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A decision model for recommending which building occupants should move where during fire emergencies

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ABSTRACT

This paper describes a decision model for managing the movement of building occupants during fire emergencies. Currently available guidance from standard practice, egress modeling, codes and the research literature, is too general to provide much help to persons charged with the responsibility of where groups of occupants should be located given a fire scenario. The *occupant movement decision model* described in the paper uses three basic yes–no questions to divide building occupants into groups during a fire emergency. For any particular group, the decision model recommends one of two basic actions: (1) people remain where they are already located; or, (2) people relocate to a safer area in or outside the building, including the means by which they should travel to the new recommended location. The model specifies informational inputs that are used to decide which strategies are best used for which occupant groups—both in planning the emergency and for maintaining the situation awareness needed to adapt the plan when situations evolve in unexpected ways. By clearly determining which occupants should use which strategies, the model yields more effectively tailored strategies than those commonly prescribed for building-wide strategies of full and phased building evacuations, partial building evacuations, in-building relocations, and sheltering-in-place.

1. Introduction

Persons responsible for managing a fire emergency may lack a clear understanding of how they should move occupants in response to a fire given the fire protection features of a building and the capabilities of its occupants. This paper describes an *occupant movement*[1] *decision model* intended to assist those people. The normative decision model[2] described here is used first, to divide building occupants into groups, and, second, to recommend an appropriate protection strategy for each group. Each group is provided with a recommendation to either remain in their present location or to move to a safer location. If people are asked to move, then the means (i.e., routes and assistance) by which they are expected to travel to the safer location can be provided. While the decision model is primarily intended for persons who will direct the movement of people, it value to fire safety systems designers (e.g., fire protection engineers and architects) who are expected to recommend effective egress strategies appropriate to the occupant capabilities and the physical fire safety and layout features of specific buildings.

Occupant movement strategies are often categorized using schemes similar to the following: [1]

- Simultaneous whole building evacuations. All occupants leave the building at the same time when they are notified.
- Phased whole building evacuations. All occupants leave the building, but in a phased sequence based on the vulnerability of building occupants.
- Partial building evacuations. All occupants in a certain part of the building leave.
- Relocating people within a building. Persons in the building relocate to safer areas.

However, in many large buildings, these approaches are oversimplified. A combination of strategies should be recommended to different groups of occupants depending on the factors discussed in this paper. For example, in a tall building, persons above and below the fire zone may be requested to remain where they are already located and evacuate the building if necessary (defend-in-place with a partial building evacuation as backup), persons in the fire zone may be requested to move below or above the fire zone

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[1] To avoid confusion, this paper uses the term “occupant movement” because people may be advised to remain in their present locations or to move to a different location in the same building. The terms “evacuation” and “egress” are sometimes used when referring to all movement of people during emergencies, but in many other contexts these terms imply that people move to the outside of a building.

[2] In contrast to descriptive models, a normative “model” is a prescriptive decision model that is used to evaluate alternative solutions to a problem.

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(relocate), and persons with disabilities may be requested to move to refuge areas to await rescue (relocate, defend-in-place, and rescue if necessary).

1.1. Some investigations of fires implicate poor managerial decision making that contributed to large losses of life

Because persons charged with the responsibility of managing a fire emergency often lack a clear understanding of the logic underlying fire protection features, it is not surprising that they make mistakes when responding to emergencies. Unfortunately, these mistakes are rarely revealed because investigations of fires focus on problems with physical systems—shortcomings in code provisions or maintaining systems mandated by codes. Even when mistakes are made, they are often attributed to "panic" instead of attempting to understand the mistaken logic that provided the erroneous rationale for these mistakes. However, there is evidence where managerial mistakes contributed to the severity of fire incidents. A high rise office building fire in Chicago resulted in several fatalities attributable in part to errors in managing the movement of building occupants [2]. Chertkoff and Kushingian [3] document fires where delayed and poor managerial decision-making may have contributed to large losses of life. These included (1) managerial delays in starting an evacuation caused by a fear that occupants would "panic," and (2) the unavailability of people to guide occupants to safe egress routes. Chertkoff and Kushingian explain that, in addition to poor decision making in response to fire, building management also failed to understand how pre-conditions such as highly combustible interiors and convoluted and blocked egress routes greatly increased the risks if a serious fire were to occur.

1.2. A simple mental model might improve decision making for the movement of building occupants in response to fire

Sophisticated education and training would certainly improve the responses of occupant movement managers, but it seems unlikely that a great increase in resources will be dedicated to that purpose. However, a simple *mental model*[3] should help occupant movement managers avoid mistakes in both planning for and responding to fire emergencies. Such a mental model might help people managing the movement of occupants to better understand how strategic responses to fires can take advantage of building features and to compensate for human limitations under a range of potential scenarios. The occupant movement decision model described in this paper serves as a mental model that is easily understood and recalled with relatively little fire safety education and training.

1.3. Existing recommendations about managing the operational responses to fire emergencies are too general

There are references that describe the *general* issues about planning to manage responses to fire emergencies. Examples include the *Life Safety Code* [4] where detailed recommendations are available for conducting required life safety assessment in assembly occupancies. Burtles [5] has published a guide based on the process of business continuity planning. In England and Wales, occupancy-specific "fire safety documents" are available online [6]. The Building Owners and Managers Association has published useful but general guides to emergency planning [7,8]. Extensive coverage is available that describes the logic that underlies the physical design of building features that enable the safe movement of people [1], but there is little guidance about how physical systems should be leveraged when making operational decisions about moving people during fire emergencies.

1.4. Computational models of egress times have limited value in managerial decision making for occupant movement during a fire

A rich body of research and development deals with the development of models that calculate travel times during fire emergencies. Calculated egress times derived from these evacuation models are used to design egress systems that ensure adequate carrying capacities to evacuate building occupants.

