WHERE THE SMOKE WAS COMING FROM:

RISK ASSESSMENT, SOCIAL TIES, AND EXPANDING ROLES

IN THE EVACUATION OF THE BEVERLY HILLS SUPPER CLUB FIRE

by

Eileen Young

A dissertation submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Disaster Science and Management

Spring 2024

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ACKNOWLEDGMENTS

Dr. Ben Aguirre, a tremendous mentor, who has made me a better scholar.

Dr. Sarah DeYoung, who has supported me through a great deal of chaos.

Tristan Tinder, who has made sure I occasionally took a break.

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ABSTRACT

The Beverly Hills Supper Club was the second-worst nightclub fire in American history, and we can learn from the tragedy. Using archival data including police statements and evacuation route maps I propose to build a computer-readable dataset and then model the evacuation. This will contribute to the state of fire evacuation science by contributing a dataset that can be used for future modeling, an improved and expanded open-source model of evacuation, and insights gained from examining the overall patterns of behavior that occurred during the fire. This dissertation also includes discussion of policy implications and suggested future directions in fire evacuation research.

Chapter 1

INTRODUCTION AND RATIONALE

Problem Statement

In 2019, approximately 3700 people in the United States died in fires (Ahrens and Evarts, 2020). Most of them were in the approximately 360,000 residential structure fires estimated to have occurred in that year. The general human protective response is to get away from the flames: to evacuate from building fires.

There is significant under-explained nuance in exactly how people make evacuation decisions and then how they execute them (Kinateder and Warren 2016; Kinsey et al. 2019). This research explores evacuation decisionmaking and fire evacuation nuance quantitatively by modeling behavior in the Beverly Hills Supper Club fire in an agent-based model and mapping evacuation outcomes to existing theoretical and conceptual models of evacuation behavior. It also includes an analysis of the secondary data (interviews with the Kentucky State Police and evacuation maps) from staff and other people who were at the club the day of the fire.

Significance

An enhanced understanding of how people make decisions and behaviors they engage in to get away from fire will set up a road map for better planning, guidelines, or even architecture that could allow for more people to successfully get away from fire. The goal for this research is to create evidence-based policies that lead to risk reduction and fewer fire fatalities. Incremental contribution by the mechanism of adding to better understanding or to better approaches in building the kind of software that predicts how quickly many people can safely evacuate a building are both contributions to the goal.

The significance of this research is tripartite: 1) the computer-readable dataset generated through archival research will provide a new dataset for future researchers to use, 2) the improved agent-based model (PrioritEvac) will be an open-source tool for researchers and practitioners to use, and 3) the analysis and findings aim to provide new knowledge of evacuation behavior.

Research Purpose Statement

The research aims of this dissertation are to understand fire evacuation behavior. Part of this involves building on earlier research, specifically an agent-based model of social factors in evacuation from the Station Nightclub fire in 2003 that successfully and stochastically replicates most of the evacuation behavior seen that night (Young, 2019). The stochastic element means that the model does not merely recreate: the replication is a result of having agents respond to stimuli in their environment the way that people responded to theirs in the actual fire. This current project focuses on an archival dataset for the Beverly Hills Supper Club fire, including evacuation maps and police statements. Using this data, this dissertation research will examine whether the behavioral rules that govern my existing simulation are generalizable to other building fires. The use of the Beverly Hills Supper Club fire as a case study will involve both analysis of the rich data at hand as well as building a computer-readable dataset to run through the model, either validating it again or exposing underexplored areas in the original computer model. This will also test whether environmental stimuli and internal motivations are what drive behavior rather than a serendipity of coding. I documented as possible the internal motivations of the people in the BHSC in the context of group behavior, intra-group ties in the cases of people who went to events together, but also in terms of the parasocial relationships[1] of venue employees with patrons. Employees must balance their own evacuation against professional commitments and feelings of responsibility for patrons (Johnston and Johnson 1989). Other scholars (Trainor & Barsky, 2011) have explored responsibility in terms of the role of emergency responders, but examining the statements and actions of venue employees at the Station nightclub and Beverly Hills Supper Club fires offers the opportunity to explore different permutations of real and perceived responsibility and their potential impact on evacuation behavior.

[1] Defined as “an apparently intimate, face-to-face association with a performer" (Horton and Wohl 1956).

Chapter 2

OUTLINE OF THE LITERATURE

Introduction

Behavior in fire is a broad topic, comprised as it is of ideas of behavior broadly and behavior under stress and in groups as well as specific studies of behavior in fire, but this in this dissertation I will explicitly examine the behavior of people who are not working in the capacity of trained firefighters, which narrows the field of literature and scope of the research questions. Tierney (2012) makes the point that there is frequently little synthesis between environmental sociology and disaster research, and that is a limitation for both scholarly perspectives. This lack of synthesis can lead to individual disciplines revisiting the same basic research, because related research in another field is by unfamiliar authors and may use different terms. That is why this literature review does not attempt disciplinary synthesis, instead tackling thematic areas individually to build to syncretic methods and approaches. Starting with a discussion of the Protective Action Decision Model (PADM) (Lindell and Perry 2012) as the theoretical framework of reference because it provides an overarching model encompassing the relevant topics, I will triangulate through several bodies of literature.

Maier (203) recommends the inverted pyramid of a broad subject narrowing to specific research in a literature review, but the nature of disaster studies mean that multiple fields have, separately, arrived at relevant narrow points. Because of this, this literature review is a series of pyramids all eventually pointing towards the same narrow area. The first pyramid is risk: how people understand risk, what people are at risk from, narrowing to how they prepare for it and then how they are alerted to it. The second is decisionmaking – a note on the specifics of the language at the end of this introduction – as a way of understanding individuals, leading to the narrower focus of individuals in context of other people. This leads, then, to the third pyramid, which looks not at individuals but groups, starting very broadly with concepts of collectivity before narrowing to groups in fire, how they behave in fire, and how group leaders emerge and behave when evacuating from fire. The final pyramid is computer models of evacuation: types of models, sub-types of models, and the reasons for pursuing the proposed course of modeling. To tie this to later implementation of ideas, at the end of each section I have included a callout box with bullet point details that are carried throughout the work.

On Language

A central argument this dissertation puts forward is that decisionmaking most resembles itself, regardless of context: the process and procedure is only ever that of decisionmaking, with any other considerations as synthetic rather than integral. Compounding language is the process of combining words to create new or more specific meaning. In general, people tend to drop hyphens as the word becomes more familiar (Sun and Baayen 2021). This can be traced through the popularity and usage of the terms ‘e-mail’ versus ‘email’ in the general population. But familiarity also implies distinction as a concept: people no longer view email as an accessory form of mail, but a distinct form of communication. Tracing the compounding process of decision making to decision-making to decisionmaking carries significantly more nuanced connotations. The uncompounded version denotes decisions as things that are made, like bread or mistakes. Decision-making as a hyphenated compound implies specificity of process: the making of decisions will be procedurally unlike the making of bread. Decisionmaking as a compound word implies, although weakly, a singularity of process: that this is a verb on its own. Decisionmaking is the term I use throughout this dissertation, because this research treats it as an active verb and a unique process.

Decisionmaking is one word.

Theoretical Model & Concepts

The Protective Action Decision Model (PADM) (Lindell and Perry 2012) is the theoretical underpinning of the current research project. The overall model offers an iterative approach to hazard response that is applicable on multiple levels and has been applied fruitfully to fire (Kinateder et al. 2015, Kinsey et al. 2019, Strahan and Watson 2019). The decision point, however, is where the cognitive model comes to its most decisive point and the synecdoche where ontogeny recapitulates phylogeny, where cognitive and social psychology and sociology all supply potential insight into the heuristics and mechanisms that drive behavior most immediately. The protective action decision making point is, in short, the most compelling and applicable location to site research into fire evacuation because it is where the action happens. I sited this research specifically at the decision point to help identify the scope and range of the applicable literature.

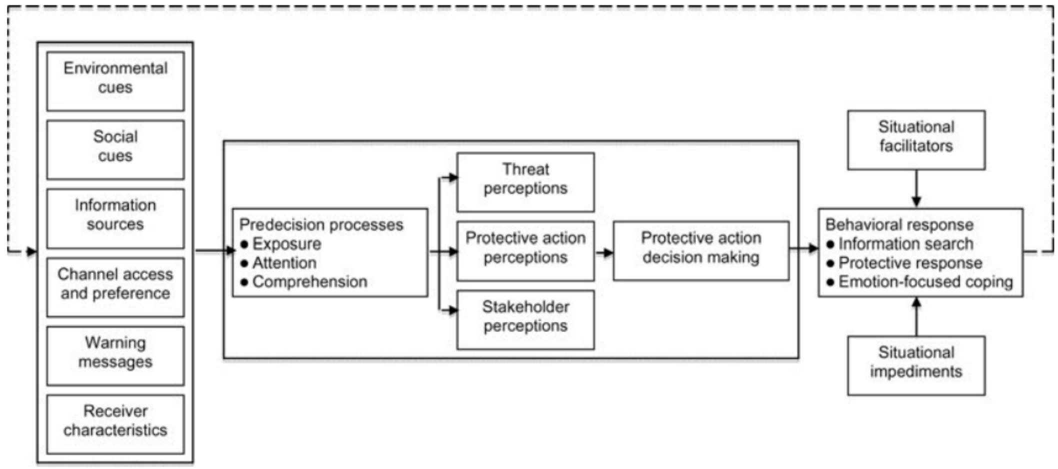

Figure 1 Information flow in PADM, source: Lindell and Perry 2012

To contextualize the following section, it is necessary to define some terms that are already familiar: namely, model and simulation. A conceptual model, like PADM, is the theoretical framework for behavior. A model can, however, also refer to the equations and algorithms that are fed into a computer to allow the execution of the theoretical framework. PrioritEvac (Young 2019b), the model I designed and programmed, is one such model. A simulation is the execution of the computer model, carrying out the equations and algorithms programmed. Therefore, even in the most tightly coupled software development and experimentation, a simulation is a minimum of two steps removed from the underlying theoretical model.

'Model' remains an ambiguous term because it can refer to a program or a theory. In this dissertation, I use PADM to refer to the theoretical model outlined by Lindell and Perry (2012) and PrioritEvac to refer to the computer model I developed and, separately as well as conjointly, the theory behind it where it differs from or builds on PADM.

As an example, protective action perceptions are a component of how Lindell and Perry conceptualized response in PADM. In PrioritEvac, the agents perceive the hazard response action of evacuation as completely effective; there is no mechanism for considering other action.

Lindell and Perry (2012) identified several key cognitive components of the actual protective action decision making phase. They are named and summarized below, with the coupled phase in PrioritEvac identified to firmly site this research in the broader PADM framework.

Table 1 Phases of PADM in comparison to PrioritEvac

Phase	PADM	PrioritEvac
Risk identification	People become aware of a hazard	A vision mechanic that allows agents to observe smoke and fire
Risk assessment	Adjudication of whether action is required in response to the identified hazard.	Not just observation of fire and smoke but also of people nearby. This allows for execution of milling, the process of checking in with and observing other people before deciding on an action in an unfamiliar situation (Wood et al. 2018). PrioritEvac's assessment weights individual observation of fire as holding equal weight to observation of bystanders who have already assessed the risk as requiring action.
Protective action search	Looking for potential solutions.	Currently limited in this respect, as evacuation is treated as the only solution, and the search involves exit selection.

Phase	PADM	PrioritEvac
Protective action assessment	The point of decision between protective actions, it involves comparing protective action alternatives based on their various attributes.	See next section
Protective action implementation	Whether the protective action decided on needs to be undertaken now.	Automatic and immediate, in part because of the immediate nature of building fire evacuation. One of the major assumptions is that a building that is currently on fire requires immediate evacuation.
Information needs assessment	Can occur at any point of this process and consists of determining that available information is insufficient for their decision-making process.	Information gathering in the form of vision as a constant process, which is suitable for a decision-making process wherein the most relevant information is visible, such as fire wherein information about distance to the exit and spread of smoke and fire are high-priority information. The handling of this point of the protective action decision making process, though, highlights that I designed PrioritEvac for fire and that this research seeks generalizability in terms of scale and scope of fire rather than type of hazard. The execution of this stage may evolve as the research progresses.
Communication action assessment	The follow-on to information needs assessment, in that it is how one is to acquire information identified as needed.	It is irrelevant in the current incarnation

Phase	PADM	PrioritEvac
Communication action implementation	The corollary to protective action implementation: a matter of determining if one needs information now, and if so, pursuing the identified action and getting it.	Not included

Protective action assessment

This is the major departure point for PrioritEvac, both the source of the first half of the portmanteau name and the crux of the research. Not necessarily a choice between the protective actions identified during the protective action search. Instead, if a person in the model has an emotional attachment to other people in the building, locating those people and ensuring a group exit is the priority. That prioritization of other people, of social ties and group safety, is set up as only breaking down in the face of overwhelming and imminent danger or upon the deaths of those people. This difference in conceptualization of protective action assessment may be due in part to the timelines of decisionmaking inherent in the hazards PADM and PrioritEvac were developed most directly in response to. While Lindell and Perry discuss multiple hazards, including earthquakes, severe weather, and volcanic eruption, the hazards discussed are, on balance, larger and slower in their impacts than building fires. Lindell and Perry also say, “more detailed plans include a procedure for reuniting families if members are separated,” (622) while examination of building fire data lead to the PrioritEvac construct that reunification attempts in building fires frequently occur before evacuation, even if later reunification would be the approach that in fact did more to preserve life. The basic premise of PrioritEvac is that people have priorities they will act in service of, and so the protective action people take will likely favor those priorities rather than the actual merits of any available plan. Phrased more simply: the findings of previous research (NSF grant 1638186) suggest that people care about seeing their friends evacuate more than about evacuating alone, as well as that trying to evacuate together, particularly if the group was split up, is bad for the likelihood of survival for every member of the friend group. This is the load-bearing portion of the research: assessing the mechanisms of assessment.

PrioritEvac already encompasses many ideas from PADM. PrioritEvac is most applicable at the point of decision.

Design literature with a focus on evacuation

Risk and the protective actions that can accompany it have a necessary spatial component: the environment in which they occur. Since the subject of this research is building fires, that means a built environment. How buildings are constructed with respect to risk and hazard interaction is thus a vital component.

Sime (1985) emphasized one of the first questions that arises when looking at building design and how people then actually use it. This critical question is in their manuscript title: “Designing for people or ball bearings?” This addresses a core frustration and dialog in the design and construction of buildings, as well as the standards to which they are held and models that are used to analyze potential movement within them. However, this frustration in approach and the ongoing discussion around it should not be taken as an indication that the varying approaches to building design in use now do not work, only that they could be better.

Hall (2013) reviewed specifically high-rise building fires, because high rise buildings have more injuries per fire than non-high-rise buildings and because apartments, hotels, offices, and facilities that care for the sick account for half of high-rise fires, creating a specific profile of buildings that could be examined. For this purpose, a high rise is a building more than seventy-five feet tall - roughly seven stories, depending on architectural variances. Because this was a report for the National Fire Protection Association (NFPA), the information used in this analysis came from the National Fire Incident Reporting System (NFIRS) and a national survey of firefighters. Because of changes in how NFIRS calculated high rises and contained fires, there is not a continuous historical dataset, but sufficiently similar definitions are available to let us compare average numbers of deaths and injuries in high rise fires from 1985-1998 to 2007-2011. The average number of deaths in high rise fires in the four categories of interest from 1985-1998 was fifty-five; from 2007-2011 it was twenty-seven. Injuries show a similar pattern, with 639 average per year 1985-1998 and 370 2007-2011 (Hall 2013, 4). No matter how anthropocentric or mechanical the approach to building design, improvements in design, material, warning systems or other factors are helping reduce the amount of human suffering that fire causes, at least in high rises.

Because improvements are already occurring, this research might be deemed irrelevant. This is not the case, because people are still dying in fires. The National Fire Protection Association codifies improvements in general understanding, approach, and guidelines in the Life Safety Code, a broadly used document to assess and improve both new and existing structures. It has had nineteen editions since 1966, including the 1981 edition that made specific improvements (requiring sprinklers and alarm systems in large assembly occupancies) based on findings from the Beverly Hills Supper Club Fire (Walker 2021). But the existing improvements mean that in this section of the literature review I focus not on gaps to fill as much as on the acceleration rate of improvement as well as maximizing the directions from whence improvements can originate. The literature here, then, can be understood as being primarily concerned with the acceleration rate of improvement in reducing loss of life in fires as well as maximizing the directions from whence improvements can originate.

Keating (1982) and Sime (1985) both discuss the relationship between people and the buildings that they spend time in, emphasizing the need to make buildings that fit people's needs instead of shoehorning people into the 'needs' of the building as present in ease of construction or control of building users. Sime's metaphor of designing for ball bearings persists through the overall discussion of neglecting the relationship the users of a building are likely to have with its physical design: people do not roll along paths of least resistance but have preferences and interactions with both each other and their environment. Keating focused more on information and how people require it to navigate their choices in the face of a hazard - an argument fundamentally in favor of more prevalent alarms.

Stollard and Johnston (1994) had a very different approach as editors of a book primarily by professionals rather than researchers, beginning with addressing one of the persistent social barriers to maximally fire-safe design: they talk about the high frequency with which owners, engineers, architects, and builders see building codes and fire inspectors as the enemy. Correspondingly, they find that frequently those doing the construction do the bare minimum to satisfy the codes as opposed to using them as a baseline and direction to maximize safety. They also point out that absolute safety from fire is impossible, so codes and inspectors ask only that the architect for any given building reduce the risk to reasonable levels. Since the case study for this dissertation is the Beverly Hills Supper Club fire of May 28, 1977, it must be noted that on the night of the fire there were “almost double the number of people that the building could safely accommodate” (Best 1978, ix) and that the building overall failed to comply with the NFPA Life Safety Code and National Building Code at the time. Stollard and Johnston also address the movable aspect of fire risk: housekeeping. Reduced escape potential in terms of blocked exits or inaccessible egress windows, tripping hazards, and artificially narrow corridors all impact how likely someone is to be able to evacuate safely, while flammable clutter increases risk of fire that spreads. They also found that existing models of human behavior in fire tended to poorly define non-structural variables in the physical environment, which is interesting as a point of examination for the models published since this book. Papinigis et al. (2010) emphasized the importance of accurate modeling even as they identified computer models as important for the evaluation of buildings, pointing to both progress and a continued need to test and innovate models for fire evacuation.

Fire, of course, is not the only hazard that a person might encounter, and other hazards can require other design considerations, which brings us to the topic of delineating the specifics of those other hazards.

Building design is important for safety. How people use buildings is important and sometimes overlooked.

Evacuation in other hazards

Evacuation is not the only available protective action, depending on the hazard type (Cova et al. 2016). But this is not an all-hazards dissertation, so I am primarily interested in other hazards which may require evacuation and the behavioral factors that may overlap factors in fire evacuation. Ready.gov is part of an American national public service campaign to provide hazard-related information, and they have a long list of hazards to consider, from active shooters to winter weather. Information sheets are available for twenty types of hazards, including recommended actions, and only some of those include evacuation - some of them conditionally:

- Flood
- Hurricane
- Landslide
- Tsunami
- Wildfire

Because this list has significant internal differences, the hazards on it relevant to this dissertation are in two subsections: hydrological hazards and heat hazards.

Hydrological hazards

Hydrological hazards with evacuation as a potential recommended protective action include flood, hurricane, landslide, and tsunami. One thing they all have in common is lead time and visible environmental cues, also called ‘triggers’ in warning literature (Cova et al. 2016): weather reports and environmental conditions for flood, hurricane, and landslide, and earthquakes and the retreating ocean for tsunamis. These may vary in length, from the known months of hurricane season paired with weather radar that can watch a storm path for days to the estimated 11 minutes of postearthquake receding tide Iwate Kamaishi had between the Tōhoku earthquake and tsunami (Japan Meteorological Agency 2011), but all are still more notice than the three minutes between ignition of the pyrotechnics in the Station nightclub fire and complete engulfment of the building.

