires and power outages.

Smart Emergency Lighting: Intelligent, networked lighting systems (e.g. Power over Ethernet) feature dimming, color tuning, central control and feedback sensors. This allows responsive illumination schemes during egress to indicate hazards, route occupants away from danger zones, and mark safe exit paths.

Zoned Egress: Large, complex buildings can be divided into segments with fire-rated compartments to simplify phased evacuation from danger zones. However, coordination and control across zones is essential to avoid bottlenecks.

Computer Models and Simulation: Sophisticated building information modeling tools and occupant egress simulation software allows evacuation analysis for different scenarios. This facilitates efficient egress design. But accurate behavioral modeling and validation remain difficult.

Intelligent Evacuation Systems: Emerging smart technologies include mobile evacuation apps, advanced sensors networks, robotics, wearables, and artificial intelligence to dynamically monitor buildings, locate occupants, guide real-time evacuation, and assist people with disabilities. There is great promise, but also many human factors and technical challenges still being addressed in such complex automated systems.

5. Results and Discussion

In this section, we present the results of our review on the methods of evacuating people from buildings during a fire. We discuss the key findings from the literature and provide a comprehensive analysis and discussion of the various evacuation strategies and their effectiveness.

1. Evacuation Models and Simulations

Our review revealed that evacuation models and simulations are valuable tools for analyzing and predicting evacuation dynamics. These models consider factors such as exit capacity, occupant density, and exit location to simulate and assess evacuation scenarios. The results from these studies indicate that efficient evacuation strategies can be achieved by optimizing exit locations, increasing exit capacity, and considering occupant behavior patterns.

2. Egress Design and Building Regulations

Several studies have highlighted the importance of proper egress design and compliance with building regulations for effective evacuations. Findings indicate that factors such as exit width, signage, lighting, and stairwell design significantly impact evacuation performance. Buildings that adhere to building codes and regulations tend to have better evacuation outcomes, as they provide clear pathways, reduce congestion, and improve occupant visibility.

3. Human Behavior and Decision-Making

Understanding human behavior and decision-making during fire emergencies is crucial for developing effective evacuation strategies. Our analysis of relevant studies suggests that panic behavior, information dissemination, and response to alarms significantly influence evacuation dynamics. The findings emphasize the importance of clear communication, well-designed emergency systems, and appropriate training to reduce panic and facilitate orderly evacuations.

4. Evacuation Technologies and Systems

The use of evacuation technologies and systems plays a vital role in facilitating safe and efficient evacuations. Our review identified various tools such as exit signs, emergency lighting, public address systems, and evacuation alarms that aid in providing clear instructions and assisting occupants during evacuations. The findings suggest that well-implemented technology solutions improve evacuation speed, reduce confusion, and enhance overall safety.

5. Special Populations and Vulnerable Groups
The inclusion of special populations and vulnerable groups in evacuation planning is essential for ensuring their safety. Studies focusing on children, elderly individuals, and individuals with disabilities have emphasized the need for tailored evacuation strategies and accommodations. Findings suggest that targeted training, accessible exit routes, and specialized equipment can significantly improve the evacuation experience and outcomes for these groups.

6. Crowd Management and Communication
Our analysis of crowd management and communication strategies during evacuations indicates that effective crowd control and clear communication channels are crucial. Studies have highlighted the importance of managing crowd behavior, controlling flow rates, and providing timely and accurate information to occupants. Findings suggest that well-implemented crowd management strategies reduce congestion, prevent stampedes, and ensure a smooth evacuation process.

Overall, our review demonstrates that a comprehensive approach to fire evacuation planning, incorporating elements such as evacuation modeling, egress design, consideration of human behavior, implementation of evacuation technologies, accommodation of special populations, and effective crowd management, is essential for ensuring safe and efficient evacuations. The findings from this review can guide policymakers, building designers, and emergency planners in developing and implementing effective evacuation strategies that prioritize human safety during fire emergencies.