Computational predictions for building evacuation times generally compare Required Safe Egress Time (RSET) to Available Safe Egress Time (ASET). Depending on a selected scenario (the design fire and the numbers, locations and capabilities of building occupants), the margin of safety provided by a building's physical features is calculated as the amount of time that available safe egress time exceeds the required safe egress time. The available safe egress time is derived from engineering models of fire growth that measure the amount of time before a space becomes untenable, a function of heat, visibility and smoke toxicity [1]. As an example, ASET for a given space ends when a layer of smoke descends to a height where building occupants may not survive.

Fire protection engineers widely apply computational egress models to performance-based design solutions. The ASET/RSET approach guides the design of physical systems that facilitate the movement of people in buildings, especially the design of egress system. Nonetheless, the approach has important limitations.

- Well-managed occupant movement should use a more conservative (but very difficult to measure) objective, for example not to expose people to conditions where they feel their lives are in immediate jeopardy.
- Older simulation models generally treat people as physical objects, ignoring their cognitive attributes and lack of information about available egress routes, both important determinants of actual behavior. Therefore, these models often calculate optimal times, assuming that people follow the quickest safe route, and thereby underestimate actual evacuation times. Beyond the speeds at which people are expected to move, recent innovations are extending the approach to include the cognitive attributes of people, including pre-evacuation times (i.e., that amount of time the people take before beginning their movement toward egress routes) and interactions of individuals with their environments, including egress familiarity, fire hazards, other people and physical features such as building layouts, and the visibility of exit signs [9,10].
- Simulation models have either excluded or been very limited in their ability to incorporate the *variable and adaptive* behaviors of building occupants [9].
- Using computational models to optimize the design of egress routes often requires a tedious process of comparing various configurations, fire scenarios and assumptions about the locations and capabilities of building occupants. Recent innovations may provide more efficient computational methods to finding the most efficient strategies for moving people [11]. Even if we assume that entirely valid means to computationally model optimal occupant movement strategies are forthcoming, *realizing the potential is impossible without some way of conveying this information to the persons responsible for managing the movement of occupants.*
- Central to the concerns addressed in this paper, these computational models do not include the decision processes of the

[3] "Mental models" are simple beliefs that people have about how something works in the real world. To the degree that mental models accurately represent the real world, people are less likely to make mistakes.

very persons responsible for directing the movement of people during a fire emergency.

1.5. Historic processes have led to changes in occupant movement strategies

Historically, decisions about how to manage the movement of building occupants have evolved by a trial-and-error process for specific types of occupancies [1]. For example, in response to fires in health care facilities, building features have evolved that protect patients in their rooms, a concession to the reality that staffing levels are often insufficient to quickly relocate more than a few *immediately* endangered patients to safer areas. In tall buildings, building features have evolved that enable relocation of occupants from only the areas that are most immediately affected by a fire, hopefully providing exit stairs that are sufficiently uncrowded while not having to dedicate excessive leasable floor areas to stair enclosures.[4] In large assembly occupancies, tragic fires have led to increased egress capacity, multiple routes, and requirements that staff be trained to direct occupants.

Despite the considerable historical improvements, the logic that underlies the decisions about which occupants should move where remains obscure to the people who are expected to make these decisions. Mistakes where staff failed to take advantage of code-mandated fire protection features have resulted in fatalities in health care fatalities [12]. Understanding the bases for occupant movement decisions is important both in planning for fire emergencies and in adapting to situations as they occur during fire emergencies. Further, understanding the logic for occupant movement decisions reinforces the critical importance of maintaining key building features and conducting training drills that will contribute to the effective movement of occupants during emergencies.

1.6. Code requirements related to managing the movement of occupants in buildings are not tailored to different groups of occupants

1.6.1. Codes primarily govern the physical attributes of egress systems

Building codes, both prescriptive and performance-based, provide detailed requirements for the physical protection of egress routes. Performance-based design solutions generally require the use of a computational model (see Section 1.4). A review of code requirements governing egress is beyond the scope of this paper and is available elsewhere [1].

1.6.2. Planning requirements provide little guidance about how to tailor occupant movement to specific groups and scenarios

Fire and occupancy codes often include very general mandatory and recommended fire emergency planning requirements, but they omit details about how plans can best be tailored to the specific characteristics of buildings and their occupants. In many instances, codes simply require the existence of a plan. At a considerable level of detail, the *Life Safety Code, NFPA 101* [4], requires a life safety evaluation for assembly occupants with large numbers of occupants. While the details are left unspecified, an annex to the *Life Safety Code* includes detailed recommendations for the types of content that should be included in the analysis. Nevertheless, given the numerous contingencies, the recommendations understandably lack advice about what occupant movement strategies are best used in response to which fire scenarios.

Local jurisdictions, typically cities, sometimes have detailed requirements for emergency planning in certain high-risk occupancies such as tall buildings and large places of assembly. As an example, New York City has adopted local laws requiring Emergency Actions Plans in tall commercial buildings and large hotels [13]. These requirements charge a certified fire/emergency action plan director with the task of writing an Emergency Action Plan (EAP), defined as “a written plan which sets forth the circumstances and procedures for the sheltering in place, in-building relocation, partial evacuation or evacuation of building occupants in response to an emergency.” However, it is important to note that the plans written to meet these regulations do not address how fire safety/EAP directors can determine which strategy should be employed in which circumstances, a problem that this paper attempts to address.

2. The occupant movement decision model

2.1. The occupant movement decision model has these basic features

This paper presents an analytic tool for understanding which decisions are appropriate in a specific building given the evolving locations of fire hazards and people, along with the limitations of occupants and the availability of assistance to overcome those limitations. The model has the following essential features:

- The model is based on a sequence of three yes–no decisions that the occupant movement manager uses to divide building occupants into groups. Groups are not defined solely by their location in the building in relation to the fire hazard; different recommendations may be provided to different groups in the same location based their capabilities and the availability of help in overcoming their limitations (see Sections 2.4.5 covering occupant capabilities and Section 2.4.6 covering the availability of assistance).
- Each group receives a simple recommendation to either remain where they are presently located or to move to a safer location using a specific means (e.g., horizontal compartments, stairs, or elevators, either with or without assistance from fire fighters or members of a building emergency response team.)