Hydrological hazards generally have two possible courses of action, sheltering in place or evacuating, with further protective actions branching from those courses. Lewis et al. (2019) specifically noted hurricanes as sometimes resulting in ambiguous advice from trusted authorities, with vulnerable populations less likely to evacuate even while this is frequently the safer course. There are complications to vulnerability and choice in hurricane evacuation, but a compelling reason not to evacuate is lack of capital - either social, for friends to evacuate to, or monetary, for ability to pay for gas and accommodations (Kyne et al. 2018). Because flooding is sometimes a consequence of hurricanes, there is significant overlap in literature, though communities in non-hurricane flooding circumstances can and sometimes do take more protective measures in advance of actual flooding (Soetanto et al. 2017).

Tsunamis are not a matter of sheltering in place, though this is a matter of degree: the same Tōhoku tsunami that caused severe damage to coastal Japan also impacted the west coast of North America, and in some areas of British Columbia resulted only in minor surges with no impact on life or infrastructure. But this becomes a question of risk assessment, then, and when a tsunami presents a more than minimal hazard risk, evacuation - specifically to higher ground farther from water - is the primary appropriate action (Leelawat et al. 2018).

Landslides are between the two in terms of environmental cues, in the overlapping section of a Venn diagram of disruption through damp and giving way of ground. Land saturated with water is more likely to slide, particularly if it lacks flora to anchor topsoil, which can result from land use change such as deforestation, extended drought, or other effects of climate change (Jaiswal et al. 2013). Earthquakes can also shake earth loose. Evacuation is generally recommended in situations where conditions are conducive to landslides such that they present a clear risk, but this is subject to the same limitations as hurricanes and floods.

Warnings and evacuation decisions

Paul et al. (2015) examined the 2011 Joplin tornadoes and whether people complied with tornado warnings by seeking shelter. For this context, Paul et al. took seeking shelter as the warning being effective. Paul et al. found four statistically significant components that influenced effectiveness: number of warning sources, whether respondents were at home when the tornado struck, past tornado experience, and gender. I discuss location and experience more at length in the section on behavior, specifically as regards familiarity with the environment; since the theme of this section is warnings, the focus is the number of warning sources. The number of warning sources is a point of interest because it highlights the role of confirmation. Tornado warnings have the vulnerability that not all tornado warnings will result in everyone who received the warning seeing either a tornado or the aftermath of one.

Trust in the body issuing the warning, social confirmation, and environmental warning signs all also contribute to whether a warning in general sparks action (Kluckner et al. 2012). Escaleras and Register (2008) found that tsunami warnings were effective. They sought empirical evidence of effectiveness rather than an underlying reasoning, but their findings are congruent with Kluckner et al. because of the environmental cues associated with tsunamis.

These findings can be related back to PADM in that the number of warnings, social confirmation, trust, and environmental cues all support risk assessment. Familiarity with the environment - such as being at home - supports a straightforward protective action search and subsequent protective action assessment.

Heat hazards

Hot hazards with evacuation as a potential recommended protective action start with wildfire. McGee and Russell (2003) examined factors in wildfire evacuation and found primarily that those who felt they had agency and the ability to defend their property adequately were more likely to shelter in place than evacuate.

Wildfire presents a potential topic for future research, partly in applying PrioritEvac to the additional and more spatially distributed context, with the complications of traffic and risk communication over a greater span.

> People evacuate from multiple kinds of hazards; building fires are not conceptually or heuristically isolated.
> How people find out about a hazard and have it confirmed as dangerous is important to how they respond.

Concepts of preparedness

FEMA and the National Emergency Management Association (NEMA) developed the Capability Assessment for Readiness (CAR), which they aimed at states to assist in their preparedness efforts. Sutton and Tierney (2006) discussed these in a more detailed fashion, including addressing the fact that these items in many ways conflate mitigation and preparedness. In the broader picture, this is an important disambiguation, because policymakers can approach them differently to improve overall community resilience. But the policy implications of conceptualizations of disaster phases are not in scope of this research, so this literature review will progress merrily discussing all of CAR as preparedness.

While the focus here is on the moment of decision, preparedness is directly informative because of what it implies about threat perceptions and protective action perceptions.

Preparedness also impacts varieties of response actions - for instance, in fire specifically, the preparedness action of acquiring a fire extinguisher adds a distinct extra option in terms of response. A core principle of disasters is their cyclical nature: mitigation, preparedness, response, and recovery (James 2014). The focal point of this research is response - and not even organized response involving first responders or emergency managers, but immediate onset and instinctive reaction more than deliberate response - but cycles mean that each stage impacts the others. In the BHSC fire, for example, the local fire chief responded to the fire, and then, during recovery and discussion with fellow firefighters, decided to increase inspections of businesses from yearly to thrice yearly (per interview tape), which action would trigger more opportunities for mitigation in those businesses.

Preparedness as hazard identification can take the form of smoke or heat alarms, differentiated because of the different mechanisms in particulate alarms that would indicate smoke and thermal alarms to indicate fire (Stollard and Johnston 1994). Alarms react to the presence of a hazard which would then contribute to cueing people to move away from fire, as other warnings contribute to evacuation decisionmaking regarding other hazards. While not the only potential cue or even the entirety of cues used for many people, how long it takes them to start to evacuate is important (Proulx 1995, Averill et al. 2005) and alarms in an active fire situation communicates a warning, and thus may serve to influence pre-movement time in an evacuation. I included this pre-movement time in the discussion of preparedness because one component of that pre-movement time would be not only alarms that would help cue evacuation but establishing norms and culture that would prompt evacuation in the face of those alarms, which is both more complex and more abstract than the mechanical elements of preparedness. As Proulx (355, 1995), "knowledge of human behavior is essential."

Disasters are cyclical. Prior experience helps people understand current hazards. Understanding is a precursor to action.

Decisionmaking

Decisionmaking is only one aspect of human behavior, but it is the element most of interest in this research overall. Tong and Canter (1985) noted a difference between predicted and observed evacuation times, highlighting that at the time there was significant need for additional data and study on hazard perception and how these decisions are made. While significant time has elapsed since this study and their conclusion that evacuation decisions are more complex than basic knowledge of the presence of fire, which ties in with the PADM structure of multiple factors in protective action decisions, the questions Tong and Canter raise and the predictions they make – including that women are more likely to evacuate immediately than men – are still relevant in the current state of the field.

This leads to a discussion of what constitutes the human behavior that influences pre-movement time and the decision to evacuate. Of note both in this section and several of those to follow is that, while study continues – as in this research – and concepts evolve more nuance, significant stretches of our understanding of human behavior and decisionmaking build on the same and sometimes older foundations. Thus, the scope of the literature reviewed for social theory is temporally broad. Kahneman and Tversky (Kahneman 2013, Tversky and Kahneman 1974 and 1986) shaped modern social psychological understanding of heuristics, the rules of thumb that people use to navigate uncertainty, including Kahneman, Slovic, and Tversky (1982)'s book on judgement under uncertainty, which I view as a long precursor to Slovic (2010)'s book *The Feeling of Risk* and even Ripley's (2008) *The Unthinkable*. Decisionmaking in general is both an emotional and mental exercise, not purely rational nor purely irrational. It is also, per Iyengar (2010), something which requires mental effort – and thus something where heuristics would be employed to reduce that effort.

Decisionmaking is both an emotional and mental exercise.

Decisionmaking distinct from psychology

While COVID-19 has highlighted the need for research into psychology during an ongoing disaster (FEMA 2021), the focus nevertheless frequently remains on trauma or retreads sociological and disaster research (Drury and Cocking 2007) – affiliation and normative behavior where disaster science as heritor of significant sociological influences and vocabulary would address collective behavior.

Thus, some of the history of how disaster science arrived at its current paradigms and vocabularies and the parallel and convergent evolution of paradigms in other fields can help with delineating the concepts and approaches used in this research. Disaster studies as a dedicated field – albeit one with a notably sociological approach – started under the auspices of the National Academy of Sciences in 1951, with a focus on using ‘natural’ disasters as a proxy that would translate into usable wartime knowledge (Quarantelli 1987). The several decades since then have involved significant field research (Quarantelli 2009) and a broader emergence of emergency management as a concern that disaster studies can address, including looking at decision making in hurricane evacuation (Lindell et al. 2005, Kyne et al. 2018). But, as denoted by the decoupling of the compound, this research primarily focused on broad factors and influences rather than the singular process. While this is important research, this disambiguation may help explain the omission of discussion of theories from those and related research.

> Decisionmaking as addressed in this dissertation is emotional, mental, and social, and not economic or broadly logistical.

Collective behavior & protective action

One of the persistent myths in disasters is that of panic (Schulze 2015), defined as a breakdown of social organization and specifically as a dissolution of intragroup ties (Sime 1983). This is particularly true in emergency management, where prevention of panic is a pressing and recurring concern (Drabek 2013). But, because of the temporal limitations on building fires, the focus in this research is not on the damage disaster myths can do at the emergency management level but at the incident level. Because of the persistence of these myths, selfish and aggressive behavior can become an emergent norm for individuals in a situation (Johnson 1987). This is more prevalent in situations with limited resources, such as bank runs where there is finite money available and a rush to acquire it before others do.

This ties in to #FOMO: the Fear of Missing Out that has risen to mass marketing advice and hashtag status in the last few years (Milyavskaya et al. 2018). Bank runs are tied to FOMO, because banks have limited cash on hand. Similarly, on the Titanic, there was fear of missing out on the limited lifeboat spaces (Lord 1998), though the treatment of the third-class passengers also points to elite panic (Clarke and Chess 2008). Elite panic is when those with more power, control, money, prestige, or some combination of the above experiencing FOMO not only as relates to missing out on something directly, such as cash or a spot on a lifeboat, but as in fear of the threat of the hazard they are presented with damaging one of the components that supports their own self-perception as elite.

In the overarching framework, 'Elites' exist within and may utilize PADM, but would identify not just a personal hazard, as anyone else, such as fire and smoke as a direct threat to their health. 'Elites' would also identify a separate threat to status and might act in response to it. Those responses have been documented, though not always associated with the term elite panic, in the cases of lifeboats with first class passengers launching when far from full (Lord 1998) and notably in the grocery store fire in Asunción, Paraguay, where the owner ordered the doors locked in order to prevent customers from leaving the burning building without paying for groceries (Balmelli et al. 2006). One of the major social factors that impacts egress is not whether an individual might panic, but whether an individual or group might perceive the timing, nature, or direction of mass egress as threatening to their status.

Motivations

Related but distinct is the idea of fractionated crowds: those wherein groups have priorities or motivations that put them in opposition with each other. In

Asunción, it was not the owner but the security personnel who barred the doors during the fire. Smelser (2013) focused on hostile actions, and Hundley and Quarantelli (1969) examined civil disobedience, focusing on an incident of a protest against a student being arrested for jaywalking shutting down traffic on a university campus. Hundley and Quarantelli approached this as a test of Smelser's cognitive model of opposing forces with potentially hostile attitudes, and examined Smelser's ideas about conditions that would contribute to this kind of crowd formation and behavior:

- structural conduciveness
- structural strain (of note in this case is that in the early 1960s there were multiple ongoing civil rights clashers, including several explicitly involving police and university students)
- generalized hostile belief
- precipitating factors
- and mobilization (including leaders as unwitting or deliberate and the involvement of formal groups with existing structures)

While Smelser focused on instigators and explicitly hostile action and Hundley and Quarantelli started from the premise that that was what they were investigating, their conclusions were that protest was not an inherently hostile action and that the reaction of social control agencies were a vital component.

Social control agencies, and even more so, the specific social control agents interacting with non-affiliated crowds, create a feedback loop with the crowd. Drury et al. (2015) also found that treating crowds as an inherent source of danger increased their chances of becoming one. Thus, the actions of social control agencies and 'elites' who sometimes interact or intersect these agencies can sometimes create the circumstances and interactions that they fear.

This leads us neatly into symbolic interaction. A sociological theoretical framework with roots in social psychology, the essence of social interactionism is that people have archetypes. To expand from the literary criticism term to encompass Charon (1991)'s carefully laden terminology, people enact roles which are the symbols that have been collectively socially created. Succinctly put, "All the world's a stage, And all the men and women merely players" (Shakespeare 2.7.146-147) in that people perform roles in relation to each other. Charon's approach built on Mead (Baldwin 1981) and Shibutani (1955, 1961), and neatly elucidated five central premises here presented as a superficially uncomplicated list:

1. People are social.
2. People think.
3. People define their situation.
4. Things happen in the present.
5. People are active, not passive.

Re-stated, Charon's central premises are that we control what we do (we are active, not passive) and that reality is socially defined (we both think and define our situations: these are also things with a temporal component). Social interaction, then, creates society. Charon also dedicates a whole chapter to Erving Goffman, discussing how interaction order and dramaturgy influence how people both interact and understand their interactions. Goffman (1983)'s own writing stands out markedly as mid-century and middle class, with discussion of etiquette manuals as items that people can and might casually buy, but this markedness emphasizes the observations that do stand up to time and can aid our understanding of things happening in the present. Goffman's central thesis is that social occasions have a 'spirit' that sets the framework for what is appropriate, which in symbolic interactionist terms means that context and occasion can highlight specific expected roles. Most relevant to our discussion of protest are the contexts that can create expectations on the part of social control agencies of the roles of hooligan, anarchist, or troublemaker, sparking potentially hostile attitudes towards protesters that are counterproductive. Finally, and most relevant for the research here, symbolic interaction and expectation states on the part of employees at the two venues created the potentially important point that a patron is different from a person, with employees feeling a sense of responsibility for patrons under some circumstances.

Group panic does not exist in evacuation scenarios. People and groups respond to their environment and each other. Roles – both official and unofficial – matter.

Concepts of Collectivity

The concept of patrons as different from persons – at least to waitstaff – is an interesting starting point for the numerous ways in which scholars have conceptualized collectivity. This is in part because the relationship between patrons and waitstaff is not one of collectivity: it bears more similarity to a parasocial relationship because of the performative nature of customer service. Collectivity is a complicated thing, and deeply contextual. Sociometry is the measure of social connection, and the strength of a connection is a combination of time, emotional intensity, intimacy, and the reciprocal services involved (Granovetter 1973). The factors are independent, but likely correlated. For example, colleagues would have social connections based on, at the very least, time spent together, but also likely based on reciprocal services such as the give and take of covering shifts or even basic collegiality. Drury et al. (2009) also suggest that people may experience social ties in the face of an outside hazard. Drury et al. frame this in terms of self-categorization theory, wherein people categorize themselves as part of an in-group under threat, with accompanying affiliative and generally prosocial behavior. Psychological membership of a crowd and shared identity can be a source of safety, particularly in that this can result in collective self-regulation (Drury et al. 2015). In sociometric terms, facing an external hazard together carries emotional intensity, and the prosocial behavior involved could in some cases function as reciprocal services.

Prosocial behavior, particularly in disasters, is broad in scope. O'Brien and Mileti (1992) found that in the aftermath of the Loma Prieta earthquake of 1989 members of the community identified as victims even if they had not been personally injured or experienced property damage, emphasizing the level of community unity in the wake of the disaster. Many people in both Santa Cruz and San Francisco helped with emergency response activities – search and rescue, providing food and water, counseling. This resulted in significant non-skilled, one-on-one assistance – the kind of reciprocal or pay-it-forward services that could strengthen the sociometric ties of the entire community.

Granovetter also emphasizes that in a network, there is usually more than one way from point a to point c because proximity proliferates ties. A specific individual, then, is rarely the only way between any two points, and so multiple kinds of connections between people hold weight. This means that in studying the outcomes of the Station and BHSC fires, I mapped and acknowledged multiple kinds of social connections to form a more complete picture.

Also guiding this research will be Dyaram and Kamalanabhan (2005)'s theories of cohesiveness, with the contrasting ideas of task cohesion and social cohesion. Most of the literature in this section has not differentiated between the two, but with the introductory and ongoing focus on coworkers and emergent groups in response to disaster, task cohesion has been the underlying theme. Or rather, task cohesion is the goal theme. "Cohesiveness was recognized as one of the best possible predictor [sic] of group performance" (Dyaram and Kamalanabhan 2005, 186), but with the caveat that the group must be task oriented. Dyaram found that in the absence of task orientation, more cohesive groups become less effective. This dovetails with findings (Young 2019a) that cohesive groups with spatial separation will reunite before shifting to the task at hand: evacuation from the burning building. Therefore, this concept of task versus social cohesion provides the last essential component of our map of concepts of collectivity. Now that I have mapped collectivity, we can explore how these groups behave.

Collectives come in many types. They tend to stick together, particularly in the face of a hazard.

Group Behavior in Disasters

Group behavior, particularly in crisis, is an ongoing topic of research in multiple arenas. One aspect of group behavior in crisis is a repeating theme and topic, not because of any ambiguity in the overall trends in the findings, but because it is a perniciously persistent myth. This myth is, of course, as mentioned earlier, panic. Panic as a motivating force has been largely discredited and discarded over the past several decades (Torres 2010; Aguirre et al. 2011, 415-432; Johnson 1987, 362-373; Best 2013; Sime 1999, 313-324; Drury and Cocking 2007, Keating 1982), both because it does not adequately explain observed behavior and because findings will directly contradict it as even a possible explanation. Even some of the disordered and seemingly purposeless behavior that is sometimes mistaken for panic is often significantly better explained by milling (Wood et al. 2018). Scholars have repeatedly observed actual behavior as more rational and discriminate than panic.

This means that, when examining group behavior, social bonds and affiliation and the ways in which scholars (Johnson, Feinberg, and Johnston 1994, 168-189; Li et al. 2016) can and have quantified them are particularly illustrative. Self-categorization theory inhabits the fuzzy borders between group behavior and concepts of collectivity (Templeton et al. 2015). Templeton et al. used self-categorization theory in examining crowd modeling, typing models initially as whether they treated crowds as a mass versus crows as a collection of small groups. The typology is in Table 2, and the categorizations they made were tested for intercoder reliability to validate that they had internally consistent schema. Their intercoder reliability was high, indicating that the categorization functioned well, at least for their team.

Table 2 Crowd Modeling Typology

Category	**Sub-categories**
Mass	Homogeneous
	Individuals
Groups	Non-perceptual
	Perceptual
	Cognitive

Having this typology helps understand possible ways to think about group behavior and adds the dimension of social coherence separate from social cohesion. Coherence serves as a lens not just on modeling and how much the groups as delineated in models make sense, but also on groups as they occur, including ad-hoc groups and loose self-categorization that may not prove persistent after – or even for the entire duration of - a disaster. The focus of this research includes the group sub-categories. Non-perceptual groups simulate the physical groups but not the psychological groups, and so would include such real-life corollaries as people coincidentally taking the elevator together as a group. Perceptual groups can perceive their own group membership and act according to that role. Cognitive groups can, well, think about their group membership, and are thus likely closest to reality. Templeton (2015) categorized Aguirre et al. (2011) as perceptual. In contrast, Templeton would likely categorize PrioritEvac (Young 2019b) with its focus on reunification and bounds of group loyalty as cognitive, to highlight some recent and relevant work in this context.

Keating (1982), working from the contagion theory of crowds, posited that having guidelines, habits, or concrete information in a crisis could serve as a sort of positive contagion. This relates to Granovetter's (1978) threshold model, at least from three years into the COVID-19 pandemic, where concerns about contagion and the tipping points of infection reservoirs have permeated quotidian concerns. Both the idea of positive contagion and thresholds in social behavior have the fundamental idea that there are social norms at play, and emergent norms in a rapidly changing situation. These emergent norms need to, in both theories, be adopted by some number of people before an action in line with the emergent norms or guidelines or incoming information will be adopted. Kinateder and Warren (2016) articulated the same idea, but in terms of a socially influenced tipping point in deciding to evacuate. They built on Latané and Darley (1968) to establish a positive as well as negative valence in how people influence each other: Kinateder and Warren found that bystanders could influence participants to evacuate as well as influencing them to ignore fire alarms. The threshold or tipping point model maps most neatly to PADM as opposed to contagion. This is because a threshold number of people assessing a risk as something to take seriously (the second step in decision making in PADM) would be what triggered the movement to the next step, the protective action search, rather than an evacuation norm spreading by means of contagion. Granovetter considers that people within a group might have varying norms or risk tolerances, such that the threshold model does not require a change in those norms but rather a combination of factors such that a group then would act collectively. The PrioritEvac ODD Protocol, Appendix D, reflects this, where a combination of factors such as direct risk assessment in terms of seeing smoke and fire in addition to the reactions of nearby people are considered before an individual makes the decision to evacuate. In examining the way this individual behavioral modeling plays out, it ripples through crowds while not impacting outliers such that the assembled individuals appear very much to be acting as a collective.