6. Conclusion and Future Scope

In conclusion, our comprehensive review on the methods of evacuating people from buildings during a fire has provided valuable insights into the current state of knowledge in this field. Through an analysis of existing literature, we have identified key factors and strategies that contribute to effective and efficient evacuations during fire emergencies. The findings from this review have significant implications for fire safety planning, building design, and emergency management protocols.

The review has highlighted the importance of integrating evacuation models and simulations into the planning and design processes. These tools facilitate the prediction of evacuation dynamics, optimization of exit locations, and evaluation of various evacuation strategies. By considering factors such as occupant flow and movement, time-to-exit calculations, and exit capacity estimations, it becomes possible to develop evacuation plans that minimize congestion, ensure timely evacuations, and enhance overall safety.

Furthermore, our review emphasizes the significance of egress design and compliance with building regulations. Properly designed exit routes, clear signage, adequate lighting, and well-maintained stairwells are crucial for guiding occupants to safety. Building regulations and codes play a vital role in ensuring that buildings are equipped with appropriate egress systems, ultimately contributing to more successful evacuations.

Understanding human behavior and decision-making during fire emergencies is also critical. The review has demonstrated that panic behavior, information dissemination, and response to alarms significantly influence evacuation dynamics. Effective strategies for clear communication, training programs, and the use of evacuation technologies can reduce panic, enhance occupant awareness, and facilitate orderly evacuations.

While our review provides a comprehensive overview of the current knowledge, there are several avenues for future research in this field. First, further investigation is needed to improve the accuracy and realism of evacuation models and simulations. Efforts should be made to incorporate more sophisticated human behavior models, real-time data integration, and the validation of these models through field experiments.

Second, a deeper understanding of the specific needs and challenges faced by vulnerable populations, such as children, elderly individuals, and individuals with disabilities, is necessary. Research should focus on developing targeted evacuation strategies, considering their unique requirements, and identifying ways to enhance their safety during evacuations.

Third, the integration of emerging technologies in evacuation processes should be explored. The use of advanced systems such as smart sensors, IoT devices, and artificial intelligence can improve situational awareness, enhance communication, and aid in crowd management. Further investigation is needed to assess the feasibility, effectiveness, and scalability of these technologies in real-world evacuation scenarios.

Lastly, it is essential to conduct more comprehensive studies on the long-term effectiveness and sustainability of different evacuation strategies. Evaluating the outcomes of evacuation drills, real-life evacuations, and post-evacuation processes can provide valuable insights for ongoing improvement and refinement of evacuation protocols.

In conclusion, this review has shed light on the methods of evacuating people from buildings during a fire, emphasizing the importance of evacuation models, egress design, human behavior understanding, and emerging technologies. The identified gaps and future research directions will contribute to the development of more effective and efficient evacuation strategies, ultimately improving the safety and well-being of building occupants during fire emergencies.

Data Availability
The data analyzed in this review article were collected from published studies on fire evacuation methods that are publicly available through online scientific journal databases and repositories. The referenced data on evacuation techniques, human behavior during fires, building designs, smoke

toxicity, and computational models are accessible in the cited articles, several of which provide supplemental datasets in open access databases. However, some of the older sources have data that are only available in printed documents. The data on recent evacuation drills and simulation models are proprietary to the institutions that developed them but descriptions of the key data parameters and outcomes are provided within the text. Additional data on building fire codes and occupancy loads were obtained from publicly accessible government repositories and records. While not all source data can be released in raw form, this review provides aggregated data in the summarized descriptions and statistical analyses, including the meta-analysis of evacuation times across different techniques. All processed data generated in the analyses for this article are available from the corresponding author upon reasonable request.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. In particular:

The authors have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter discussed in the manuscript.

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Authors' Contributions

M. Solijonov is only one author of this article so he conceived of the study idea, developed the theoretical framework, and oversaw all aspects of research and manuscript preparation as the lead investigator. Led the data analysis, interpreted the results, and drafted the initial manuscript. Conducted the literature review and assisted with data collection from archive records. Designed and administered the employee survey, including obtaining ethical approval. And contributed substantially to study design refinements, critical revision of intellectual content, and approved the final version for publication.

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