- The decision model is applied to specific fire scenarios. The ways in which occupants are divided into groups depends on the informational inputs associated with the scenario under consideration. Informational inputs include both conditions in-place before an incident begins (for example, building fire protection features and the likely locations and conditions of people in the building) and dynamic information that evolves during a fire incident (i.e., the extent of hazards and changes in the locations of people and their conditions). Building codes are generally reactive; the scenarios considered by code writers are based on unspecified historical fires that have caused fatalities. These fires are not described in the code itself, although commentary on code requirements can provide some guidance. Performance-based requirements in the *NFPA Life Safety Code* [4] include a set of fire scenarios that can serve as a starting point in selecting scenarios appropriate to fire emergency planning in a particular building.
- The decision model can be used for both planning and for adapting a response during the fire emergency. After the model description, which applies to both, there is a separate discussion (Section 5) about using of the model to adapt to the way that an emergency develops. The optimal decision for moving a group may change during a fire emergency. In these circumstances, a backup strategy is advisable. Occupant movement managers

[4] The opinion that people will wait for their turn when evacuating tall buildings has been questioned following the World Trade Center attacks on September 11, 2001 [29].

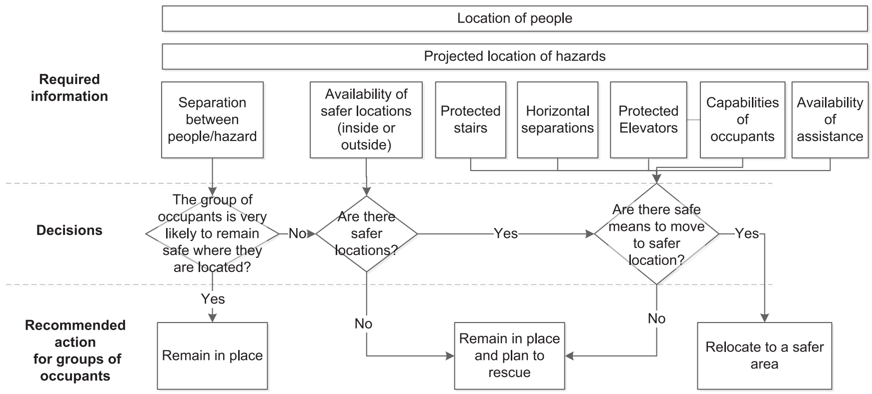

Fig. 2.1. Occupant movement management decision model.

need to maintain sufficient situation awareness to understand when a change is desirable. To the extent that occupant movement managers have planned for these contingencies, it is likely that the transition to a different backup strategy will be implemented efficiently and accepted by building occupants.

The decision model in its entirety is shown in Fig. 2.1.

2.2. *Decision number one: which occupants are in danger where they are located?*

This is the first decision for an obvious reason; where occupants are safe where they are already located, it is simplest to request them to stay where they are already located. This also frees the people managing the movement of people to focus their attentions on the remaining two decisions. The first decision and its required informational inputs are shown in Fig. 2.2.

2.2.1. *Building features that limit the projected locations of hazards*

Compartmentation, sprinklers and smoke control are building fire protection features that are likely to be reliable enough to allow decision-makers to consider occupants as safe even when there is a fire in the building—assuming that these features are maintained to ensure their performance as designed. A careful assessment of these features is essential to understanding the expected extent of fire hazards for each selected scenario.

- *Compartmentation* refers to the use of barriers the limit the travel of fire hazards (i.e., heat and smoke) from one building space to another.[5]
  a. Obviously, people are generally safe when they are located in a different building. In some special situations, codes will permit connected spaces to be considered as separate buildings, but only where extensive building features reliably prevent a hazard from spreading across the separation between the "buildings."
  b. Barriers can generally be divided into two categories, vertical and horizontal. Vertical barriers limit the spread of fire and smoke from one floor to another. Where vertical openings are unprotected against the travel of a fire hazard, none of the occupants above the fire can be considered safe in their locations. Horizontal separations limit the spread of fire and smoke on a single floor of a building. Where people need to travel from one side of a horizontal barrier to the other side, codes may allow the installation of a *horizontal exit.* Horizontal exits include fire-rated and smoke-resistant doors that must either remain in a closed position or that automatically close when either an alarm is activated or smoke is detected at the location of the doors. Therefore, people who are separated from a fire by a horizontal exit may be considered to be safe throughout the duration of most fire.
- *Automatic suppression,* especially sprinkler systems that automatically detect and suppress fires, may prevent the spread of hazards beyond the area where the fire started.
- *Smoke control* can be used to remove smoke before occupants are exposed, increasing the likelihood that occupants can remain where they are already located.

A relocation backup strategy may be required in the event of an unusual severe fire or performance failures in the buildings fire protection features (see Section 4). Horizontal exits are extensively used in health care facilities because it is exceedingly difficult to move patients between floors using stairs (the use of elevators is typically prohibited during fire emergencies). They are also common in large residential buildings so that longer corridors, when divided by horizontal exits, can be used without exceeding code requirements for maximum travel distances to an exit.

2.2.2. *The number of people in the various locations of the building*

Decision-makers need a general idea about both the number of people and their likely locations in the building. At the onset of an emergency, the most conservative answer is that there may be people in any and all occupiable spaces. In some occupancies, the number of building occupants varies considerably depending on working hours.