This also ties to Keating (1982)'s position that in ambiguous situations, people can doubt themselves, leading to indecision and longer pre-movement time. Observing the reactions of others clarifies some of the ambiguity, again reinforcing the risk assessment portion of PADM. This is particularly important in the case of the Station fire, where pyrotechnics had been used non-disastrously in previous shows, and so the determination that this fire was a problem rather than a performance was one that took some time to resolve, as evidenced by a delay before evacuation started (Fahy et al. 2011). Crowd dynamics are important not just because of this dynamic of information and assessment, but also because larger groups move more slowly (Gorrini 2015). Considering this in light of pre-movement time, then the rapidity with which a group can decide to move and the size of the group and thus its likely movement speed all become important factors for group survival and the individual survival of members of those groups.

Dense crowds also mean that maintaining spatial cohesion is a consideration, which leads to Bellomo et al. (2012), who took the complex systems viewpoint when looking at crowds. Their theoretical approach considered macro and micro behavior patterns as separate but linked, as opposed to the theoretical approaches discussed in the rest of the behavior section, which treat crowds more as being collections of individuals. In fact, looking at macro and micro behavior patterns can also be related to Templeton et al.'s framework: micro-level patterns would relate to groups, while macro-level patterns relate to crowds as a mass.

Having outlined these several approaches and considerations in thinking about group behavior generally, this literature review now moves to the specifics of behavior in fire.

Group behavior does not include panic.
PrioritEvac treats groups as individuals with social ties, not as a mass.

Behavior in Fire

Keating noted that “the people-piece of the fire puzzle remains out of place” (1982, 1), and the field of disaster science has come a long way in the time since that observation while still not completing the puzzle. First, one of the things we as a field are confident in as an important piece of behavior is that people are basically prosocial in responding to a disaster, and generally try to help each other (Drury et al. 2009, Johnson 1987, Donald and Canter 1992).

Donald and Canter (1992) found that those who died during the King’s Cross underground fire behaved similarly to survivors, pointing to the idea that there is not a panacea we can apply to ensure survival. But similarity is not indistinguishability, and it is the gaps that provide interest and the potential for saving lives. This study discussed scripts and roles and schema, providing a significantly symbolic interactionist approach to analyzing the behavior of the people involved. But regardless of approach, Donald and Canter found that people primarily evacuated by known exits or their previously planned exit, and that there were a small number of helpers whose interactions, roles, and behaviors were somewhat more complex.

In line with the basic finding, numerous empirical studies (Johnson and Feinberg 1997, Shipman and Majumdar 2018, Sime 1983, 1985, 1999) have found that people use heuristics extensively in crisis, moving towards the familiar whenever possible. This also relates to Keating’s (1982) ideas of pre-existing guidelines as removing ambiguity from decisionmaking: if people have a pattern to use, people will use it. Fire drills, familiarity with building evacuation maps, and knowledge of exits and fire doors all provide heuristics, remove ambiguity, and short-cut the protective action search: even as the question arises during the PADM protective action decision point, the answer is already there. But even in the presence of ambiguity, people are generally internally rational and act intentionally.

I argued (Young 2019a, Young and Aguirre 2020) that, based on this use of heuristics and affiliative behavior, decisionmaking in fire is fundamentally the same as decisionmaking in other contexts, with rational choices influenced by logic, emotion, and priorities. This is essentially congruent with other understandings of decisionmaking in fire, such as that put forward by contemporary scholars (Bourgais 2018, Valette 2018). I discuss nuances of that behavior in the following sections.

Leadership in Fire Behavior

Leadership in small groups is an essential part of group behavior. Gorrini (2015) also concluded that high-density crowd conditions require and result in a leader. Enarson (2008) and Goktepe and Schneier (1988, 29-36) both found that men are more often leaders in general, but this contrasts with other studies and even with other ways of understanding leadership. Specific to fire evacuation, Best (2013) found that already being a leader was the highest single factor in whether someone became or continued as a group leader for further evacuation from the building.

Arnatt and Beyerlin (2014) studied special operations team leaders specifically, a context that bears the potential for insight while at the same time being quite divorced from the context of interest. They found that leaders differ from followers on relational transparency, morals and ethics, sociability, and disaster self-efficacy. This last point is where the study offers potential for insight, namely that self-efficacy, the willingness and ability to make a protective action decision and act on it, resolving ambiguity in the situation.

Li et al. ran the same evacuation experiment two years in a row, with the same students, and were able to quantify those relationships in several ways (2016). Importantly, they quantified both popularity (the number of connections someone had) and leadership (willingness of other people to follow them in evacuation). Li found both factors relatively stable over time, suggesting that these are not volatile factors even when individuals and groups are under pressure from an external hazard. Li et al. did not find a difference in leadership between genders; in an examination of network prioritization and subsequent matrix analysis of the popularity and leadership traits amongst a group of 30 university students, women had an average leadership score of .26 while men had an average leadership score of .25 (2016 5 – 6), which is reinforced by Goktepe and Schneier's (1988, 29-36) finding that men and women are evaluated about equally as leaders in a general context. Gender may play some role in who becomes a leader, but if so, it is inextricable from the idea that expectation plays an influential role in leadership (Berger, Wagner, and Webster 2014, 19-55) and we live in a heteropatriarchal society.

In additional general research on leadership, Norton, Ueltschy Murfield, and Baucus (2014, 513-529) identified emergent leaders who have no formal authority but may use charisma to take leadership roles in crisis or just exhibit additional disaster self-efficacy. In small groups and family units during a fire evacuation, we can turn to the Disaster Research Center typology (Dynes 1970) as a sense-making device. Evacuation would presumably not be an established activity for a family. But, depending on the composition of the family group and their collective rather than individual conceptualization of the events – i.e., what kind of jobs, training, and experience they have and how they talk to each other about it – it may be a matter of expanding their professional roles to the home front, helping organize family or a neighborhood in an evacuation. Evacuation might also constitute extending the organization of carpooling and going on trips to the different context of evacuation. In this conceptualization of small group leadership, truly emergent leaders and internal group structures would be unusual in pre-existing units like nuclear families or established households but might be more common in congregate housing or newly organized living groups.

As an additional factor, Chu (2015), Sime (1999, 313-324), and Berger et al. (2014, 19-55) all found that guests at a location listened to employees who directed them in an evacuation of the building where they were employed. Expectations and perceptions of familiarity and authority stemming from employee status are taken as influential on small affiliative groups attempting to evacuate together, easy protective action implementation and hopefully addressing communication action implementation. This points to employee behavior in evacuation of guest venues as an important topic for examination and complexifying factor in leadership. Ketrow (1991) does offer a split model of understanding leadership, though, which helps contextualize the leadership and direction provided in some cases by employees as not disruptive of internal small group loyalty. Ketrow differentiates between social and task leadership, with task leadership requiring procedural behavior that is towards a goal. Procedural leadership as available from employees providing a substantively different social function than social leadership as available from members of a small group.

Procedural leadership raises the question, however, of why exiting a building might require that sort of guidance in an emergency. Why is exiting a building not straightforward and obvious enough so as not to require more than environmental cues? Why is the building itself not designed to provide all the cues someone might need? The section on design literature earlier in this literature review does not answer these questions but does suggest that more accessible and comprehensive information may help in the design of future buildings.

Helping Behavior

While there may be questions about why guidance is needed, where and how people provide it has been studied to some extent. In the Beverly Hills Supper Club fire, many employees acted in an extension of their usual role and assisted patrons in evacuating (Johnston and Johnson 1989). The term extension is a deliberate term of art in this case, referencing the DRC typology (Dynes 1970) and how assisting patrons is a primary component of waiting tables.

> People help each other.
> People move towards the familiar, including familiar exits.
> Leadership is ambiguous.
> Patrons will take direction from employees in a fire evacuation.

Computer models of evacuation

As computers grow in computational power and ability to handle complexity, the benchmarks for usefulness have been raised. Bryan (1999) wrote about the history and development of the field of studying human behavior in fire, and his primary concern over time was the validation of models, a concern that Bellomo et al. (2012) echoed. Therefore, it is fitting to explicitly address those specific models discussed here are all validated using the dataset from the Station nightclub fire, which is one of the most complete readily available datasets of humans and outcomes in evacuation from fire in addition to significant information about the fire itself.

Torres (2010) claims that emergency egress models will only produce useful findings if they incorporate knowledge derived from the social sciences. This is borne out throughout the literature, wherein models of the Station nightclub fire that include social dynamics are consistently more accurate than those that do not include them (Young 2019a). There are three common types: those that employ particle physics, use cellular automata (network models), or are agent-based models. As Shipman and Majumdar (2018) note, one of the major problems in modeling currently is that there is a dearth of models that incorporate both human behavior and emergency situations. Feinberg and Johnson (1997) modeled decisionmaking in evacuation using Turbo Basic, an ideal square room, and a linear increase in environmental hazard. An agent-based model where individuals and dyads respond to social and environmental factors, I omitted it from that section because it does not use data about the physical hazard or environment. The Station nightclub is one of few building fire emergencies that offers sufficiently broad data to begin to assess the role that human behavior plays in crisis-originated evacuation. Neither particle models nor network models are structured in such a way as to consider sociological factors sufficiently, which brings us to the third common type of model.

Agent-Based Models

Agent-based models (ABMs) are preferred because they allow for complex individual cognition resulting in more valid findings. They also allow for small group formation and interactions (Templeton et al. 2015). ABMs possess computational description at the level of analysis of agents, stigmergic interactions, autonomy of the agents, and spatially distributed populations of agents (Goldstone and Janssen 2005). They allow group-level social emergence from a foundation of individual behavior. In so doing, they can help isolate and verify plausible causes of those emergent behaviors (Squazzoni 2014). ABMs have been employed in a variety of fields related to social science, from economics to epidemiology (Manzo and Matthews 2014). The focus here is primarily on ABMs as used in evacuation modeling, and so the bulk of this literature review focuses narrowly on this body of work, with a preference for the Station fire. (For a broad overview of ABMs, see Bonabeau 2002). Within ABMs, there are different approaches. Two of the most common are pattern-based and force-based (Fang 2015). Pattern-based behaviors consist of ordered and coded actions triggered by something in the environment; agents have scripted actions triggered by other events in the program. Force-based behaviors consist of attractive and repellent pressures in the environment that influence movement; agents are repelled by fire and move away from it, with other actions and movement a matter of navigating other environmental influences. Table 3 shows the types of ABMs of the Station fire that are publicly available, with the number of dead that each model found, to disambiguate the general types of ABM approach used.

Table 3 Approach types in agent-based models

Model	**Type**	**Dead**
Valette (2018)	Pattern	121
Bourgais (2018)	Pattern	98
Chu (2015)	Pattern	100
Best (2013)	Pattern	131

Model	Type	Dead
Galea (2008)	Force	84
Fang (2015)	Force	105

Pattern-based ABMs

All the ABMs included, regardless of type, have a number of dead that falls within thirty-one of the actual results. All models reviewed taken together have a standard deviation of sixty. Most of these ABM results falling within less than half a standard deviation of the actual outcome shows a reasonable degree of accuracy, which endorses this overall modeling approach.

Valette et al. (2018) employed the GAMA agent-based modeling package and focused primarily on individual motives. Motives generate specific patterns, like running away or searching for group members. Staff members additionally had specific patterns assigned to them, primarily directing people towards exits. Bourgais (2018) built on Valette's work, incorporating social norms.

Chu (2015) developed an agent-based model that was primarily pattern-based and included significant examination of people as social entities. Group size and composition impact outcomes, as well as leadership. Staff members participated in role extension, serving as "social control agents who regulate(d) the actions of the individuals in the crowd" (28). Chu's validated their model using models of real buildings but not of real incidents. The model also used a particle physics model to calculate the flow rates through the exits as part of its validation.

An exemplar of pattern-based ABM specifically developed to study the Station nightclub fire is SocEvac by Eric Best (2013), which assigns behavior patterns to agents based on the data used by us, interviews, codified analysis of witness statements gathered by Fahy, Proulx, and Flynn (2011), and extensive field work observations done by Barylick (2012). Best went through multiple iterations of a pattern-based ABM, starting with a first-generation model that differentiated between three distinct levels of group cohesion: no cohesion, weak cohesion, and strong cohesion. The version with strong group cohesion produced the most promising results, as seen in Table 2. SocEvac also incorporated group leadership sub models and patterns of individual behavior that ranged from passive to aggressive. Best's (2013) model more closely matches the events of the fire (see Table 2) than any of the non-ABM model included or mentioned in the literature reviewed.

Force-based ABMs

Galea et al. (2008) did not employ the behavior vs. force distinction in their ABM, which used the commercial software buildingEXODUS. It is not clear from r publication which type they used. Their model coupled individual behavior and fire. Galea et al. added a 15 second delay to the start of the fire reportedly because without the delay the simulation resulted in 180 fatalities and with the delay the model resulted in only 84 as compared to the 96 dead on site and 100 total dead, which they considered to be "in good agreement" (2008, p. 1).

Fang (2015) employs a force-based ABM in EgressSFM, specifically a scalar field model, which uses equations to represent forces that govern the ways agents approach goals, preserve personal space, and attempt to not bump into walls. This dynamic is as an example of bounded rationality, for the agents can behave in a somewhat rational way. They are still moving in accordance with basic field forces, but with some discrimination. Valuing social relationships is part of that bounded rational behavior, so the agents in the simulation primarily try to go towards their group members and to try to ensure the survival of the group. Their approach yielded promising results. Fang et al. made several recommendations for future research, some of which I pursued in PrioritEvac (Young 2019b), which used priorities as the basis

Agent based modeling is the best approach for modeling the evacuation of people from building fires.

for the simulation.

Fire Modeling

There are many approaches to fire modeling, from focusing on evacuation to atmospheric influences on the fire itself to the impacts of different materials on burn rates. The National Institute of Standards and Technology (NIST)'s Fire Dynamic Simulator (FDS) is possibly the best-known fire simulator currently available. Capable of incredible granularity and detail, many scholars (Young and Aguirre 2020, Khan et al. 2017 use it for structure fires,) but it has limitations when used in complex outdoor environments (Cicione and Walls 2020).

FDS is the best option for modeling fire itself.

Conclusion and Research Questions

Considering the theoretical models and literature spanning risk, decisionmaking, group behavior, and computer models of evacuation, I have narrowed the precise topic of interest to decisionmaking in building fire evacuation. I have listed brief takeaways from each section both at the end of each section, above, and in Table 4, below.

Table 4 Literature Takeaways

Decisionmaking is one word.
PrioritEvac already encompasses many ideas from PADM.
PrioritEvac is most applicable at the point of decision.
Building design is important for safety.
How people use buildings is important and sometimes overlooked.
People evacuate from multiple kinds of hazards; building fires are not conceptually or heuristically isolated.
How people find out about a hazard and have it confirmed as dangerous is important to how they respond.
Disasters are cyclical.
Prior experience helps people understand current hazards.
Understanding is a precursor to action.
Decisionmaking is both an emotional and mental exercise.
Decisionmaking as addressed in this dissertation is emotional, mental, and social, and not economic or broadly logistical.
Group panic does not exist in evacuation scenarios.
People and groups respond to their environment and each other.
Roles – both official and unofficial – matter.
Collectives come in many types.
They tend to stick together, particularly in the face of a hazard.

Group behavior does not include panic.
PrioritEvac treats groups as individuals with social ties, not as a mass.
People help each other.
People move towards the familiar, including familiar exits.
Leadership is ambiguous.
Patrons will take direction from employees in a fire evacuation.
Agent based modeling is the best approach for modeling the evacuation of people from building fires.
FDS is the best option for modeling fire itself.

The research questions for this project can be expressed as the following, with corresponding propositions that will be tested:

1. What impacts do social relationships have on decisionmaking and prioritization in evacuation from fire?

    a. Proposition: people prioritize the safety of the people with whom they have relationships and will make decisions to try to promote their safety.

2. How do perceived roles and responsibilities influence building fire evacuation decisionmaking and behavior?

    a. Proposition: waitstaff will extend their roles (for example, shepherding their own tables) in an evacuation to include helping direct the evacuation.

3. Are patterns of group behavior observed and modeled in the Station fire also applicable to the Beverly Hills Supper Club fire?

    a. Proposition: general group behavior will be consistent across decades and incidents. Additionally, BHSC data will provide insight as to why all extant models of the Station fire underpredict kitchen exit use in that employees may have directed patrons to use that exit.

4. Does PrioritEvac as it exists now model the evacuation of BHSC with any degree of accuracy (such as number of dead within one hundred of the actual dead).

    a. Proposition: deaths will be overpredicted because helping behavior is not currently a component.

Chapter 3

THE BEVERLY HILLS SUPPER CLUB FIRE

This chapter describes the events of the Beverly Hills Supper Club Fire in Southgate, Kentucky on Saturday, May 28, 1977. The fire resulted in the deaths of 165 people. It was the subject of much investigation after the fire, from the State Troopers who conducted interviews with employees to Norris Johnson who conducted survey research to National Institute of Standards and Technology (NIST) documentation of The Life Safety Code changes made in response to the fire. It was also the subject of speculation and obsession, resulting in numerous books on the fire.

Sometime between 8:30pm and 8:50pm on Saturday, May 28, 1977, a fire broke out in the Zebra Room. It spread. A call was placed at 9:01pm to 911. People evacuated as they were instructed to do so or as they noticed smoke and became concerned. A hundred and sixty-five people died, more were injured, and the building burned completely.

Beyond those spare facts, the progress of the fire is a matter of reconstruction from rare photos (Best 1977), physical evidence, and individual accounts of the fire (interview data). Which is to say that one of the books reviewed while examining all the relevant literature thinks the Mafia did it (Bronson 2020). I do not agree and think the premise and execution of that research showed bias and a desperate desire to make a city of 3,800 in Kentucky exciting and glamorous, but it does provide points for discussion with reference to the more rigorous literature.

Space

The first things to note are the layout of the BHSC. The records are approximate, because the Schillings did or caused a significant amount of unpermitted work on the Club, and it burned too thoroughly to be reconstructed accurately. But the approximations are things like the exact placement of walls and curtains and edges backstage on the multiple available stages–- for anyone who has worked backstage, those feel like artificial constraints anyway, because brushing against a curtain is worse than brushing against a wall in that it might be visible to the audience – or where the walls were completed in the under-construction areas of the kitchen. Thus, maps used here are interchangeably from –FPA (Best 1977) or the Norris Johnson Collection, with the accompanying request to not worry too much about the discrepancies.

The broad strokes, at least, are consistent. Patrons walked up a main stairway into a foyer with a reservation desk. The coat check and gift shop stood to the left, restrooms to the right as the foyer narrowed to a hallway before opening into the main bar. The main bar boasted a long, curved bar, and the club branched from there. To the left, the café room or main dining room, with its own entrance to the kitchen. Straight back, the Empire Room and further unfolding rooms, additions that put the 'main bar' somewhere in the front quarter of the building. To the right of the main bar was an alcove hidden behind a curtain where Eileen, the reservation clerk, handled phone calls and reservations. The back of that alcove shared a wall with the Zebra Room, a small function room tucked behind the grand and grandiose Hall of Mirrors with its curving Cinderella staircase that was the main access to the small second floor. The second floor had party rooms, as well as two of the potential thirteen bars that could be set up throughout the BHSC for more convenient service for the patrons (Elliot 2010).