2.2.3. *The communication of recommended actions even when people are not asked to move*

As a generalization, persons assessed as most in danger from fire hazards need to receive the highest priority in receiving information about recommended actions. Persons in relatively less danger may be requested to wait for further instructions that depend on how the fire emergency is developing. When people are considered safe in their present locations, they still need to be instructed to remain where they are already located. For these reasons, communications should not only provide instructions, but also a brief explanation about why it is advisable to remain in place instead of moving [14].

Another imperative reason for communications is because more than likely occupants will receive cues that may motivate them to leave areas where they are safe. These include observations of fire cues such as the odor of smoke, arriving fire fighters and sightings of other evacuating building occupants. The problem

[5] There are many other relevant building features that are also important in determining the growth of fires, but which are not discussed here. Examples include the flammability of wall coverings, systems that vent smoke from atriums, and the fuel load provided by furnishings.

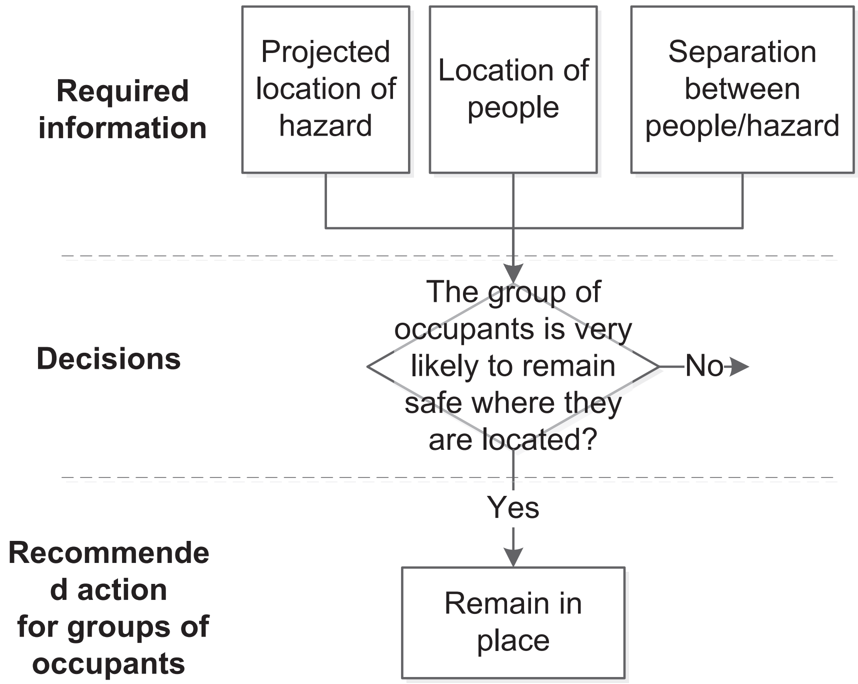

Fig. 2.2. Decision 1, Which groups of occupants are in danger where they are located?

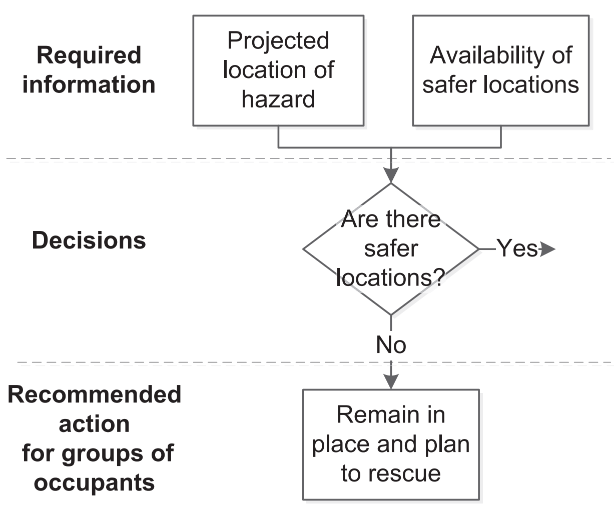

Fig. 2.3. Decision 2, Are there safer locations?

is compounded by the widespread use of social media that enable occupants to quickly and easily acquire information from both inside the building and with persons outside of the building. They are likely to take actions in the absence of advice from occupant movement managers, potentially leading them to make mistakes that endanger themselves by moving to more vulnerable locations or interfering with the movement of people in greater jeopardy, for example, by increasing congestion in stairs or by unnecessarily endangering rescuers.

2.3. Decision number two: are there safer locations?

A “safer” location is relative. In the first decision, we asked whether a group of occupants is very likely to be safe throughout a fire incident. In buildings that are well-designed for fire safety, there will always be safer locations in the event that occupants may not remain safe throughout a fire emergency. The problem for occupant movement managers is to understand where these safer areas are located (if any are available) for each particular group of building occupants. However, occupant movement managers can inherent building with deficiencies (see Section 4.2) or they may face fires that exceed the scenarios for which the building was designed. Therefore, occupant movement managers should be prepared to ask whether safer areas exist. If safer areas are unavailable, then plans to rescue occupants are needed in the event that these occupants are endangered (Fig. 2.3).

The projected location and extent of the fire hazard. The same basic considerations as reviewed in the first decision apply to this decision as well. In particular, this requires an assessment as to whether the paths of travel to a safer location are likely to remain relatively free of smoke and heat. This will depend on the same fire protection features of the building considered in Section 2.2.1.

2.3.1. The building features that often provide safer locations than where people are already located

Exits are primarily intended to move people to safer locations in the building or outside the building. However, because they are typically well-protected using fire-resistant barriers and closed doors, they can also serve as areas that are relatively safer from the areas that they are leaving. However, exits are rarely recommended as the final destinations during fire emergencies because fire hazards can still enter the exits (especially because fire fighters often use exit stairs to stage their fire suppression activities, allowing smoke to enter) and because they can become so crowded in large buildings with high occupancy loads that some people may be unable to enter the exits or travel rapidly once inside the exit stairs (see Section 2.4 for a discussion of vertical and horizontal exits).

Exit discharge refers to the areas outside of a building where the path of travel will remain free of obstruction and will locate evacuating occupants to areas where they are safe from fire hazards, will not obstruct fire suppression operations, and may serve as an assembly area where occupants can be accounted for (also see Section 2.3.3).

Areas of refuge are spaces inside of building specifically designed to provide safety during a fire emergency. At a minimum, a well-designed area of refuge will be separated from surrounding areas with fire-rated or smoke-resistant barriers and doors, and may also include a pressurization system that provides air from the exterior of the building and impedes smoke from entering the area, as well as a two-way communication system that connects persons in the refuge areas with an occupant movement manager. Areas of refuge are frequently intended for use by persons who are unable to evacuate unassisted to the outside of a building, generally because they have disabilities or are patients in a health-care facilities. In some newer high rise buildings, entire floors may constitute an area of refuge [15,16]. Some buildings have designated areas of refuge that fail to meet these requirements. These substandard areas are better considered as areas of rescue assistance where people who wait temporarily until they can be safely evacuated by fire fighters. As an example, some buildings have enlarged landings in exit stairs that can accommodate a few wheelchair users without impeding the progress of other persons using the exit stairs to relocate to safer areas or the outside of the building.

2.3.2. *Provision for rescue when occupants may not remain safe*

When occupants may not remain safe during a fire emergency, provisions should be made in the event that they must be rescued. For example, occupants with mobility impairments are a group that may require assistance to descend the same stairs that other occupants have used to relocate to safer locations. In many situations, responding fire fighters will be expected to rescue occupants, so it is important that building managers can identify their locations and relay this information.

2.3.3. *Determination of whether people are safer outside the building*

When occupant movement managers determine that occupants should relocate, they need to decide whether they should recommend another location inside the building or outside the building (see Fig. 2.4). As a generalization, people are safer outside of a building where there is a fire. There are exceptions. Fires outside of buildings or in locations that involve the exterior of the building can expose occupants to fire and smoke when they exit. When a fire is located outside the building, smoke often enters the building leading to the misperception that there is an interior fire. Someone with poor situation awareness (see Section 4.3) may order the evacuation of all or part of the building, thinking that people will be safer outside. An accurate understanding of the location of the fire is needed to evaluate which areas outside the building are safer than inside.

An adequate exit discharge and a viable area of assembly are other considerations. Codes require that occupants be able to relocate at a distance sufficiently away from the building so that they are not exposed to hazards and do not interfere with firefighting operations. For some buildings, it is important to consider the locations where occupant movement managers want evacuees to assemble [5], a particular concern where evacuees may be exposed to very uncomfortable weather.

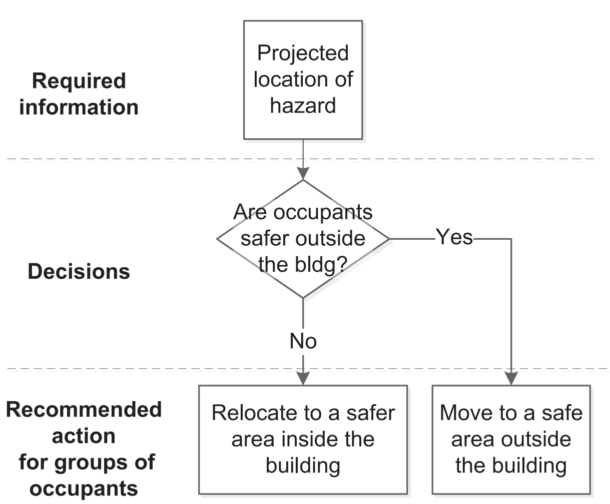

Fig. 2.4. Decision, Are occupants safer outside the building?

2.4. *Decision number three: are there safe means to relocate to a safer location?*

The decision about whether to move people to a safer location depends on whether they can be safely moved without exposing them to hazardous amounts of heat or smoke. Determining the safety of routes and providing the assistance needed to use those routes is the most complex of the decisions facing occupant movement managers (Fig. 2.5).

2.4.1. *Stairs*

There are two basic types of stairs, "exit" stairs and other less protected stairs. Exit stairs have two basic features that provide protection from smoke and fire: (1) the stairs are lined with uninterrupted fire-rated barriers; and, (2) the doors to the stairs are fire-rated and have closers that will prevent the doors from remaining open during a fire emergency. Once people are inside of an exit stair, they are better protected than if they remained in areas that are more easily exposed to the smoke and heat from a fire. Therefore, exit stairs usually provide a safe means to relocate people to areas where they are better protected from fire hazards.

Stairs that do not qualify as part of an exit may still be good means to relocate people, but they are best used only when (1) the use of an exit stair is potentially hazardous, (2) the stairs are unobstructed, (2) they have been examined and found to be relatively free of smoke.

Multistory buildings without any exit stairs are usually either single or two-family homes or older residential structures. Apart from single and two-family homes, most buildings will have two stairs. Some jurisdictions use performance-based design approaches where a single stair might be allowed as a result of other design decisions that are considered as providing sufficient protection. Further, older residential structures may have only a single "exit" stair, with a fire escape serving as the alternative means to escape from upper floors.

In certain buildings, exit stairs may be either smoke enclosures or pressurized. A smoke enclosure is a stairs where building occupants enter the stairs by passing through the vestibule. Vents in the vestibules allow smoke to escape to the outside of the building before it enters the stairs.

Stairs can also be protected using pressurization. A mechanical system of fans raises the pressure inside the exit stairs. When the pressurization system works properly, little of the smoke will enter the exit stairs. However, in tall buildings, stack effects and multiple open doors can limit the effectiveness of pressurized stairs—another reason to maintain good situation awareness (see Section 4.3) [1].