The NFPA report details more of the interior finishes, but suffice to say that, even aside from the bunting used for the wedding, they were mostly flammable. The building also had no automatic sprinkler protection, which was required by the NFPA Life Safety Code and the National Building Code that were in effect at the time of the fire. The Schillings had extensively renovated and expanded the building since a fire in 1970 (Best 1977), but the permits in that time covered only chunks of the building that were obvious additions, and internal renovations and electrical work such as the lighting in the Zebra Room were broadly unpermitted.

Because the party using that room for a wedding reception had moved to Garden Room 4 for dinner, there were no people in that room at the time of the fire. When staff members noticed smoke, they opened the Zebra Room doors to investigate and dark smoke billowed out. Smoke progressed down the Hall of Mirrors towards the Cabaret Room, towards the Main Bar and the entryway, and up the spiral staircase towards the Crystal Rooms. People evacuated as employees cued them to do so, or as they noticed the darker smoke of the fire and became concerned, or as they noticed mass exodus and joined (per interviews).

Many people ended up evacuating out of the kitchens towards the back of the building or out of the Garden Rooms which opened directly to the formal gardens. In a questionnaire, 86% of respondents reported an employee helping them to locate the exit they used (Best 1977). Fatalities were concentrated in the Cabaret Room, which was crowded with patrons there to see the night's act. As shown in Figure 2, there were a significant number of people in many of the rooms at the start of the fire. The 1200+ figure, though, is notable for the fact that the Cabaret Room was only approved by the fire marshal for 617 occupants. Not patrons (plus staff and entertainers), but total occupants. The room was known to be far over capacity for the space. And, as a supper club, patrons were not merely standing but occupying tables to eat their meals or enjoy after-dinner drinks while they watched the show.

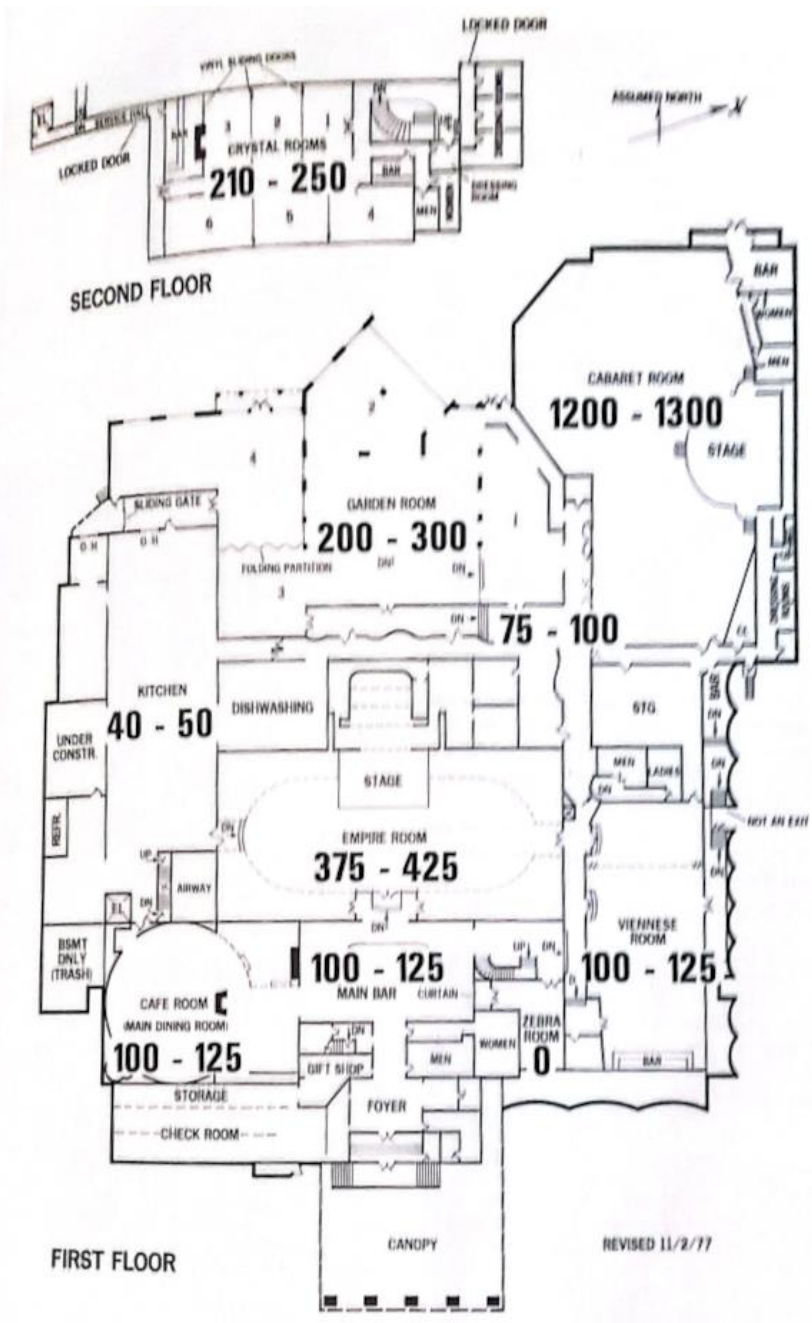

Figure 2 Estimated Actual Occupancy at Time of The Fire, Best 1977 p 19

As shown in Figure 3, the Cabaret Room was also the location of significant fatalities. But that total was tallied after firefighters had extinguished the fire, and many severely injured and dead were evacuated from the building during the immediate response, potentially obfuscating the number of deaths that can be attributed to that one crowded room – that one oversold show.

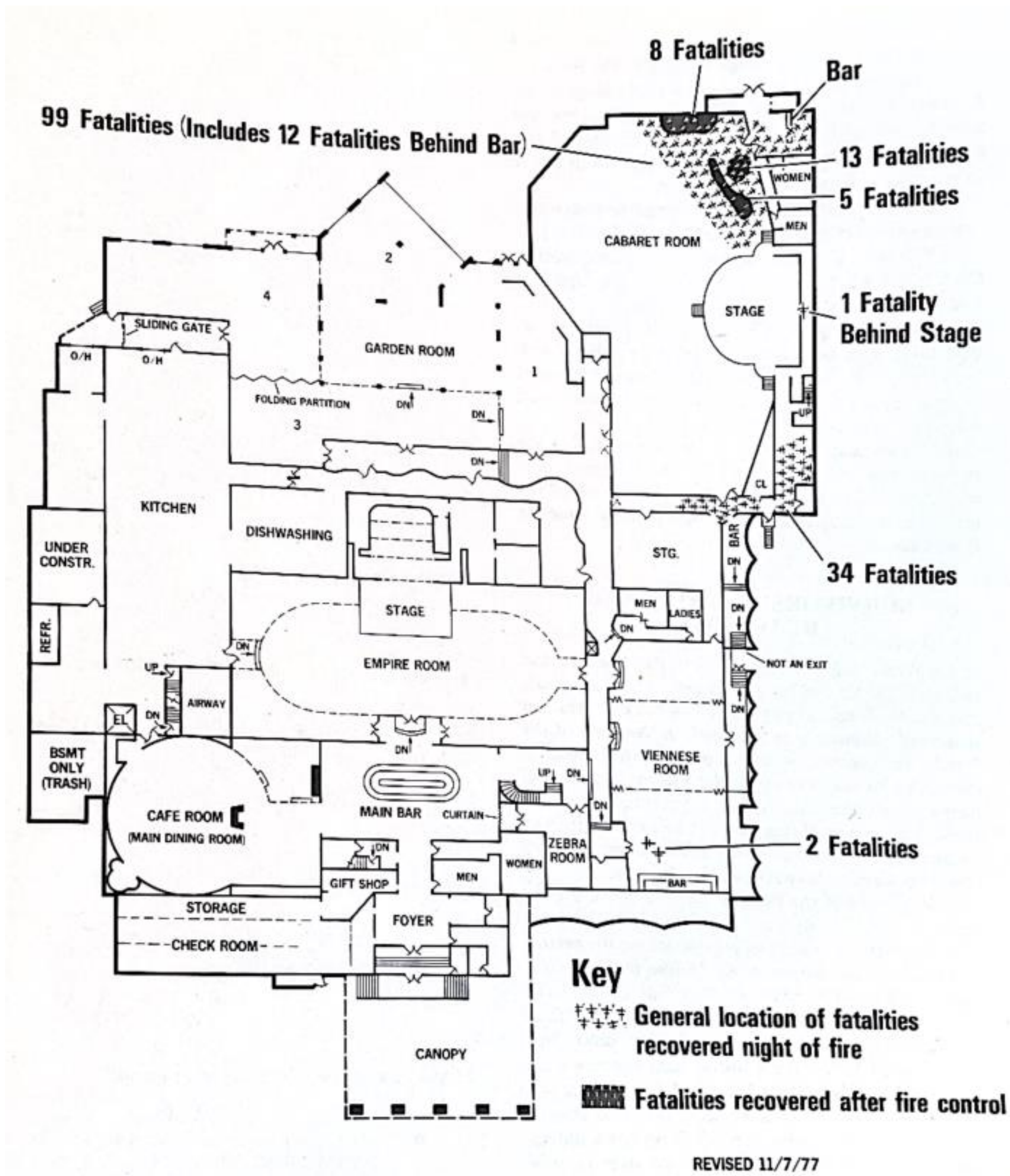

Figure 3 Fatalities, Best 1977 p 53

Distributed Response

The scale of the building impacted response in both space and time. I discuss the asynchronous nature of the response in the section on time, but the spatial distribution is also relevant, because events occurring in one section of the Club were not necessarily evident to those in other sections.

Richard Riesenberg, the chief of the Southgate volunteer fire department, gave an interview to the Kentucky State Police on June 16, 1977, about the BHSC fire response which illuminates some of the spatial distribution factors at play amongst the first responders to the fire. The Southgate volunteer fire department – department #1300 – consisted of fifty-five active firefighters, two fire trucks and a "small but well-equipped rescue van" for the life squad [interview]. This, of course, was not sufficient to the task of fighting the BHSC fire, but Southgate FD was part of a mutual aid system in Campbell County, and part of the Northern Kentucky Move-Up System. At one point, a former fire chief showed up on scene and asked what he could do to help. The current chief told him to get on the radio and ask for more support from other fire stations. In all, through the various channels of communication, the BHSC fire ended up with response from as far away as Cincinnati and fifty-two departments had been contacted and were in some way involved in the response.

The command center for the response was in the front of the building, but firefighters also responded through the Cabaret Room bar door, as that was one of the major means of egress. These were entirely separate from the "temporary hospital" [interview] set up in the chapel by the doctors and nurses who had been attending a party in the Viennese Room.

So now, with a summary of how the fire interacted with the space, I can add the dimension of time.

Time

The timeline of the fire has two functional components which operate mostly independently. The first is the progression of the fire itself. The second is people's awareness of and response to the fire. This may seem counterintuitive – surely people responded to the fire as it spread. But risk communication, risk assessment, and how people respond are all more complex than a linear response to hazard, as PADM details the multiple factors people assess in their decisionmaking.

What happened earlier, both in the day and the history of the club, also shaded both the physical building and the sensemaking of the fire that took place. Bronson (2020) goes back to the 1930s, tracing the history of the Mob in Kentucky and Ohio and making the tenuous connection that because Schilling bought the BHSC with seller financing from someone who bought the club from a trust handled by a mob accountant for $10 years before, there was still some sort of mob involvement. The renovations and work done since the 1970 fire were what set up the immediate environment for the fire. Bronson also had multiple interviewees who noted people being "suspicious" in and around the club earlier the day of the fire – notably wiping down the walls with what they described as a milky liquid.

Highlighted In Absence: Cleaning Staff

Here, a digression: Bronson's interviewees were primarily front of house staff. Front of house are generally those who interact with customers – servers and bussers – as opposed to the back of house, who work in the back – usually the kitchen staff such as cooks and dishwashers. The one exception was Wayne Dammert, the banquet captain acting on the second floor. This mention of a banquet captain was part of what prompted my interview of Alice Bongard, a chef who has worked in various restaurants and fine dining establishments for over a decade. Aside from the general picture and social science focus of Wilson (2021), I wanted someone who could answer the questions of where specific positions fit into the heuristic divides of the house. A banquet captain, I learned, is still considered back of house, and in general would be expected to have both low-level resentment and clean uniforms for when interacting with patrons directly. But Dammert was the one representative of the back of the house that Bronson interviewed, and nowhere in Bronson's notes did he mention interviewing or even discussing the existence of regular cleaning staff.

Bongard currently works at a restaurant that closes on Mondays. Because she goes in on Mondays to prep for the week, she is familiar with the woman who does the deep cleaning that is part of keeping a restaurant sanitary but not covered by closing duties or the kind of cleaning possible while working around patrons. Bongard discussed how going in on Mondays as the kitchen manager was the only reason she was familiar with the cleaning staff; how none of the rest of the front- or back-of-house staff were familiar with cleaning staff; how cleaning staff were not front- or back-of-house at all but existed outside of the ways staff were accustomed to conceptualizing their coworkers. Bongard also clarified that some tensions existed between front- and back-of-house because front was generally tipped, while back generally was not, leading to resentment on both sides at times as the variability of tipped wages make for sometimes dramatically unequal pay. People not included in those general groupings would not be included in the general tensions, but also would not always be thought of at all. Then, because this was a long but casual interview with someone I went to high school with, in response to my sudden thought and subsequent question about where delivery drivers fit in the taxonomy of restaurants, Bongard gave me the absolute gift of the serious but not literal quote, “Delivery drivers don’t exist.” This means that even in context of a discussion of the people who are ‘invisible’ within the restaurant context, that invisibility is persistent, and potential interview subjects can be overlooked.

This is not to say that Bronson’s interviewees would not have recognized regular cleaning staff who had worked at the BHSC every day since it opened. But cleaning staff being both outside the groups of coworkers his interviewees would have been familiar with from working alongside and outside the taxonomy of staff commonly conceptualized by both restaurant workers and people studying the social factors in restaurants does suggest that Bronson’s interviewees finding people doing plausibly cleaning-related tasks suspicious is irrelevant at best. Also mentioned were individuals doing air conditioning maintenance in the Zebra Room earlier that day – apparently, they were somewhat brusque with wait staff, which was related to Bronson as being suspicious behavior. The fact that these suspicious individuals were mentioned in interviews with Bronson but not in interviews with the Kentucky State Police is also notable, with any relevant conclusions left to the reader.

A Timeline

On the night of the fire, people noticed – not that there was smoke, but that there was more and darker smoke than there should have been. This was 1977, when smoking in a bar was legal everywhere and 36% of American adults smoked (McCarthy 2018). And already, at 7pm and 7:30pm, patrons had complained to the Assistant Head Hostess of the main dining room that it was smoky. This was over an hour before the fire started.

Once it did start, notice of the fire spread asymmetrically. For example, the clerk sharing a wall with the Zebra Room noted smoke and communicated a concern with the front desk, resulting in a 911 call placed at 9:01pm. Up the Cinderella staircase, directly above the Zebra Room, someone told the banquet captain, Wayne Dammert, about the fire at exactly 9:00pm – a time he noted because he was running late – and he started urging people to evacuate immediately. Down the long hall from the Zebra Room, on stage in the Cabaret Room, Walter Bailey directed people to evacuate sometime between 8:45pm and 9:10pm[2]. According to the interview data, awareness of the fire started to spread around 9pm, but in different ways and to different people. This might have been simpler if there were smoke alarms or a fire suppression system that included alarms; revisions to the Life Safety Code indicate a broad concurrence with this idea. Table 5 shows a summary timeline of events as well as locations, with notes on events of interest, such as the table in Main Dining who got conflicting information from various staff before finally evacuating.

Table 5 Timeline of Events

Time	Event	Location
7:00 PM	First complaint of smoke	Main Dining
8:30 PM	Wedding party paid bill by check, left	Zebra Room
8:40 PM	Shirley Barker finished tidying, blowing out candles, left	Zebra Room
8:45 PM	Couple was seated, told to leave by a busser, then to sit by their server, then finally to leave by their server	Main Dining

[2] Consensus time of 9:06pm was arrived at by Best

Time	**Event**	**Location**
8:45 PM–-8:50 PM	Fire discovered (Best 1977, p. 17).	Zebra Room
8:48 PM	Cincinnati fire captain had been waiting in line 2-3 minutes when he saw agitated servers	Hall beside Empire
8:50 PM	Apps were being brought in, but were never served	Viennese Room
9:00 PM	Banquet Captain told of fire	Second floor bar
9:01 PM	911 call (Best p. 17)	Front desk
9:04 PM	Southgate Fire Department arrived	Front
9:06 PM	Walter Bailey announced the fire on stage	Cabaret Room
9:15 PM	Firefighters at rear	Cabaret Room
9:20 PM	Conflagration, everyone who exited under their own power assumed out	Cabaret Room
9:50 PM	Visible conflagration, fire responders on scene (the first item confirmed by photos by Joseph Lalonde, starting on Best p. 23)	Front
10:20 PM	Fire clearly burning through roof	Front
11:20 PM	Chance of building collapse, all rescue personnel out	
2:00 AM	Fire under control	

A final note on the timeline itself – the first firefighters were on scene before everyone was even notified there was a fire. This is a great response time for the Southgate fire department, but also: people outside knew before people inside. That indicates a lack of communication and coordination within the BHSC, particularly for a disaster context.

Ignition

Fundamentally, the exact ignition mechanism and point of the fire do not matter. What matters is that the club was overcrowded, that there was no sprinkler system, that the fire occurred at all. What matters is that people died.

Even in the context of this dissertation, the exact ignition point is trivial and irrelevant. What matters here is how people communicated, cared for each other, and evacuated. What matters is how people lived.

Nevertheless, exactly how the fire started is mystery enough to let Bronson (2020) speculate wildly that the Mob set off an explosion in the basement, even after experts concluded that the fire was electrical in nature and originated in the Zebra Room. The experts (Best 1977, Lawson 1984) were working to determine ways to prevent this from happening again. They also, crucially, were writing when certain key players were still alive, and it would have been deeply unkind to speculate. I am writing in part to have the most complete narrative of the fire that I can persuasively put together, and in part because spite about Bronson's work has been incredible fuel to propel this chapter forward.

The NFPA concluded, after two weeks of investigation, that the exact nature of the ignition (short, arc, or heat) of an electrical (stemming from fixture, switch, or wiring) fire in an enclosed space in the Zebra room could not be determined. But they narrowed it to those particulars, ruling out the basement or the kitchen as points of origin. Initially investigators gave the basement a fair amount of consideration, but both the testimony of employees who had been in the basement and the evidence of the floor of the Zebra room ruled it out. The point where all the data and interviews agree: the origin of the fire was the Zebra room.

The wedding reception in the Zebra room moved to the Garden Rooms at around 8:30pm after paying their bill.

At 8:40pm, Shirley Barker closed the Zebra Room doors, leaving it dark and empty. She made note in her statement about making sure the candles were out every time. Shortly thereafter, Manila Poer opened them again, saying, "I went in and I turned up the main big light. See we have two big lights to turn up to see, but these little bitty ones was all around the side." The little bitty ones, combined with candles on the tables, had been the lighting sources for the wedding reception, highlighting the swathes of celebratory bunting around the ceiling. Manila Poer was a regular cleaner at BHSC and had worked there eight and a half months: long enough to be familiar with the building and to appreciate the opportunity to clean a room while it was empty between parties. "So I went over and turned up the big ones, to see how dirty the floor was. So I said I'll just bring my sweeper being as they left and gone to the show, and I'll just put my sweeper in here and nobody will bother it."

The assumption that the party had proceeded to a show was probably generally a safe one, as BHSC prided itself on being the Showplace of the Nation, so the fact that this particular party was in fact eating dinner in Garden 4 mostly highlights the lack of communication between the staff interacting with patrons and the cleaning staff. But this point in Poer's statement is also where kindness comes into prior writing. Given the scale of destruction, there is no way to accurately pinpoint the cause of the fire beyond being electrical in nature and in the Zebra Room. But: lightbulbs get hot. Particularly incandescent bulbs. The last several years of research on building fires have made me incredibly leery of scented candles but no less fond of scents: the oil warmer I use in my office melts wax with the heat of an incandescent bulb. It has a warning not to put things next to the bulb, and a glass cover to direct heat up to the dish where the wax goes. When a flickering lightbulb in our entryway got too annoying, we could not replace it immediately after turning the light off: it was too hot to touch. I suspect that the big lights, turned all the way up, were too close to the bunting, and produced too much heat. The NFPA also considered the heat from the lights, recessed as they were into combustible ceiling tile, a "strong" possibility (Best 1977, p 58).

Whether that resulted in the bunting igniting, a crucial wire melting, or the air conditioning unit that had been worked on earlier in the day doing something faulty and igniting a spark is beyond the reach of forensic reconstruction or even my educated conjecture. But that is how I suspect the fire originated: the big lights, turned all the way up.

This is not to say that I think Poer is in any way responsible for the fire. She was doing her job. She needed the lights on to see how much cleaning the room needed. Under normal circumstances, there was no bunting in the Zebra Room.

But after all that explanation, I can also understand that someone might be devastated by the knowledge that theirs was the hand that unwittingly triggered the precarious and dangerous result of whim, carelessness, corner-cutting and greed that was an overcrowded club with substandard construction and safety features.

After leaving the Zebra Room, Poer checked the bathrooms while she was in that area of the club, replacing paper. Then she smelled smoke and thought someone had dropped a cigarette in the paper towel garbage and went around to all nine toilets to check to see if they were where the smoke was coming from. She found no smoke originating in any of the bathrooms, just the smell of it. By the time she finished her inspection, mass evacuation was underway, and she exited the building.

After

The aftermath of the fire continued long after the rubble stopped smoldering.

The local medical examiner performed a limited number of autopsies. Five reports were available to the NFPA – for all five, cause of death was smoke inhalation. The medical examiner declared the cause of death for all casualties of the fire "smoke inhalation and carbon monoxide intoxication, with no other poisonous substances found" (Best 1977, p 52).

One of the dramatic and intensive responses to the fire was the report I have significantly cited throughout this section. Five National Fire Protection Association experts spent two weeks on site and data collection and analysis continued for a subsequent five months before compiling the report. In it, Best spends eleven pages detailing the deviations in the BHSC from the Life Safety Code (pp 63-74). In counterpoint to the Kentucky State Police investigation, which included hundreds of interviews that necessarily and methodically cast a broad net of inquiry amongst patrons, employees, and first responders, Best's NFPA report suggests that the building itself was problematic all along. Writing years later, Lawson (2016) concurred, describing the configuration of the BHSC by the night of the fire as a "firetrap of rare magnitude" (p 27).

Chapter 4

DATA ANALYSIS METHODS

As demonstrated in the previous chapter, there is enough documentation about the fire to piece together a story – several stories, really, and somewhere amongst them the truth – about the actual progression of events and fire that night. But my primary interest is not in the story, but in how I can translate the story into a simulation that both mirrors the events of the fire (replicability and accuracy) and can be meaningfully extrapolated to other situations. Meaningful extrapolation is the indicator that I have identified and codified useful patterns of human behavior rather than mere serendipitous mimicry.

Because of the scale of documentation of the BHSC fire, it makes for a good case study for examining the way the interviewed employees perceived their own responsibility during the evacuation process as well as overall group behavior during building fire evacuation. All the archival data on the fire started in analog format, so this research was multi-stage: digitizing data, preliminary analysis, improving PrioritEvac to model the fire, validating the model results, and then comparing the modeling principles to PrioritEvac as programmed for the Station fire.

Digitizing Data–- Archival search

The first task for this case study is acquiring the data in a machine-readable format. As it stands, the primary data available for this effort consists of the Norris Johnson Collection of the E. L. Quarantelli Collection, three boxes which contain:

- Building schematics with hand-drawn escape routes taken by individuals drawn by those individuals

- Photocopies of postcards from interview subjects (See Appendix A for samples)
- Questionnaires conducted by Johnson and others with survivors of the fire, organized by which room of the Supper Club respondents were in initially (See Appendix A)
- Transcripts of interviews with employees and patrons conducted by the State Police investigating the fire.
- Summaries of the ways in which people exited.
- Witness lists from the Kentucky State Police
- Casualty lists

I built the analysis plan to approach all this disparate data on my experience with the Station fire, which demonstrated that knowing who was where at the beginning of an incident is paramount. Johnston and Johnson also used this data in tracking the way employees aided in directing evacuation (1989), which means that although my work takes that data and feeds it into a dataset for a model rather than examining the phenomenon directly their notes in the archival documents are helpful. I read each of the 344 statements made to the Kentucky State Police that were in the archive, making notes of the following[3]:

- Employee status and corresponding role in response
- Starting location
- Ending location
- Age, if available

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[3] See Appendix B. Physical notes are the first round of coding, the medium removing any temptation to actively look for patterns before completion. Digitizing this data will serve as a review of notes that will also support further coding.

- Gender, if available
- What prompted their evacuation?
- Relevant notes about route
- Who they came with if they had additional connections (such as siblings working together)

The first item is the one most grounded on the data and the previous work by Johnston and Johnson (1989) rather than broad theory, as multiple servers reported shepherding people from ‘their’ tables through evacuation. Research into the Station fire was primarily about intragroup relationships, but this pointed to the possibility of interesting significance in parasocial relationships that conveyed even situational responsibility. I created a computer-readable dataset from them, charting all the data collected in my notes. Charting, though, requires preliminary analysis for both overall patterns and patterns of behavior.

Preliminary Analysis – Describing the Data

Analysis of the data involved both comparing to my initial conception of what to look for as well as examining emergent trends in the interviews by the Kentucky State Police. The questions they posed elicited the data described below, but the focus was on the events of the day as well as the preparedness measures taken by staff and management in terms of fire extinguishers, fire drills, employee training, and previous fires. The answers to these questions were out of scope for this research – as mentioned in Chapter 3, the cause of the fire is functionally irrelevant to my focus on behavior during evacuation from it. Thus, I extracted specific data from the interviews, itemized in the following sections, rather than performing a deep dive into any of them. I entered these data points, detailed in the sections that follow, into Excel and then used them to systematically sort and interpret the data. The following sections describe the categories used and follow the bulleted list above, with the exception that I discuss prompts and connections in the Behavior section, as they have significantly more irreducible complexity.

Role

In examining and coding the data, the first factor was employee status. I expected this to be a binary, but discovered that there were meaningful distinctions between the employees of the club and musicians who were contracted for the night, either by a group holding an event (such as 3 Way Power hire by the Choral Union for a fashion show in the Crystal Rooms) or by the Club itself (such as the union musicians in the Cabaret Room) but were not directly employed by the Club. There was additionally one interview with a partner owner, who I consider as having a different stake in the health of the Club. This suggested three meaningful categories aside from patrons, but the statements themselves indicated that this might be the wrong way to categorize. Some waitstaff noted going back to their tables – generally noted specifically with a possessive preposition[4] – and ensuring the safe evacuation of the people at those tables. A BHSC manager, however, noted ensuring the safety of three of his staff, and the manager of 3 Way Power noted ushering out the singers. This was congruent with my earlier research indicating that familiar people will be a priority, but at odds with the overall trend of employees helping patrons.

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[4] Waitstaff noted tables as 'theirs,' but the Kentucky State Police did not pursue the psychological relationship waitstaff had to their patrons as a direct line of questioning, so any parasocial relationship between waitstaff and patrons was encompassed in pronouns and passing descriptions of behavior.

A potential clue emerged in the statements of several employees who mentioned getting their purses, but nothing about patrons. These seven statements, upon revisiting, highlighted a distinction that had not stuck out on initial evaluation: several of these women were cocktail waitstaff rather than table waitstaff, and one was a cashier. As a subject matter expert interviewee reminded me, many bar staff, specifically cocktail waitstaff, are untipped. Additionally, large swathes of restaurant employees do not have significant direct interactions with patrons at all. These are colloquially referred to as back-of-house (Wilson 2021), and, as cocktail servers, generally untipped. This suggested a point of division: the restaurant-traditional front-of-house (generally waitstaff, bar staff, hosts, and bussers) and back-of-house (generally cooks and dishwashers). But, as addressed in Chapter 3, not all employees fall into these categories. The clearest distinction that emerged from the statements was between tipped and untipped staff, with tipped waitstaff such as table waitstaff specifically having the most stake in the successful evacuation of patrons. As such, I included the partner owner in untipped staff, so there are four categories: contractor, tipped staff, untipped staff, and patrons. The number of identifiable people in each category from all sources are in Table 6.

Table 6 Role

Status	**Contractor**	**Tipped Staff**	**Non-tipped**	**Patron**
Number	16	175	106	1151

These categories have corresponding data in the way the program treats them, detailed in Chapter 5, Section: Roles.

As to the specifics of managers ushering out employees, this is of a piece with tipped waitstaff ushering out their tables: in both cases, we can revisit the DRC typology and conceptualize managing and tending to these sets of people as an extension of accustomed roles. While a manager might be located front-of-house, part of their core and established job is managing the other front-of-house employees rather than the sole emphasis being on patrons. The interactions of multiple concepts and roles allow for the emergence of a coherent overall picture.

Starting Location

Starting locations were indicated in almost all interviews and were also indicated on exit maps and on the group attendance lists, which included people who did not successfully evacuate. I grouped starting locations per the rooms indicated on the layout in Image 1. For purposes of descriptive statistics here, I have simplified locations – those on stage in the Cabaret Room grouped with those in the audience or at the bar, the gift shop grouped with the foyer, etc. This simplification will not carry through to the model itself, where evacuation maps provided for exact placement and location names are not relevant.

Table 7 Starting Location

Starting location	
Viennese Room	11
Garden Rooms	22
Main Bar	5
Cabaret Room	183
Crystal Rooms	12
Zebra Room	3
Kitchen	24
Basement	2
Front Ladies Room	2
Main Dining	41
Right Hall	6
Dishwashing	5
Foyer	3
Empire Room	18

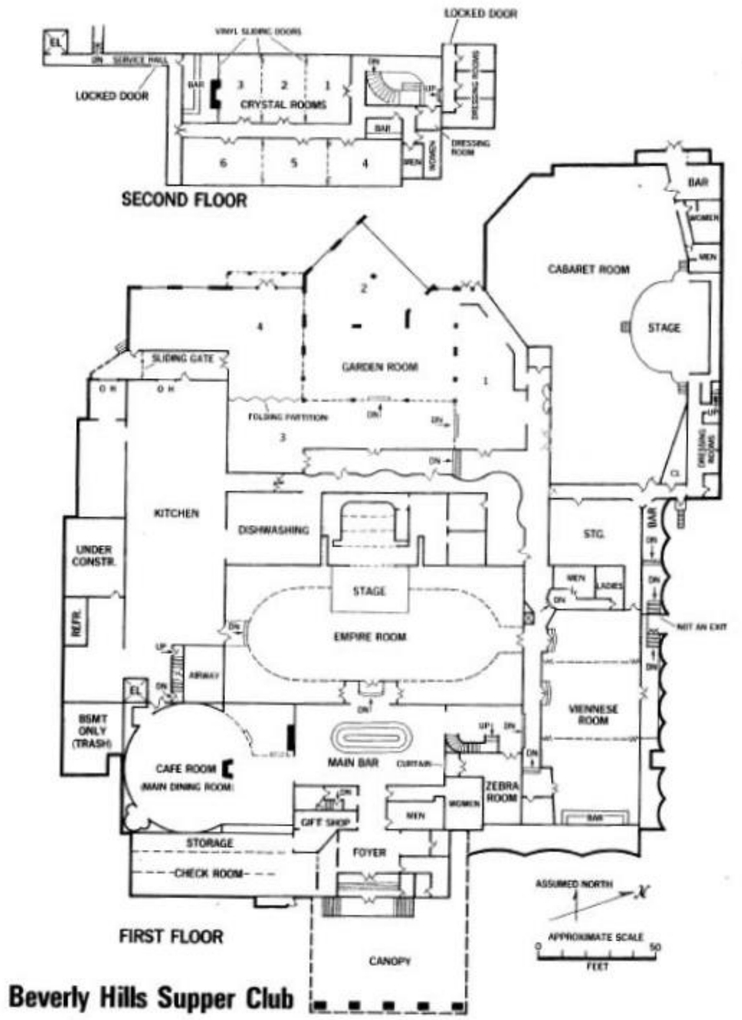


Figure 4 Layout of BHSC. Source: NFPA Case Study: Nightclub Fires, page 7

Ending Location

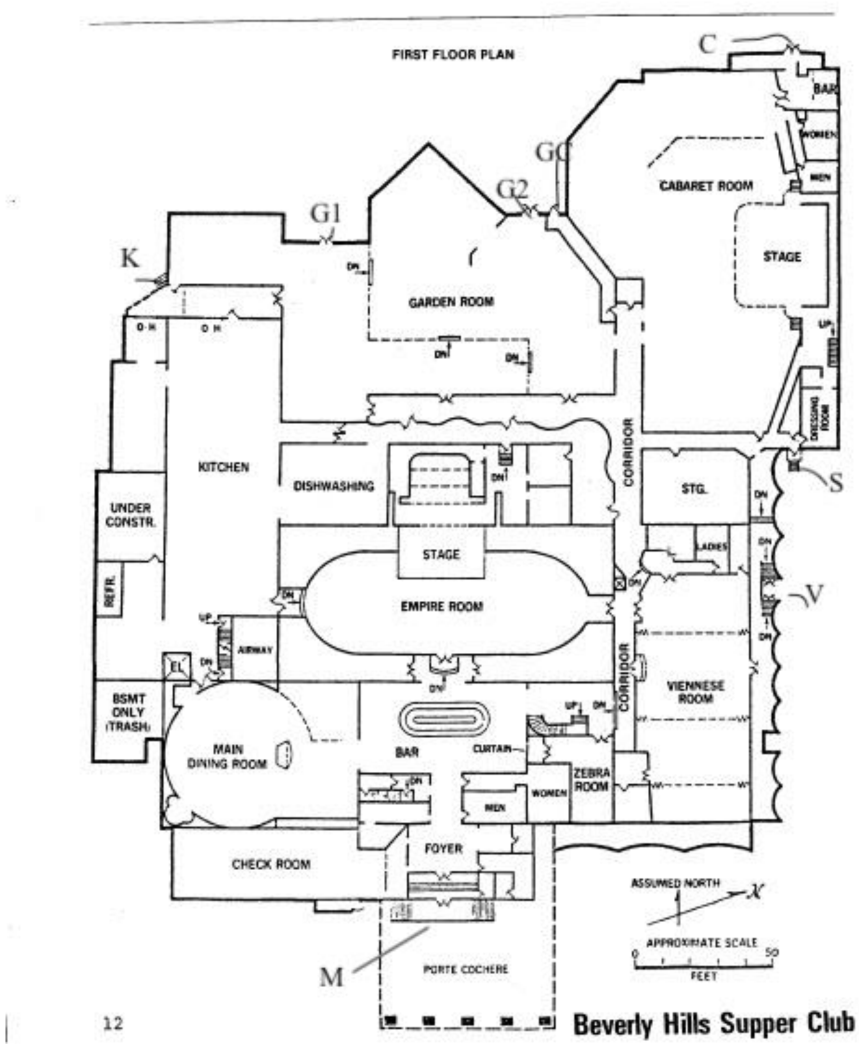
For the BHSC fire, I am not mapping the location of bodies found as prior scholars did for the Station nightclub fire. I only recorded reported exit used and will use those to validate model outcomes. I mapped the exits on a floor plan of the BHSC, visible in Figure 5. The second floor had an exit door that opened onto the roof, but per interviewee D-15 only he and one other person used it, making it less relevant for mapping.

Additionally, not all interviewees were clear on the way they exited, making the evacuation maps an important source. Table 8 depicts the exits described in the interviews, for a total of 570 of 756 interviewees total. The exit maps added significantly more data, though in some cases corroborated interviews.

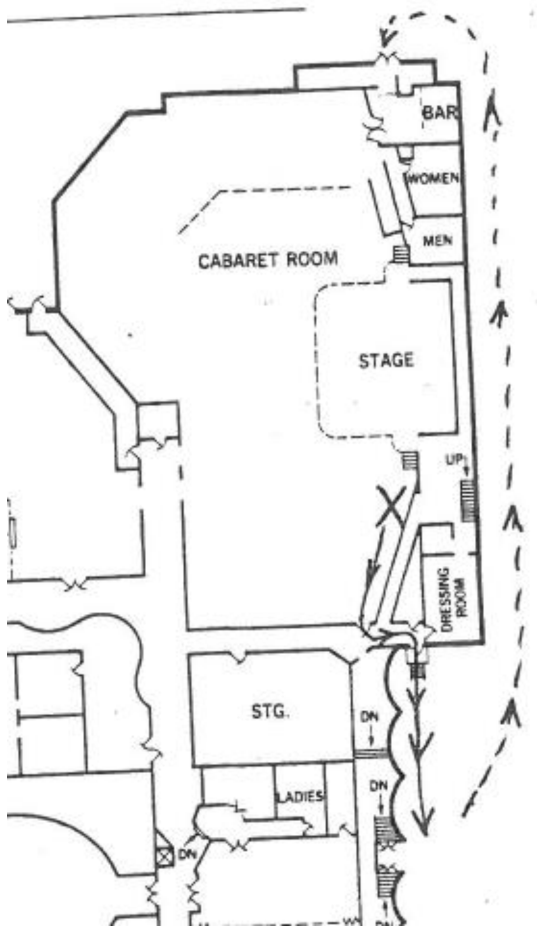
Table 8 Exit Used

Exit	Number of people who used that exit (interviews)	Total people who used that exit
C	84	274
G1	12	26
G2	11	32
GC	79	159
K	136	189
M	117	232
S	131	243

Figure 5
First floor of the Beverly Hills Supper Club, with notations of the abbreviations used for exits. Source: Appendix C: Richard Bright's Analysis: An analysis of the development and spread of fire from the room of fire origin (Zebra Room) to the Cabaret Room". Beverly Hills Supper Club Fire. Center for Fire Research, United States National Bureau of Standards



Some people also re-entered the building to try to assist others out – primarily their method of re-entry was Exit C, but since the primary focus of this research is initial exit behavior, my only comment on the phenomenon is to note the continuation of helping behaviors Figure 6 shows the relevant portion of one of these evacuation



maps.

Figure 6 Evacuation map showing re-entry.

Age

Ages were available only for a limited number of interviewees and not noted on exit maps. I included age as a parameter initially because it was also included in the Station fire, which had more complete data available, and I hoped to use it for also determining a bell curve to assign initial energy levels. But given the dearth of data, I set energy levels to one hundred for all people but one. The exception is w118a, a seven-year-old, who I assigned an energy level of eighty because of their age.

Gender

Gender is complicated, particularly in that our vocabulary around it has evolved significantly in the last few years. But for this work, I treat gender as a binary. I extrapolated gender to the dataset from pronouns, gendered titles, and modes of address used by interviewers and assumptions based on common association with names. As demonstrated in Table 9, there were more female than male interviewees. The difference in number is less than 10% and therefore not significant.

Table 9 Gender of interviewees

Gender		
f	147	53.7%
m	127	46.3%

Gender is included in the dataset.

On Layout

Because this work involves modeling, it is necessary both acknowledge discrepancies in layout diagrams and note which I am using. The layout used in the NFPA documentation differs slightly from the layout used in the evacuation maps in the archives, primarily in the exact shape of the stage, whether front stairs existed on that stage, and the layout of the restrooms, dressing room, and bars on the second floor. Some of this is a difference in reporting – probably the stage was the more rounded curve the NFPA used, with the musicians in the pit elided on both maps.

But for the sake of modeling and matching the model environment to the one people reported on in their exit maps, using the possibly more inaccurate layout reflected in Figure 2 offers more fidelity. Since this is research grounded in people and their actions, fidelity to their experiences is more important than accuracy to a layout I only suspect is more accurate.

Additionally, since the Schillings did substantial renovations without permits and thus without adequate documentation, all layouts are ad hoc at best, since the actual structure is no longer extant for comparison. Figure 7 shows the layout as rendered in NetLogo and used for simulation runs.