2.4.2. *Protected elevators*

For the most part, elevators are not used to evacuate buildings during fires. Elevators are always taken out of service when smoke is detected in the vicinity. When elevators are taken out of service (often called elevator capture or phase I service), they travel to the ground floor (or another floor if smoke is detected on the ground floor) where the doors open and the elevator cannot be used by building occupants. After elevators are taken out of service, they can still be used by fire fighters using a special key (called firefighter service or phase II operation). Fire fighters may use

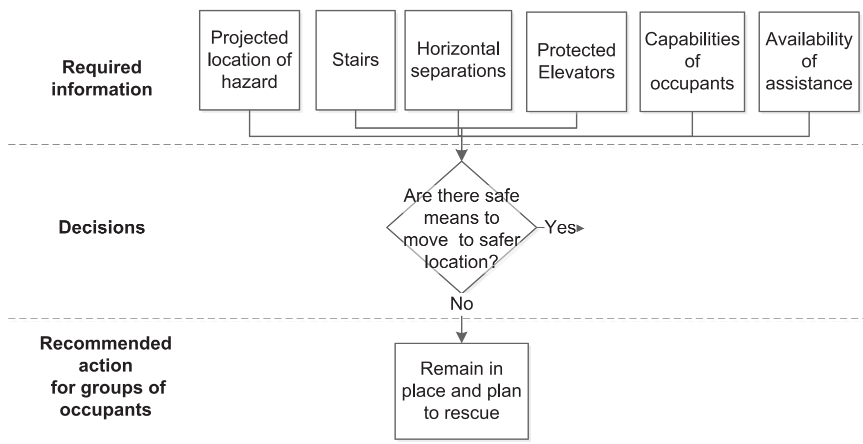

Fig. 2.5. Decision 3, Are there safe means to move to a safer location?

elevators during a fire emergency to move personnel and equipment closer to a fire and to evacuate persons who have been unable to evacuate without their assistance—but only after their safe use has been carefully evaluated.

In recent years, there have been efforts to design elevators so that they can be used to move people to safer areas even during fire emergencies [17,18]. These emergency occupants evacuation (EOE) elevators, and the lobbies where building occupants would wait for elevators to arrive, are likely to be pressurized and enclosed with smoke and fire-resistant barriers. Further, the elevators would be designed to be taken out of service when smoke is detected in the lobbies or elevator shafts.

2.4.3. *Areas of rescue assistance and rest*

In large, and especially very tall, buildings, occupants may be unable to travel the expected distances without resting in a relatively safe location. The problem is compounded for occupants with mobility limitations who may be entirely unable to descend stairs and will need relatively safe locations to await assistance. Wider landings on stairs serve the purpose, but are typically small in size. In very tall buildings, entire refuge floors, or portions of floors, are increasingly used for this purpose [15]. These larger spaces can serve not only as areas of rest, but also as safe areas to transfer to different exit stairs and to protected elevators. However, it may still be necessary to rescue occupants in these areas if fire hazards endanger them as the situation evolves. Therefore, an effective emergency plan will anticipate this necessity.

2.4.4. *Exterior supplemental evacuation equipment*

There have been recent innovations that can be used to evacuate relatively small numbers of people from upper stories in buildings to the outside. These devices are chutes and platforms. In general, building and fire codes do not qualify these systems as acceptable means to escape. In the United States, these systems have rarely been installed because of the expense, issues about safety and reliability, and the inability to quickly move large numbers of occupants.

2.4.5. *Movement performance of occupants*

Certain persons are likely to be less capable, or entirely unable, to move to other locations in the building without assistance. Occupants may have limitations because of their age (either very young or old), mobility, sensory and cognitive disabilities, and temporary “disabilities.” It is important to not categorize persons with disabilities together regardless of type and severity. In planning for occupant movement, persons should be encouraged to participate to the extent that their impairments allow. For more detailed information, see SFPE [19] or Burtles [5]

- *Mobility impairments* are the most common limitation that prevents people from moving in buildings to safer locations. Of particular importance is the ability to use stairs. While persons who use wheelchair or other assistive devices have readily apparent disabilities, for many persons with mobility impairments, the limitations are mostly or entirely hidden. Musculoskeletal problems such as back and leg problems and arthritis may not be easily observed. There are temporary disabilities such a pregnancy and broken limbs that can prevent the use of stairs. It is also important to note the distances that people may have to travel on stairs. People with relatively mild impairments may be able to negotiate a few flights of stairs without much difficulty, but traversing several flights of stairs can cause serious risks to the same people.
- *Sensory disabilities* related to vision and hearing are common limitations. Sight impairments can make unassisted way-finding difficult or impossible in unfamiliar settings. However, blind persons may have an advantage in familiar settings when emergency lighting fails and sighted persons navigate egress routes [20]. Hearing impairments create problems in alerting and instructing persons.
- *Cognitive impairments* are important problems, especially in unfamiliar settings. We typically associate developmental disabilities with cognitive impairments, although this can be misleading. Well-rehearsed persons with mild levels of retardation often respond more reliably and quickly than other persons [21]. Age-related cognitive impairments are important limitations. Young children can easily make mistakes that are counterintuitive to adults, such as hiding in closets or under beds. Persons with dementia can become confused and lose their abilities to navigate and understand instructions during the stress of a fire emergency. Intoxication from alcohol or drugs (legal, such as sleeping and pain medications, as well as illegal drugs) can create various problems. Persons who are intoxicated or medicated can be much slower to accurately assess danger, and are less likely to awaken in time to take effective responses. Intense levels of fear can also limit people’s cognitive performance.
- *Sleep* is a limitation of great importance. Persons who are asleep at the onset of a fire emergency are often much slower to respond. As noted above, persons using illegal or prescribed legal drugs can be much more difficult to wake. Alarm signals may fail to awaken young children.