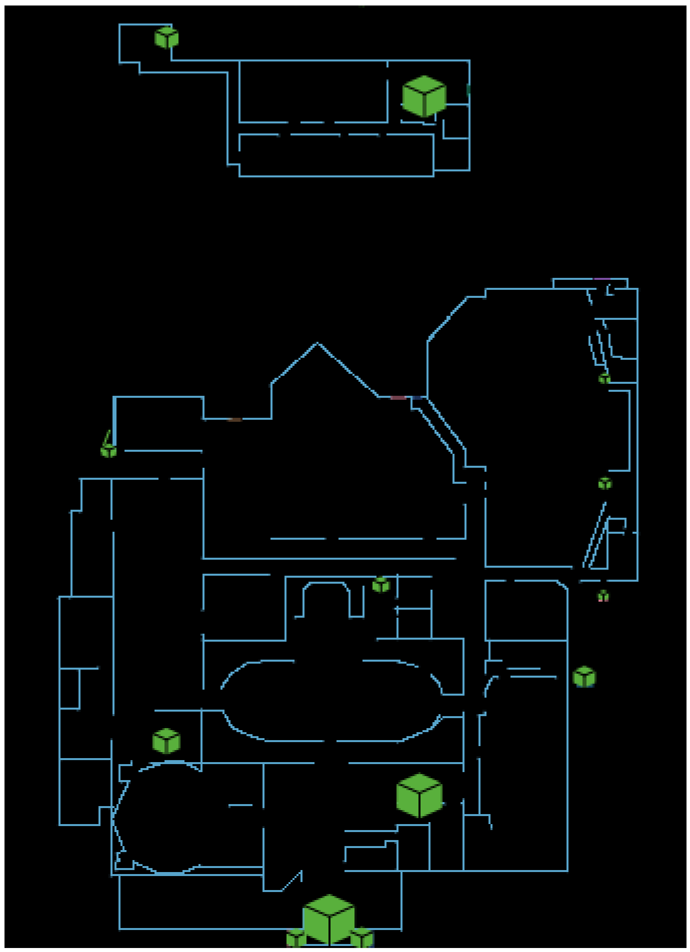


Figure 7 Layout of BHSC rendered in NetLogo.

Preliminary Analysis–- Behavior

The initial plan included nVivo coding. However, the data I was searching for was simple: employee categories, prompts to evacuate, and people or items searched for before evacuating, initial location and exit taken. The process of taking physical notes and the need to have everything for the ABM in CSV format made nVivo extraneous. The coding of interviews was inductive: an initial note of dishwasher was eventually grouped into an overall employee category of 'kitchen.' This was based both on the interviews themselves and the revealed differences between employees who had direct contact with customers and those who did not. As discussed in the literature review, a patron is potentially different from a person, with employees with patron contact feeling a sense of responsibility for 'their' patrons that they would not for other people with whom they do not have an otherwise pre-existing social tie.

Chapter 5

PROGRAMMING METHODS

After performing preliminary analysis of the interview and archival data, the next step was to run PrioritEvac with the BHSC data, adding functions for assistance behavior and for stairs.

Improving PrioritEvac

I initially programmed PrioritEvac with adaptability to different scenarios in mind. I had not tested this adaptability prior to this research. The tasks included:

- Set up physical environment–- this will involve scanning the blueprints available for BHSC and then noting the parameters of the lines in a chart. The scale is metric, with each patch corresponding to nine square meters.

- Set up fire–- this involved tracking the notes on the location of the fire over time and then documenting them. The fire started in the Zebra Room and reached the Cabaret room, but I needed to compile specifics.

- Set up smoke–- as with fire, this involved tracking the notes on both location and density over time. Occupants of the Main Bar noted that initially the smoke was indistinguishable from cigarette smoke, which they expected to see, but that later there were billows of black smoke.

- Make sure the people dataset can be integrated–- this is primarily a matter of judging how any new parameters can be operationalized in conjunction with the existing setup.

- Run simulation–- superficially the simplest, this involves fixing any bugs that crop up, and then running the simulation fifty times to get a sample-based set of results.

This will show whether the underlying assumptions in PrioritEvac carry over to other situations, with some margin of error expected because of the new role of parasocial relationships.

The underlying assumptions tested include:

1. That people behave according to internally consistent and logical rules that prioritize emotion and attachment.

2. That people require multiple stimuli to cause evacuation to begin, including social stimuli where relevant.

3. That panic has no place in evacuation modeling. Norris Johnson documented and analyzed statements from “The Who Concert Stampede” of December 3, 1979. They argue that crowd models of panics or crazes are, at best, not useful (1987, 362-373). Young and Aguirre (2020) further supports the idea that, even in fire, ideas of panic primarily serve as harmful myths.

Because preliminary research on the archival data indicates that employees played a significant role in directing patron evacuation, I added a module to allow for employee-patron interaction outside the bounds of the established group relationships and interactions. This is part of making sure the people dataset can be integrated. But, because of the deliberately inductive approach to how employee roles played out, the parameters of this module and its interactions are currently unknown.

Roles

The roles of patron, contractor, and tipped or non-tipped staff have different treatments in PrioritEvac. To start with, in the initial development of PrioritEvac, familiarity with the building and all exits therein was based on reportedly having visited the Station nightclub before. But the BHSC is a significantly larger and more complex building, with kitchen and stage exits that patrons might never see, so patrons are all limited to the main entrance and entrances they can see. Both tipped and untipped staff know about all exits. Contractors are more complicated, as bands like 3 Way Power were upstairs and not consistent presences, while the pit orchestra was there frequently, but only necessarily familiar with the stage entrances. I would appreciate feedback or suggestions for how to handle this.

The social ties in PrioritEvac before edits were all nondirectional bonds: that is, they indicated reciprocal relationships. People were friends with or married to each other. One of the key differences is that employee-patron relationships are not wholly reciprocal: one person in the relationship is the patron, and one the employee. Crucially, for this model, one knows the way to the exits and can provide directions, and the other cannot. So, this is a directional relationship from employees to patrons.

Exits

Exits other than the main exit were largely unknown to patrons. Thus, I created another categorization than role, differentiating employees from non-employees. I added this to the setup function of people, allowing only employees to know about all exits. I did not include contractors as employees in this area. While musicians playing the Cabaret room reported in interviews that they were familiar with the south entrance to the Cabaret room, this would not necessarily translate to knowledge of other exits. The south entrance was the one that led most directly backstage, and so was relevant for those musicians. Other contractors, such as 3 Way Power, playing upstairs, would have no reason to use or be familiar with that door. No contractors, whether comedians or musicians, would have a reason to familiarize themselves with other exits like the kitchen door. For patrons, I and thus the code assume familiarity with the main entrance and exits they could see. This is because, while other doors might be closer to their destination in the BHSC, management and the layout of the club both encouraged patrons to use the main entrance to see reservation desk and be directed to their seating area.

Musicians

The role of musician is an area of distinct interest, because the Great White bassist died going back in for his instrument. I did not treat musicians differently in PrioritEvac for the Station fire, though, as there was only one group of them. In that way, the BHSC dataset is more robust, as there are multiple discrete groups of musicians. There are even differentiations between types of musicians, though this is articulated in the dataset only as notes. On stage in the Cabaret room were multiple sections, including a brass section and a strings section. Their responses to the announcement of the fire were wholly split, with strings players evacuating immediately and brass players not responding as quickly. No follow-up was possible to compare thought processes between them, as the brass section died. But there would have been ready questions for them. First, whether how vulnerable their instruments were to heat was a major factor in their consideration. Brass instruments are primarily, as the name suggests, brass. Stringed instruments are primarily wood, with strings made of varyingly heat-sensitive materials – most of them on the more sensitive end. Heat damage from even minor heat exposure would generally be a concern for strings players; much less so for brass players.

But there is another distinct split between the brass and strings sections in the Cabaret room that night. Namely, all records indicate that the brass section was whole male and the strings section wholly female. Gender and risk perception have been widely discussed (Paul, Stimers and Caldas 2015, Gustafson 1998), but here are inextricable from the additional dimension of musical instrument.

Musicians demonstrated in their interviews an attachment to their instruments similar to that which non-musicians demonstrated to people they cared about. But musicians, by and large, had their instruments in hand at the time evacuation began, and so there was no searching for their instruments or group leadership at play, just attachment. So, while it is an important attachment, I did not note the attachment of musicians to their instruments in the PrioritEvac code.

Validation

The 165 deaths that occurred because of the Beverly Hills Supper Club fire are well-documented and will serve as the initial validation point. Exit use is also available for comparison to the simulation data.

Comparing to Station Nightclub Fire, 2003

Rationale for Comparison Cases

Case studies allow for a depth of understanding in a particular context. Case studies on distinct scales allow for comparisons between conclusions, seeing which patterns of behavior hold up on a larger scale.

One of the ways the BHSC fire differs from the Station fire is the wider spread of ages of those in the building. Notably, children were present in BHSC, while the youngest person in the Station fire was seventeen. This is important because, aside from the impact on group dynamics that the presence of minor children might introduce, children do not move as fast (Glenn et al. 2020). Based on the findings from the Station (Young 2019a), this did not lead to change in the code, because people were not found to move at their maximum potential walking speed due to crowding.

The Station nightclub fire is well-studied, in part because of the extensive dataset available. This dataset is a combination of reports from NIST, interviews, and video and camera footage from the night of the fire. All of this has been combined into a computer-readable dataset, ideal for running simulations. Another contributing factor to how extensively it has been studied is that it was contained: fewer than five hundred people in the building, a known layout of the building, identifiable exits, no stairs, a demographically homogenous population, and only three minutes from ignition to all survivors having evacuated the building. Having these constraints on the data means that making computer models of the fire is a significantly easier task than it would be for many other fires. It was an unspeakable tragedy, but a simple scenario in terms of modeling.

The model (Young 2019b) and a detailed description of the functions and underlying rationale for those functions (Young 2019a) are available, so this section will serve as a brief overview of the content of the data, how it was validated, and the way the inherent limitations laid out distinct next steps addressed in other case studies.

Results were compared along several metrics to identify and isolate outliers, and I examined these differences to determine whether the differences come from incompatibilities with the conceptual model or the computer model.

Data

One of the phenomenal aspects of the Station dataset available is the level of detail. For most of the individuals in the fire there are concrete records of personal details; many others can be extrapolated from context.

Of interest in this context:

- Age

- Gender
- Approximate starting position
- Whether they were an employee of the venue
- Prior visitation
- Number of people they came with
- Type of social connection to the people they came with
    - One departure from the Station dataset is that I did not note all BHSC employees as part of the same employee group, because of the interview data that revealed that not all employees necessarily knew each other. Social connections aside from this employee grouping are preserved, such as BHSC employees who are also related.
- Eventual outcome

This allows for examination of the impact of social connections on survival; it also allows for comprehensive data validation.

We also know, in general, how many people used each exit and how many were injured and killed.

Model

I compared the model runs to the known dataset first along the most basic metric: were the number of dead similar?As the complexity of the model grew, I validated it by examining exit usage. Figure 8 shows the flowchart of decisions in PrioritEvac before modifications.

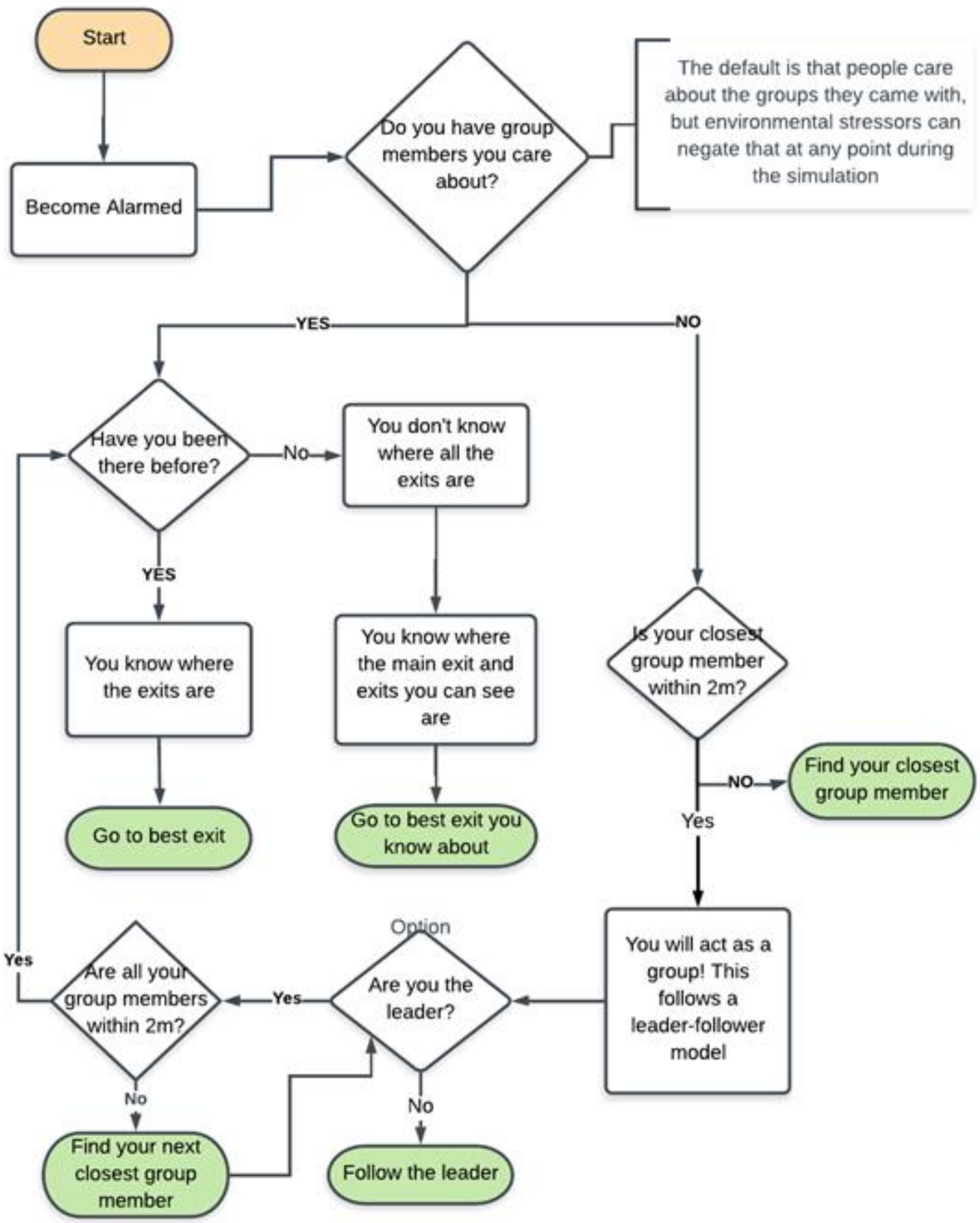


Figure 8 Original PrioritEvac decisionmaking flowchart

This allowed for more nuance, and a higher level of certainty that the movement of the agents in the model more closely resembled those of the real people in the fire. To compare the relative accuracy of the overall findings of the various agent-based models available for the Station fire, it is possible to subtract the actual results from the simulation results and then add up the absolute value of those individual differences for a measure of total difference. This avoids privileging any individual metric. Table 10 presents both the individual results along selected metrics as well as the total differential and the total square differential, based on Best (2013) suggestion that analyzing the squares of differences highlights outliers in the differences in results.

Table 10 Models of the Station fire

Model	**Sunroom window**	**Kitchen exit**	**Main exit**	**Total Difference**	**Total Sq. Difference**	**Dead**
Actual	34	17	128			100
PrioritEvac mean	36	9	137	73	985	111
Closest Exit	22	41	103	202	9090	50
Simulex (Grosshandler et al. 2005)	0	3	213	522	52582	0
BuildingEXODUS (Grosshandler et al. 2005)	0	4	214	516	51234	0
MASSEgress (Pan 2006)	0	4	293	488	49324	0

Model	**Sunroom window**	**Kitchen exit**	**Main exit**	**Total Difference**	**Total Sq. Difference**	**Dead**
Galea Scenario 1 (Galea et al. 2008)				452	39530	0
Galea Scenario 2 (Galea et al. 2008)				432	35930	180
Galea Scenario 3 (Galea et al. 2008)				368	29786	84
Pathfinder (SFPE)	0	3	207	524	54004	0
Pathfinder (Steering)	0	3	201	524	55132	0
Minimum Distance (Spearpoint 2012)	0	42	0	728	139744	0
Assigned (Spearpoint 2012)	0	3	212	522	52734	0
90 Seconds (Spearpoint 2012)	31	17	129	123	5461	145
First-Gen No Groups (Best 2013)	6	164	119	307	29005	108
First-Gen Weak Groups (Best 2013)	6	177	105	325	32611	104
First-Gen Strong Groups (Best 2013)	2	7	126	131	3947	137
SocEvac (Best 2013)	26	2	107	101	1983	131
SAFEgress (Chu et al. 2015)		4	117	116	3226	100

Model	**Sunroom window**	**Kitchen exit**	**Main exit**	**Total Difference**	**Total Sq. Difference**	**Dead**
EgressSFM (Fang 2015)		12	135	91	2493	105
BDI (Valette et al. 2018)			161	248	11316	121
Bourgais				354	29533	98.4

Thus, comparison to other models established PrioritEvac as not just a useful tool for looking at evacuation but one of the better tools available for examining the Station fire, so part of this research effort involved seeing how well the unaltered PrioritEvac replicates the BHSC fire.

Interview data also suggests that musicians prioritize their instruments in a manner similar to the way people at large prioritize loved ones, but the sample sizes are small for both situations and musicians largely already had their instruments in hand, so I made no programming changes to pursue or codify this interview data.

Thus I established a functional basis for not just my approach to the model but how to evaluate the changes that constitute the BHSC version of the model and a component of my results.

Chapter 6

RESULTS

There are several types of results that this research has generated, in line with the goals discussed in the Significance section of Chapter 1. Namely: 1) the computer-readable dataset generated through archival research, 2) the improved agent-based model (PrioritEvac), and 3) the analysis and findings which aim to provide new knowledge of behavior. After discussing each of these types of results, I address what they mean in conjunction with each other as pertains to my research questions.

Dataset

The dataset I created will be available at the E.L. Quarantelli Collection, in addition to the Git repository that stores the code for PrioritEvac (linked in Appendix C). This will enable more researchers to use it. Primarily the dataset reflects people, and I consider that the most substantial contribution, but the model, detailed in the next section, also includes basic data on the spread of the fire and smoke which has been reconstructed from witness statements. I did not find sufficient data to support the use of FDS to more comprehensively model the fire.

The dataset includes substantial information and is a potential basis for further research, as it documents starting location, role, group affiliation, exit used (where available), group type, and where people turned back if changing conditions meant that they did so.

The groups noted included 629 people in families and 165 people in friend groups as well as one couple best identified as dating. Despite the doctors' group, no groups were strictly composed of coworkers: while "Dr." in the attendee list did indicate a doctor, spouses employed at the same practice and the loose affiliations of professional and proximal professional relationships could not be determined, so only those relationships which could be determined explicitly or with the narrowest extrapolation (such as assuming the construction “Dr. & Mrs. [lastname]” indicated a heterosexual married couple) were identified. This limited extrapolation means that those 629 people in family groups were in a total of 314 groups, consisting mostly of married couples, with limited parent and child relationships. Overall, there were 274 groups consisting of two people, nineteen consisting of three, and three consisting of four. Of those nineteen groups of 3, 4 were in the Viennese room where the bar mitzvah was taking place. Two of those groups were interviewed and consisted of two parents and a child in attendance at that party; the other two only have maps available, but it may be reasonable to extrapolate an expectation that those two groups were similar in makeup.

I enumerate the number of data points for each relevant kind of data and the sources for those data points in Table 11.

Table 11 Metadata details on dataset

Data	**Points**	**Source**
x	1448	Either extracted from evacuation maps or randomized within the stated starting area
y	1448	^
age	16	Sparsely documented, primarily in table lists for parties
sex	808	From interviews, names, and evacuation maps ascribed to married couples
prior_visit	1448	From interviews
behavior_type	0	not employed

Data	Points	Source
group_number	796	Assigned from maps ascribed to multiple people and interviews
group_type	796	^
group_leader	0	None identified
initial_energy	1448	Set to one hundred except for 7-year-old assigned as eighty because of smaller size
ID	1448	Identifier
role	1448	Patron, staff, or contractor
exit	1209	Determined from interviews and maps
prompt	28	Determined from interviews
table	161	Documented for some two organized parties
party	171	From organized parties and interviews
turned back x	120	From maps
turned back y	120	^
starting room	1448	From maps and interviews
ids employees y/n	3	From maps
employee location x1	2	^
employee location y1	2	^
took	14	From interviews, what people took with them.

Limits of the data

A minimum of 2,400 people were in the BHSC the night of the fire. My dataset includes 1448. This is more than half, and a substantial dataset, but not complete. I also have not provided estimated persons to make up the numbers, which does negatively impact the accuracy of modeled crowd dynamics. The crowd being significantly reduced means that people in those crowds do not interact in the same way, with the desire to avoid crush injuries and being too close to other people at odds with the desire to evacuate. Nonetheless, I have chosen to only include actual people. This is in part because, since moving back to the Midwest, I have been invited to dine at supper clubs multiple times[5] and observing my own experiences contraindicated estimation as useful: the standard deviation for my party size is six, with a lower bound of six and an upper bound of 20. A normal distribution that includes zero is improbable. The ages of attendees ranged from 3 to 79, with average ages varying wildly. Gender, too – every outing had at least one nonbinary attendee, which is hard to extrapolate to simulated data for a period where acknowledging nonbinary genders in the Upper Midwest was unlikely. And beyond my experiences to my observations – the last time we ate at a supper club[6] there was a carpet company holding its annual dinner, with upwards of fifty people, and couples dining without other company. I have determined that any simulated people added to this dataset would be making things up, and so have limited the dataset to those people I have evidence of.

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[5] Including once where our table blocked the only visible emergency exit and the power flickered, indicating overall electrical issues. I had a very exciting time.

[6] My favorite, in fact, because our usual table is right next to a glass emergency exit door that is never blocked and leads directly to the lawn with no stairs to add a point of congestion. The tables also have adequate space between them and there are many clearly indicated egress points. It is also called the Butterfly Club, and I like butterflies, but that consideration has dropped considerably in relative importance over the course of my research.

Additionally, while the parasocial relationship between tipped waitstaff and ‘their’ tables is a point of interest and showed through in the interview data, insufficient documentation was available linking specific patrons to specific waitstaff, so those relationships are not in the dataset.

Model

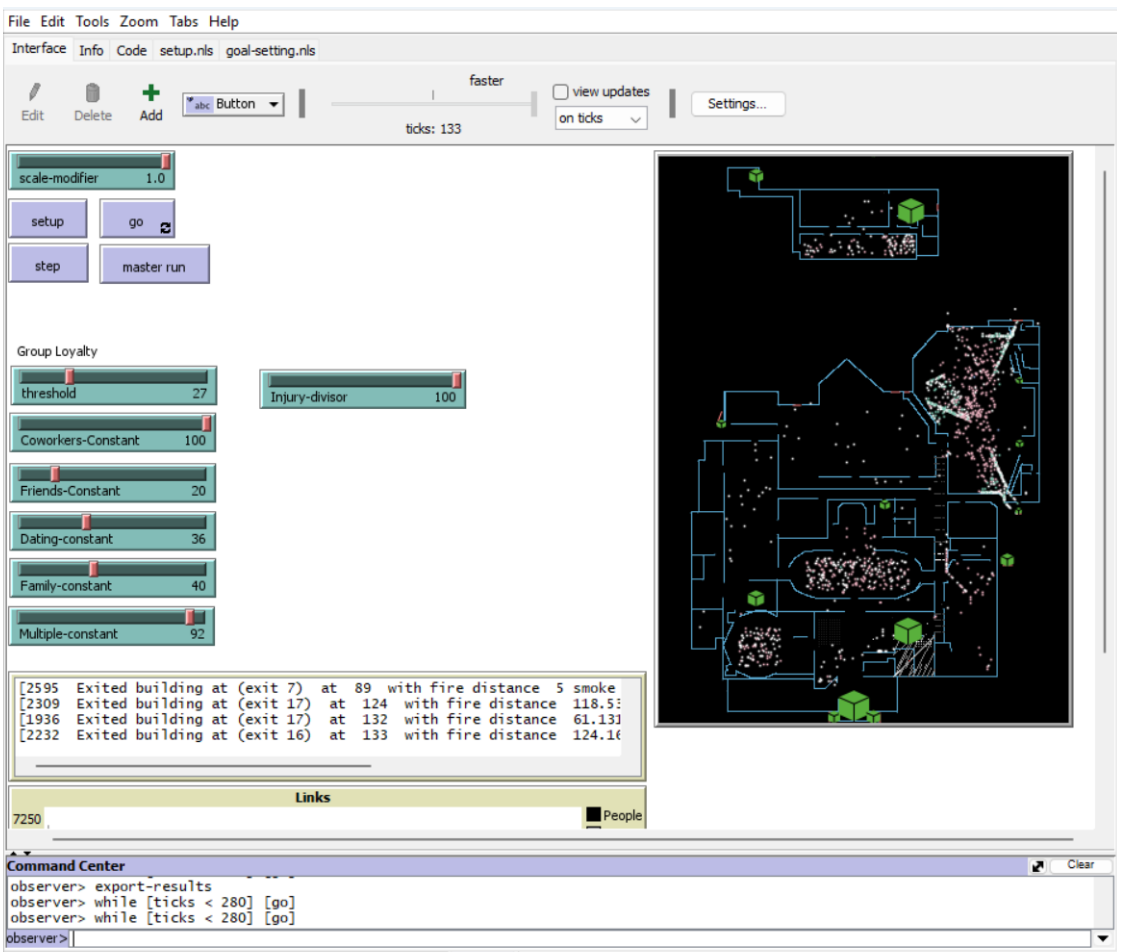

Figure 9 PrioritEvac interface at tick 133 (minute 22) of a run

Figure 9 shows the interface of PrioritEvac. It includes the layout of the building, with walls outlined in blue and staircases represented by green cubes. People are visible as dots. The number of people shown in, for example, the Garden Rooms versus the Empire Room illustrates the differences in data availability. Figure 2 shows the estimated occupancy of the Garden rooms at the start of the fire as between two hundred and three hundred. Table 7 shows the number of interviewees who indicated they were in the Garden rooms: twenty-two. With the addition of the exit maps, this number rose to twenty-three. As discussed in the previous section, there are limits to the dataset.

Fire is present in the Zebra room and hallway, but the pixel scale is small. Additionally, the order of operations in PrioritEvac covers fire with (gray or white) smoke.

The output section of the figure – the box showing parenthetical statements about exiting the building – shows the outcomes for individuals. When an individual reaches an exit or dies, PrioritEvac reports this. This allows the tracking of exit use, exit use over time, and urgency. Urgency is a combination of fire and smoke distance.

Functionally, this output also allows me to make the model faster: rather than tallying individuals at an exit location at the end of a model run, individuals are removed from the simulation after their outcome prints to the output. Removing them from the simulation means that they no longer take up processing power.

Part of modeling the fire was acknowledging that it was smoky in some areas before the fire started. Thus, in addition to the levels of smoke used to indicate toxic smoke from fire, represented as 25%, 50%, 75% and 100% to indicate a range of ‘some smoke’ to ‘impenetrable smoke,’ I also included a 10% level of smoke present in the main bar from the start of the simulation, because that was where complaints had been made earlier and interviewees in the main dining room had noted heavy smoke before notification of fire.

Another significant portion of modeling the fire was determining the most useful scale. Because of the level of detail available, the Station fire could be modeled to the second. I determined that the granularity for BHSC would be 10 seconds. This allowed for incorporation of details such as the spread of smoke down the hallway between the Empire and Cabaret rooms taking place over the course of less than 30 seconds, as indicated in interviews. It also parallels the Station fire, which was over in 3 minutes, as ignition to conflagration of the BHSC and the last people exiting under their own power took approximately 35 minutes. At ten times as long an incident, I am measuring one tenth as often. I manually reprogrammed this change.. I designed this reprogramming to be simple for future users of the PrioritEvac model as data granularity and fire spread rate vary significantly among building fires, and both changes between fires and rationale are documented in the code.

The timing of the fire was also an element for consideration based on when it was pertinent to start modeling. As discussed in Chapter 3, particularly in Table 5: Timeline of Events, the fire started at approximately 8:45pm and waitstaff discovered it shortly after, but patrons did not start to leave for several minutes after waitstaff discovered the fire. Indeed, the Crystal Rooms, right above the Zebra Room, did not start to evacuate until 9:00pm. I determined that 8:45pm was the appropriate start time, not only for completeness, but to examine how information and alarm both spread and did not spread, as compared to the Station fire where people could see the progress of the fire. The fundamental flowchart for behavior also evolved, as demonstrated in Figure 10. Some of this is cosmetic; a simpler visual path through the decisionmaking and prioritization represented, but the important difference is that prior visits no longer are considered to impart knowledge of the exits. As mentioned several times, BHSC was more architecturally complex than the Station nightclub. Exits were less obvious. But also, as noted in the white information box in the lower left corner, staff may inform people about additional viable exits.

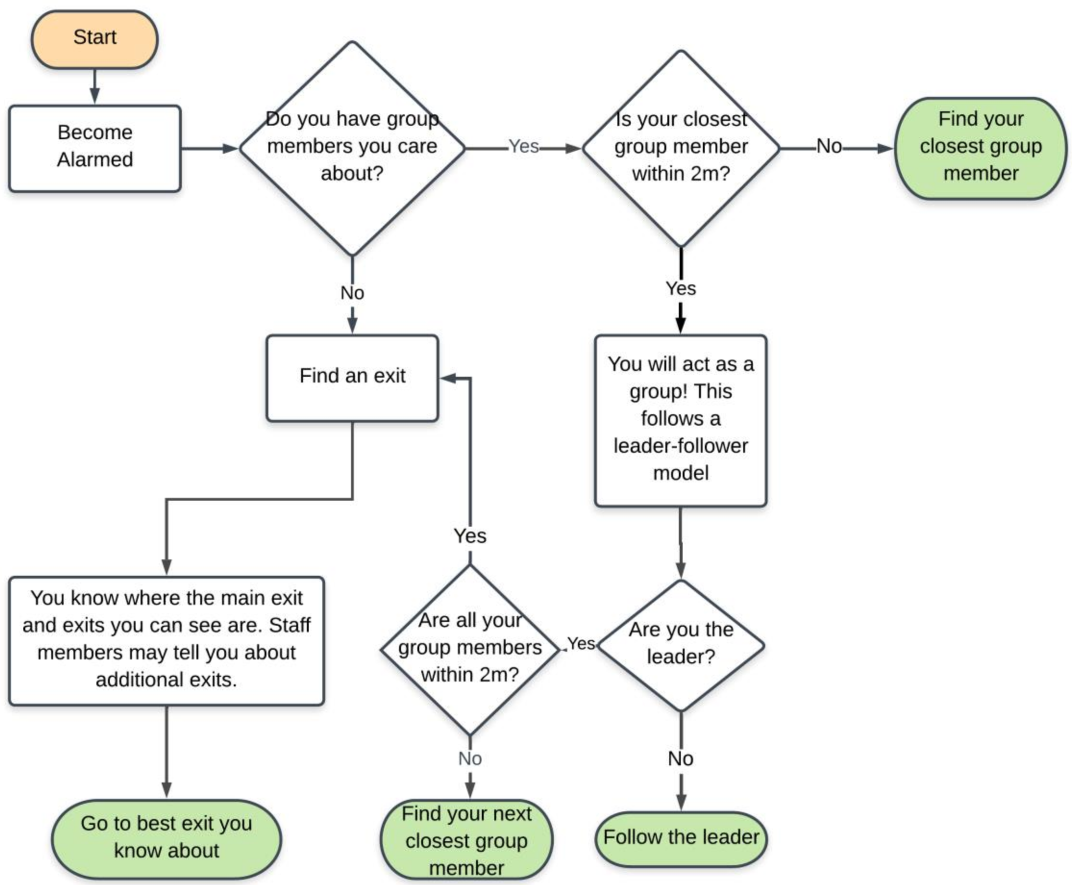

Figure 10 PrioritEvac decisionmaking flowchart as modified for BHSC.

Leadership in BHSC is determined entirely by random number generation, as quirks of personality and history determine leadership roles in many informal interpersonal interactions. The Station version of PrioritEvac included additional weight towards male gender as candidacy for leadership, but I removed that for lack of strong supporting evidence. See Appendix D, Section 2.3.4 Leadership, for full discussion. I preserved Best's (2013) finding that previous intra-evacuation group leadership is the best predictor of future intra-evacuation group leadership.

Additionally, the model now has components for allowing the inclusion of stairs and multi-story buildings.

Analysis and findings

An initial run of PrioritEvac with the BHSC data did not include a module for employees giving directions, only the 9:06pm evacuation order in the Cabaret Room. This included, as expected, less utilization of the kitchen exit and a larger number of fatalities: 635 people who had not exited the building by the end of the run. The end of a run represents approximately 9:30pm, which is ten minutes after all people who exited under their own were assumed to have evacuated (Best 1977) and thus can be assumed to be additional casualties. Additionally, zero people used the kitchen exit, in stark contrast to the 189 in the dataset who reported doing so – most of them patrons directed to do so by employees. While not definite evidence of employees directing people out of the Station fire through the kitchen, it does suggest a potential reason that every model underpredicts the documented use of the kitchen exit. Prosocial behavior in disasters is well documented, but this overall finding suggests a particular vector stemming from the social interaction that puts employees in customer-service oriented jobs in positions where part of taking care of their patrons is directing their safe evacuation.

Table 12 demonstrates the mean outputs of the model as compared to the actual results gleaned from interviews and evacuation maps. Because of the scale of the building and the number of people involved, the minimum viable resolution of PrioritEvac for BHSC takes approximately 11 hours to run. The NetLogo tool BehaviorSpace was examined as an option, since it allows for multiple runs simultaneously and quickly, but it was non-viable because PrioritEvac reflects not just social interaction but interaction with the environment.

Table 12 BHSC Results

Model	**Cabaret**	**Garden 1**	**Garden 2**	**GC**	**Kitchen**	**Main**	**South**	**Dead**
Actual	274	26	32	159	189	232	243	165
PrioritEvac mean	71	1	**15**	1	79	156	201	335
Standard Deviation	15.37	0	65.63	0	19.56	.97	10.71	77.31

Frankly, the accuracy is not what I was hoping for. Highlighted results are those which fall within 2 standard deviations of the actual outcome: the only result in this range is the number of people who exited through the second exit in the garden rooms. One of the major points of discrepancy is use of the exit between the Garden Rooms and the Cabaret Room, indicated in tables 12 and 13 as GC. I suspect that some of the discrepancy there is due to computational limits of the 20 model runs I did. PrioritEvac is set up to allow for scale modification – at full resolution, it runs very slowly but very accurately. At the smallest resolution, .1, it is very fast. I ran my simulations at .4, which took about 15 hours each to complete. At that scale, the hallway leading to GC may have been too narrow for agents to find it acceptable, because the requirement for walls to have a non-zero size means the scaling down of the building is not perfect. Additionally, the fact that outcomes are mutually exclusive means that variations influence each other; the two largest standard deviations being in Garden 2 and death suggest that some cases of evacuation were eventually choices between those two outcomes.

But due to the current nature of the reported exits and deaths, the 1320 people whose reported exits are logged in the actual dataset are not reflected in the number logged consistently by PrioritEvac. Thus, Table 13 shows the percentage of people with each outcome per run.

Table 13 BHSC Percentage Results

Model	**Cabaret**	**Garden 1**	**Garden 2**	**GC**	**Kitchen**	**Main**	**South**	**Dead**
Actual	21%	2%	2%	12%	14%	18%	18%	13%
PrioritEvac mean	8%	0%	**1%**	0%	9%	**18%**	**24%**	39%
Standard Deviation	1.09	.01	5.83	.01	2.48	1.98	2.63	7.16

Comparing percentage outcomes reveals outcomes more in line with the actual, specifically in usage of the main exit and the south exit from the Cabaret room.

Total square difference is a measure of deviations along various metrics that doesn't privilege any particular metric; for the Station fire, the PrioritEvac square difference was 985. For the BHSC it is 115,651. This is non-optimal. But, as PrioritEvac is also the first ABM available of the BHSC fire, it is the best available. The availability of the dataset should lay the foundation for future researchers to improve on these results.

To the actual implications of these findings: directions have likely been underestimated. PrioritEvac as it is makes people aware of the exits as proxy for being directed to them by staff, but these results suggest much stronger helping behavior. The consistency of the overprediction of death combined with how much the predicted number of deaths shrank with the initial inclusion of helping behavior suggest that it could – and should – be modeled as a stronger force. Additionally, in the poll that Best (1977) reported on, 76% of 1117 respondents reported that an employee helped them during their evacuation.

PADM

I discussed PADM extensively in Chapter 2 as a framing device in which PrioritEvac deals with the point of decision most directly. Because it is a conceptual framework, validation of its accuracy is impossible: the question of validation must deal with whether it is a useful way of thinking about the scenarios it deals with. Nothing in the dataset gathered suggests any emergent patterns that would run contrary to PADM. It also provides a broader explanatory framework that is congruent with the way behavior is conceptualized and implemented within PrioritEvac; Table 1 highlights the specific comparison between PrioritEvac and components of PADM. PrioritEvac can be understood therefore as operating withing the broader framework of PADM, and thus this research is another demonstration of the applicability and usefulness of PADM as an overall way to understand human behavior in the face of risk.

Answering my research questions

I started this dissertation with questions based on my previous research and the literature describing the field.

1. What impacts do social relationships have on decisionmaking and prioritization in evacuation from fire?
    a. Proposition: people prioritize the safety of the people with whom they have relationships and will make decisions to try to promote their safety.

The interviews data supported this, with people discussing both exiting as part of a group and searching for group members not immediately present before evacuation. Parents discussed searching for their children the most; this cannot be disambiguated as a matter of group preference or coincidence, since only children were noted as being absent from a greater group[7], and the Kentucky State Police did not interview minor children. But even in clear-cut groups, once all members of a group evacuated safely, attention turned to making sure more people evacuated safely.

There were four arrests for larceny after the fire, but there were also firefighters who had been patrons who went back in without protective equipment in order to pull people out as well as the entire dinner party of doctors and nurses who set up an ad hoc triage center and hospital in the chapel on the grounds. People typically

[7] From the bar mitzvah in the Viennese room, young men parted from the rest of their families to go stand in the hallway outside the Cabaret Room and just inside the entrance to catch the show, per interviews.

prioritized their in-group over strangers, but with that immediate need resolved, many also engaged in macro-level prosocial behavior.

2. How do perceived roles and responsibilities influence building fire evacuation decisionmaking and behavior?

    a. Proposition: waitstaff will extend their roles in an evacuation to include helping direct the evacuation.

Employees extended their roles (Dynes 1970). Notably, bussers, waitstaff, and kitchen staff helped to direct evacuation, both prompting evacuation and giving directions to exits, and several bussers fought the fire directly. Doctors and nurses also expanded their roles, taking on the familiar work of caretaking in the unfamiliar setting of the BHSC chapel.

3. Are patterns of group behavior observed and modeled in the Station fire also applicable to the Beverly Hills Supper Club fire?

    a. Proposition: general group behavior will be consistent across decades and incidents. Additionally, BHSC data will provide insight as to why all extant models of the Station fire underpredict kitchen exit use in that employees may have directed patrons to use that exit.

Group behavior such as group members prioritizing the safety of other group members is consistent. This is primarily evidenced in the interviews, but also in the evacuation maps, starting with their structure. Group cohesion is integral to assumptions about how people behave that of the 870 exit routes described from maps in the dataset, 547 of them come from only 260 maps. This resulted from the expectation that groups would move together – an expectation so strong that Johnson et al. only gave small groups only one map to fill out. In most cases, this was accurate: the groups did not split up. In the outlier cases where there was divergence, it was due to other group factors; the woman parting from her husband to find her son.