2.4.6. *Availability of assistance*

To the extent that occupants are unlikely to move to safer locations without assistance, help should be provided. Help can be provided by organized and trained building emergency response teams. In addition to an occupant movement manager, roles for building emergency response teams can include (1) floor wardens or monitors who direct occupants to safer egress routes; (2) persons charged with searching areas to ensure that everyone has left (assuming that they have been instructed to move to another location); (3) elevator monitors who prevent people from using elevators or, when the building is equipped with protected elevators that can be safely used, direct and reassure occupants that they should wait for an elevator car; and (4) persons assigned to help occupants with disabilities.

Instructions in many buildings are provided by a one-way public address or alarm notification systems. Building emergency response teams are typically required to ensure that broadcasted messages are understood and to reinforce the feasibility of the recommended actions when occupants have doubts. Building occupants may be unfamiliar with the layout of the building, especially egress routes. This is the likely case not only for visitors, but also for occupants who have not participated in fire drills designed to familiarize them with alternative means to travel in the building. Well-designed messages should use simple language, identify that the message is from an authorized person, explain the rationale for the recommended action, and be repeated [19]. Further, the intelligibility of messages should be assessed to ensure that they can be understood. However, messages broadcast over public address systems may lack sufficient information or credibility and will need to be explained and reinforced.

The building emergency response team may also be responsible for assisting persons who are not able or who are unlikely to evacuate without assistance (see Section 2.4.5). While some buildings maintain registers of nontransient occupants who are likely to require assistance, these cannot be relied on to be complete. Apart from the problem of maintaining up-to-date registers, registers are likely to omit visitors who have limitations, persons who have temporary disabilities and persons who have not voluntarily included themselves in the register.

Controlled descent devices (most types are often labeled as “evacuation chairs”) are used to move persons with disabilities or injuries that prevent them from using stairs. These devices move persons needing assistance down stairs operated by a single helper [22,23]. Persons needing assistance must be transferred to the chair, an operation that can injure either the occupant or the operator when poorly executed. Practice in using the devices is recommended to provide both operators and disabled persons with the confidence to use them safely. Persons with disabilities can often provide advice to operators on how they can be most safely transferred to the devices—a potentially dangerous maneuver for fragile persons.

3. Delayed movement for persons with critical functions

An important group of persons that have critical responsibilities during a fire emergency may be delayed in their movement. Categories of people in this group may include the following:

- Building emergency response team members, such as floor wardens, typically leave an area after the occupants for which they are responsible are deemed safe (see Section 2.4.6). Persons managing occupant movement and monitoring the status of fire protection systems may remain in a fire command station to improve the situation awareness of arriving public safety personnel and to cooperatively continue their activities as the emergency develops.
- Persons charged with securing key tenant infrastructure may be delayed from leaving their work stations. Examples include persons who save working files and shut down and secure computer systems. As with building emergency response team members, facilities managers may be requested to report to the fire command station to assist fire fighters in understanding and operating building equipment such as heating, ventilation and air conditioning (HVAC) systems.
- Persons charged with shutting down key building infrastructure, such as manufacturing processes and gas supplies.
- Persons charged with removing a list of persons who were in the building at the time of the emergency. In many buildings, it is unrealistic to expect an accurate roster of building occupants, especially visitors. However, some buildings with advanced security systems have more reliable access control devices that track when people both enter and leave the building and a register showing when visitors arrive and leave the premises.
- Persons charged with maintaining access control during the emergency [5]. These are most likely to be security personnel who are placed at location of ingress into the building.

People in all of the above categories should be incorporated in occupant movement planning. Sometimes tenants fail to disclose the presence of persons with these responsibilities because of resistance from building managers and fire fighters.

4. Using the occupant movement model to adapt occupant movement strategies to the way that an emergency develops

4.1. Backup strategies

Backup strategies may be required depending on how well initial strategies work taking into consideration the locations of occupants and the projected extent of fire hazards. For example, in a tall building, persons who have relocated away from the fire zone may be requested to evacuate the building when smoke from a fire begins to migrate outside of the fire zone. In many instances, all occupants will be expected to evacuate the building after occupants in more danger have already left. Occupant movement managers should incorporate backup strategies into their planning, thereby expediting the backup strategies to respond to evolving fire scenarios. The timely and appropriate use of backup strategies depends on maintaining good situation awareness (see Section 4.3).

4.2. Problems with the condition and maintenance of fire protection features and emergency operations

Ideally, a good emergency plan will allow a timely and appropriate response to a fire emergency, but this cannot be guaranteed. The decision model described in this paper serves two purposes: (1) given a scenario and the physical attributes of a building, planning occupant movement in preparation for a fire emergency can be improved; and (2) making real-time adaptions to the plan depending on how an actual fire emergency evolves will be more effective. There are inherent uncertainties in the way that fire emergencies will evolve—and the more complex the situation, the more likely that everything will not happen as planned. Examples include:

- *The fire is more severe than anticipated.* This can occur when there are unexpected types and quantities of fuels, and especially when fires or explosions are intentional.
- *Failures of fire protection features.* Fire protection features may fail to perform as designed, as when a sprinkler system failure

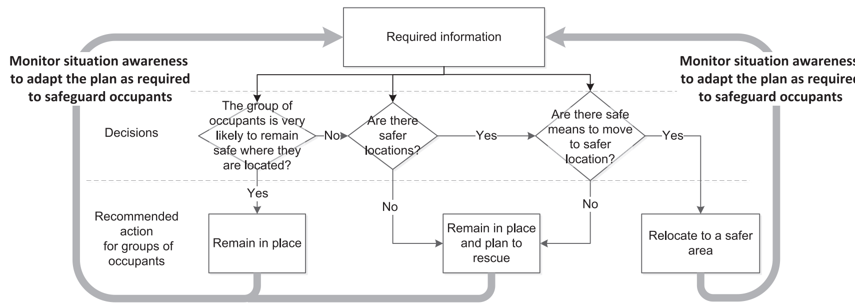

Fig. 6. Maintaining situation awareness to adapt the occupant movement plan.

allows the fire to grow unimpeded, a smoke control system operates unreliably, or penetrations in barriers allow smoke to spread to other areas in the building. Alarm and communication systems can fail, delaying notification of a fire hazard and preventing alerts and instructions from being transmitted or intelligible.

- *Organizational failures.* Persons charged with key roles during a fire emergency may not remember procedural details and responsibilities, may be absent without an available deputy, or replacements may not have been appointed.
- *Capabilities of building occupants are not accurate or are unknown.* In many types of occupancies, the capabilities of building occupants are well understood. Families know the limitations of their members. Health care facilities generally assume low levels of capability among their patients. But in other occupancies, the presence of persons with limitations and their locations are difficult to assess. Hotels are unlikely have a clear understanding of the capabilities of their guests. Office buildings may maintain a register of persons who are likely to need assistance, but even the most comprehensive registers will have omissions due to temporary disabilities and the presence of transients and visitors.
- *Fire suppression operations may compromise areas that were formerly safe.* Fire fighters sometimes begin their suppression actions before all building occupants are moved to locations where they can remain safe during the duration of a fire emergency. In particular, fire suppression may be staged from an exit stairs allowing smoke to enter, making the stairs untenable.
- *Complex systems interact in unpredictable ways.* The components of complex systems interact within the system and with the environment in ways that are arguably impossible to predict [24,25]. Most incidents that result in unusually large losses result from unforeseen (and perhaps unforeseeable) convergences of multiple faults.

Due to all of the above uncertainties, it is important to assess situations as they evolve—the topic of the next section on situation awareness.

4.3. Maintaining good situation awareness

For all the decisions in the model, a dynamic assessment of both the extent of the hazard and the locations and capabilities of people is important. Situation awareness can be defined as “the degree that people responding to an emergency (1) are aware of the situation in which they find themselves, (2) understand the meaning of the situation as it affects their abilities to pursue goals, and (3) accurately anticipate how the situation is likely to change as time passes” [26]. Good situation awareness means that occupant movement managers monitor the extent of fire hazards and the locations of occupants who might require rescue or the implementation of a backup strategy. The feedback process whereby maintaining good situation awareness leads to modifying the occupant movement strategies is represented in Fig. 6. Occupant movement managers periodically assess the likelihood that occupant groups will remain separated from fire hazards while they remain in place, await rescue and move to safer locations. When conditions appear to threaten occupants, then the decision model is reapplied to understand if there are safer strategies.

Establishing good situation awareness involves collecting information. As a generalization, information can be obtained from hardware devices and from people:

- *Interpersonal communications.* Communications between people is of critical importance for obtaining good situation awareness by persons managing occupant movement. Face-to-face and two-way communication devices are invaluable for understanding the extent of fire hazards and the locations and capabilities of building occupants.
- *Fire protection device interfaces.* The most important hardware device for obtaining situation awareness information is probably a fire alarm panel or alarm annunciator panel. These panels show the zone where a fire detection device (for example, a smoke detector) has been activated.[6] Alarm panels may also show the locations of fire sprinkler, heat detector, and ductwork damper activations. Sensor technologies increasingly integrated with building information systems provide new capabilities and are likely to become increasingly provide more detailed information about conditions in buildings.
- *Elevator system annunciator interfaces.* Another type of annunciator may provide valuable information about the status of elevator cars—their locations and whether they are available for service or can only be used by fire fighters. Protected EOE elevators are required to provide this capability.
- *Closed-circuit television systems (CCTV).* CCTV has the potential to provide valuable information to occupant movement managers. Many large buildings have CCTV systems with cameras in egress routes, including exit stairs and building exteriors, albeit for the purposes of security and not the emergency movement of occupants. These can provide useful information about smoke conditions and the flow of persons using egress routes. In most instances, CCTV systems are monitored from security stations that are separate from where fire alarm systems are monitored and fire departments stage their efforts.

[6] Alarm panels are not an entirely reliable means to pinpoint the location of fires. Apart from false and nuisance alarms, it is important to note that buildings are often “leaky” allowing the activation of smoke detectors at some distance from the fire.

5. Conclusions: uses for the occupant movement management decision model

Current research and development dealing with occupant movement is dominated by computational models of egress times (Section 1.4). Once a building is occupied, it seems unlikely that the building owners and management would assume the costs of examining various strategies using computational evacuation models. The approach proposed in this paper relies on the abilities of people to analyze and synthesize inputs based on a simple heuristic decision model. People are notably effective at this task given a mental model that is simple enough to easily recall (especially if a person has trained in applying the model) and that provides solutions of obvious relevance to their goals

For the most part, people charged with the responsibility of moving people during building emergencies are the likely users of the model. As noted earlier, code requirements and recommendations often specify the contents of fire emergency plans, but lack guidance about how to make decisions governing which occupants should be located in which areas. The model is intended to provide an easily understood heuristic and specifies the types of information that are needed to make those decisions.

Despite the focus on building managers, fire protection engineers and architects should find the model to be of value for several reasons.

- The model can guide the inclusion of design features that facilitate better strategies for protecting building occupants. Building designers should understand the types of decisions that need to be made during a fire emergency, and include building features that better facilitate improved decision making during fires and to ensure that designs are consistent with the capabilities of occupants.
- To the extent that the people who manage the movement of building occupants use the model, it should reduce the uncertainty about how people are likely to behave during fire emergencies and enable occupants to make better use of the fire protection features designed into the building [27]. To the extent that building design and the management of occupant movement are harmonized, both the Required Safe Escape Time (RSET) and uncertainties about how building occupants will behave during fires will be reduced. Reducing RSET and uncertainties has the potential to increase the flexibility in the performance-based design of buildings [28].
- The model can be used by building designers to guide the documentation that they should be providing to building managers. Once the building is occupied, building managers should understand the fire protection features, and limitations, of the building—especially as regards their decisions about whether and where to move which people during a fire emergency.

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