4. Does PrioritEvac as it exists now model the evacuation of BHSC with any degree of accuracy (such as a number of dead within one hundred of the actual dead).

    a. Proposition: deaths will be overpredicted because helping behavior is not currently a component.

Deaths are 3.8x overpredicted in PrioritEvac without direction-giving behavior. Some of this overprediction may be due to the way exit knowledge is handled, but Best (1977, p 67) noted that not all exits were visible, and in fact the hallway to the south of the Cabaret room – the one that lead to an exit – was concealed behind an unmarked wall panel. This malarkey supports a model that does not allow for knowledge of the exits unless one is employed at the venue, highlighting the importance of helping behavior in the evacuation of the BHSC.

Table 14 Summary of research questions and findings

Question	Proposition	Evidence	Verdict
1. What impacts do social relationships have on decisionmaking and prioritization in evacuation from fire?	People prioritize the safety of the people with whom they have relationships and will make decisions to try to promote their safety.	Interview data	Supported
2. How do perceived roles and responsibilities influence building fire evacuation decisionmaking and behavior?	Waitstaff will extend their roles in an evacuation to include helping direct the evacuation.	Interviews, difference between sample run without extension and actual results	Supported

Question	Proposition	Evidence	Verdict
3. Are patterns of group behavior observed and modeled in the Station fire also applicable to the Beverly Hills Supper Club fire?	General group behavior will be consistent across decades and incidents. Additionally, BHSC data will provide insight as to why all extant models of the Station fire underpredict kitchen exit use in that employees may have directed patrons to use that exit.	Interview data	Supported
4. Does PrioritEvac as it exists now model the evacuation of BHSC with any degree of accuracy (such as a number of dead within one hundred of the actual dead).	Deaths will be overpredicted because helping behavior is not currently a component.	Deaths dramatically overpredicted (600+ in model, 165 actual)	Supported

I was able to answer these questions to my own satisfaction. However, other questions arose while conducting this research, discussed in the next chapter.

Chapter 7

DISCUSSION

Dr. Joe Trainor reinforces, in all his Introduction to Emergency Management courses, that knowledge is the accumulation of small pebbles; that rarely will we have the opportunity to unearth a sublime and perfect boulder of discovery, but that our collective knowledge grows greater through the accumulation of small pebbles. In honor of that, the first items for discussion stem from Best (1977)'s two broad categories of recommendations for future research, the role of risk perception in effective escape behavior and role acceptance and fire emergency behavior (p. 82).

Recommendations for future research from Best (1977)

Because I drew significantly from this book in reconstructing the timeline of the fire, answering these questions seemed not only apropos in the spirit of building a body of knowledge but also a direct way to show how this dissertation research is a contribution to the field.

Role of risk perception in effective escape behavior

The delay in evacuation because some people initially took the instruction to evacuate the Cabaret room as part of the ongoing comedy show had an incalculable impact on the number of fatalities. Interviews suggested that Bailey's insistence corrected the misapprehension quickly, and people proceeded to evacuate from the Cabaret room to the exits as directed. Risk perception was in many cases communicated by the staff; in those cases where it was not, it was arrived at as a group consensus about too much smoke, and groups evacuated early and safely. To apply PADM to those small groups who evacuated in advance of general evacuation, risk identification was primarily based on smoke. Since these groups were all in the main bar or main dining, protective action search and assessment would be straightforward: the main entrance was still nearby. Implementation was the sticking point, in that the group discussions reported to the Kentucky State Police circled around whether to leave right away. But the nature of evacuation meant that all those interviewed who had participated in these sorts of discussions had reached a consensus that it was time to implement protective action and leave and everyone in that group had survived. Risk perception was important, as was decisive follow-through.

To build on this research more decisively in future, targeted information-gathering after a fire would be paramount. The evacuation maps Johnson *et al.* collected were invaluable, but linking waitstaff to the patrons they interacted with would help build a more comprehensive dataset, as would detailed interviews with musicians.

Role acceptance and fire emergency behavior

One of the questions Best raised was whether role acceptance would be seen in other supper clubs. The Station was a nightclub rather than supper club, and what I can assert with certainty in that regard is that it does not have strong evidence against role acceptance as Best framed it, with helping behaviors bundled in.

Other Questions

Other questions, however, arose during this research. To provide context for the other questions that arose, I will explain the single interview I conducted for my thesis research. In October of 2018 at 2am in the Philadelphia airport I was waiting for a flight to Toronto. To stay awake, I was blithering about my research to a fellow traveler a few seats away. We spoke at conversational volume, but given the hour, few other people were speaking. A woman in the next row of seats over around and asked if I was talking about the Station nightclub fire.

I said yes.

We ended up sitting across from each other, speaking very quietly. She had worked for the radio station that had been covering the concert that night. She had known and cared about the two interns who had been present and helping with the booth. During our conversation, she ended up in tears, because this was an emotional topic for her: the Station fire devastated her community. I told her, in all sincerity, that my research was about building better buildings so this kind of thing never happened again.

I think I was wrong.

The NFPA updated the Life Safety Code after both the BHSC and Station fires, but neither building was originally in compliance with the codes in place before the NFPA amended the Code to prevent these specific tragedies. No better understanding of human behavior or more accurate model of evacuation can circumvent oversold venues and slapdash renovations. No engineering approach or construction policy improvement can address club owners who disregard both for the sake of profit.

The matter of renovations can theoretically be addressed by more consistent application of existing regulations; building codes do exist. Additionally, as demonstrated by Table 13, existing regulations provide for the safe evacuation of the populations they are designed for. The reforms to the Life Safety Code may have prevented more fires from starting in the years between 1977 and 2003, but a higher percentage of people died in the Station fire than the BHSC fire – 21% of the occupants of the Station died, as opposed to as few as 5.8% of the occupants of the BHSC. Even if many fires were prevented, devastating consequences still occurred.

Table 15 Safe capacities and fatalities

Fire	**Occupancy limit**	**Number of people**	**Difference**	**Fatalities**
Station	317	465	148	100
BHSC (specific to Cabaret Room)	511 (Best 1977, p 64)	1200-1300	689-789	99

Thus, while buildings could theoretically be made safer, be made safe for as many people as can fit comfortably – well, what is comfortable? What is profitable? Should all buildings be designed to safely hold and safely evacuate as many people as can be packed in physically, tight as tinned sardines? How likely are people to crowd that tightly? And, since people demonstrably will crowd, how often will they do so, and with what impetus? The show that night in the BHSC was supposedly a good one, and the Saturday of Memorial Day weekend is an attractive night to go out and celebrate with a good meal and a good show. But it is only one night a year. Then, should buildings be planned for this edge case? People died, so obviously something should be done. And the NFPA amended the Life Safety Code to reflect those design principles which could have ameliorated loss of life. Even so: the BHSC did not meet the code even before the amendments. So, this approach would not address the case it studied. The Station also did not meet the code in place at the time of the fire. But in the case of the Station, pyrotechnics were set off inside the club, igniting the blaze that eventually killed one hundred people.

Building Codes

States and municipalities adopt building codes as law to further public safety. The Life Safety Code is not actually a building code; it is a consensus standard but explicitly not regulatory. The reasons behind this are complex but boil down to states' rights – the reasons are also unrelated to the general state of implementation. Individual jurisdictions can – and do – adopt iterations of the Life Safety Code into law, with and without amendments. Consensus standards provide a baseline defined by experts that officials can adopt locally. Jurisdictions can then implement codes how they see fit, as well as adopting measures to require buildings to exceed the Life Safety Code as written; this was what happened in Kentucky after the BHSC fire, with both new requirements about inspection and a unified Office of Housing, Building, and Construction (Carroll 2007). This new approach may have contributed to the 29% decrease in annual average fire deaths between the periods of 1981-1985 and 2015-2019 (NFPA 2021). This could represent a potentially hopeful avenue of institutional learning.

Except that in 2016 Governor Matt Bevin replaced the whole Office with an advisory committee (Bevin 2016, Coleman 2017).

Definitions

One of the first things one must do in addressing disasters is define what a disaster is. In Chapter 2 I asserted that the scope of this research focusing as it does on building fires is very strictly about hazards interacting with a built environment.

Luckily, there is building design literature that focuses on how people use space as an important component of both design and safety (Keating 1982, Sime 1985, Stollard and Johnston 1994). One potentially missing link in this research is the different ways different stakeholders can use a building at the same time. Patrons, for example, are generally present in a supper club to have a meal and a nice time. Their active role in the design and situation of the building may consist of queueing, crowding, and sitting. Employees are there to earn money and interact with customers. Their active role in the situation of the building consists primarily of guiding people and moving small items, with some interaction with the placement of chairs, tables, and serving dishes over the course of the night. Management has significantly more control over the situation of the building, with control over the approximate number of tickets sold and bookings made, the number of tables ordered and set out, and what renovations are done when and by whom. Management controls risk. Management is using the building to generate profit. While patrons having a good time is the source of revenue and thus profit, there is motivation to maximize the number of patrons and minimize the amount of capital outlay to secure those patrons. In the case of both the Station and BHSC, this meant some unpermitted renovation work.

This is not to say that the renovations were done with deliberate disregard for safety. On the contrary, the primary implication is that the first part of PADM, risk identification, is something that people are generally unaccustomed to and need to be primed for.

Leadership

One of the themes in the literature and one of the items coded for in examining the interview data was leadership. But aside from the role extension of the BHSC staff, little leadership stood out in the interviews. People discussed leaving together as opposed to leading or being led out; where there was directionality, the staff largely provided it. This, then, was not intra-group leadership but an expression of the parasocial relationship between employees and patrons, of interacting with customers as part of the way employees interact with the space of the club.

Limitations and modeling

The primary limitation to both this research and the modeling of building fire evacuation overall is that this approach to building fires does not help to mitigate casualties. People still make bad choices. Particularly, nightclub owners and managers still make choices that prioritize profit over human life. Engineering cannot correct for that.

Separately, the detail and fidelity of fire, smoke, and person movement was not available for BHSC the way it was for the Station fire.

Recommendations for future research

The most direct recommendation I have for future research is to explore policy solutions to the problem of overcrowded venues with unsafe conditions. This might take the form of affording fire marshals the budget, staff, and authority to do enforcement activities on a broad scale or more regulatory scrutiny of venues such as restaurants, supper clubs, and nightclubs. Enforcement as an overall approach to any problem raises questions of equity and is vulnerable to policies that undermine regulation.

Advances in engineering and building have improved the safety of buildings. But accelerating that rate of improvement requires research beyond the physical.

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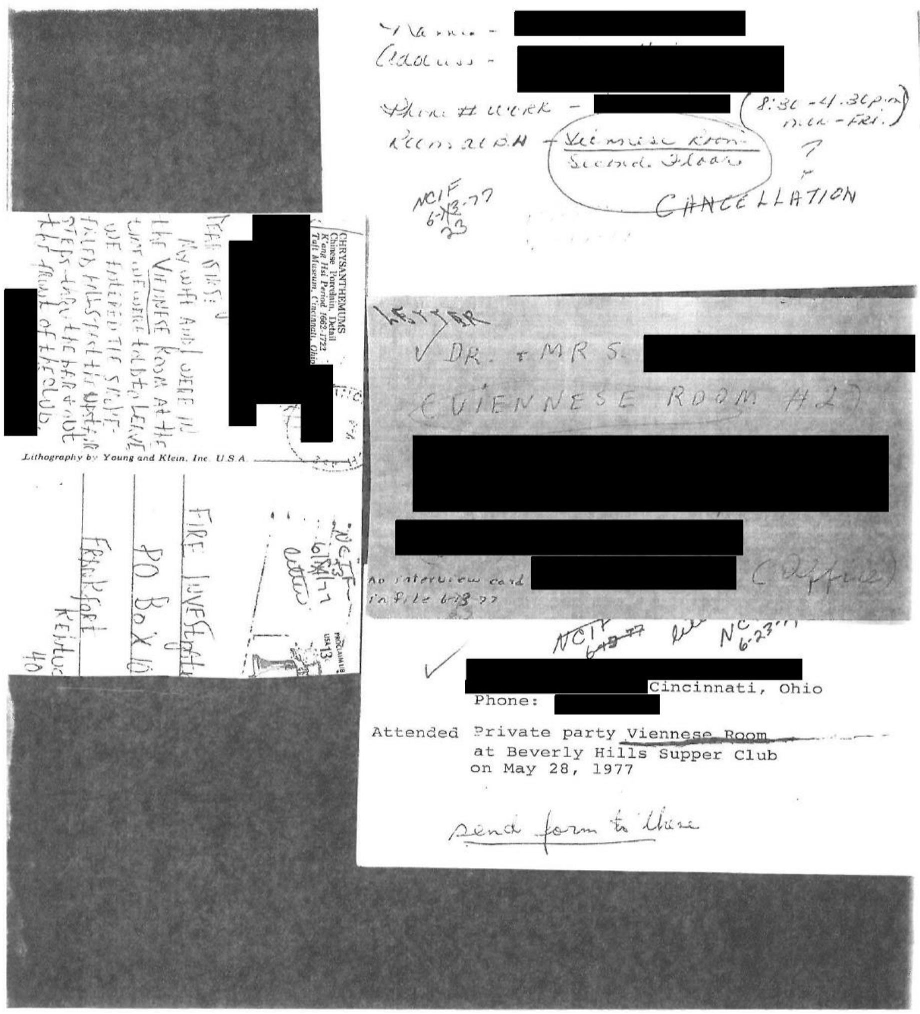
Appendix A

ARCHIVAL SAMPLE DATA

These are an image of one of the sets of postcards scanned into the archival documents, as well as an embedded file containing one redacted questionnaire.



Name - [redacted]
Address - [redacted]
Phone # work - [redacted] (8:30 - 4:30 p.m. Mon - Fri.)
Room also - Viennese Room Second Floor ?
NCIF 6-23-77 23
CANCELLATION

[redacted]
Lithography by Young and Klein, Inc. U.S.A.

LETTER
✓ DR. & MRS. [redacted]
(VIENNESE ROOM #2)
[redacted]
no interview card in file 6-23-77 [redacted] (Office)

NCIF 6-23-77
[redacted] Cincinnati, Ohio
Phone: [redacted]
Attended Private party Viennese Room
at Beverly Hills Supper Club
on May 28, 1977

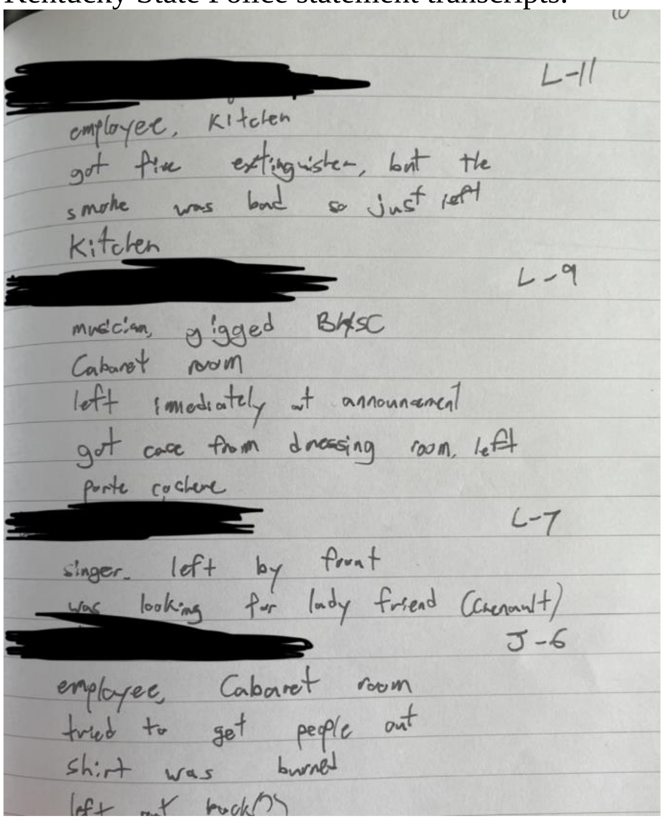
send form to them

Johnson 32121 M13132 REDACTED.pdf

Appendix B

CODING EXAMPLE

Included here is an anonymized page from my first round of notes on the Kentucky State Police statement transcripts.



[redacted] L-11
employee, kitchen
got fire extinguisher, but the
smoke was bad so just left
kitchen
[redacted] L-9
musician, gigged B~~K~~SC
Cabaret room
left immediately at announcement
got case from dressing room, left
porte cochere
[redacted] L-7
singer, left by front
was looking for lady friend (Chenault)
[redacted] J-6
employee, Cabaret room
tried to get people out
shirt was burned
left out back(?)

Appendix C

PRIORITEVAC CODE

The complete code is available https://www.comses.net/codebases/5f78b0ef-60b6-4049-9157-a2e82e7cc286/releases/1.0.0/ and through the Digital Object Identifier https://doi.org/10.25937/dhtz-a433.

So far it includes only the anonymized Station data. The model itself is peer reviewed.

Complete code for the modified BHSC data is available at https://github.com/efyoungud/prioritevac/tree/BHSC.

Appendix D

ODD PROTOCOL FOR PRIORITEVAC

This appendix is exactly as it appears in my thesis (Young 2019) and is provided for a more complete explanation of the various functions. It does not reflect the changes made for the BHSC fire as opposed to the Station fire and is also the reason ‘thesis’ rather than ‘dissertation’ appears throughout this appendix.

1 Purpose

The following sections lay out the variables and implementations used based on the structure laid out in "The ODD protocol: A review and first update" (Grimm et al., 2010). The ODD protocol provides a formalized framework for describing exactly how an agent-based model works and why without the need for extensive example code, and provides a general idea of what to expect (Thober et al. 2017).

2 Entities, State Variables, and Scales

2.1 Physical Environment

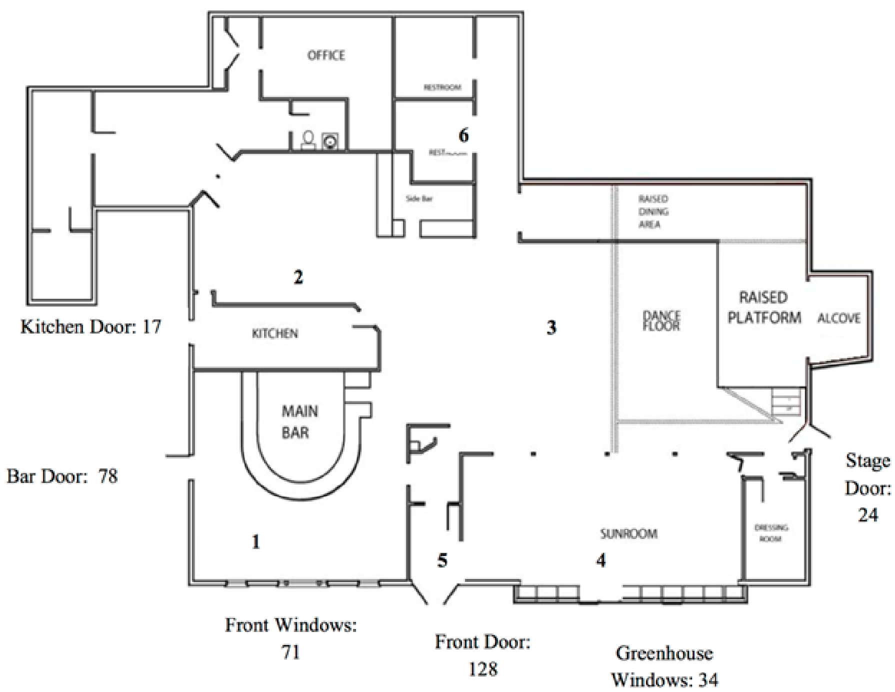


Figure 11 Appendix D Figure 1: Layout of Station nightclub (NIST 2004). It includes the egress exits from the building, the number of people who used each of them to escape the fire, and the various subecologies of the building.

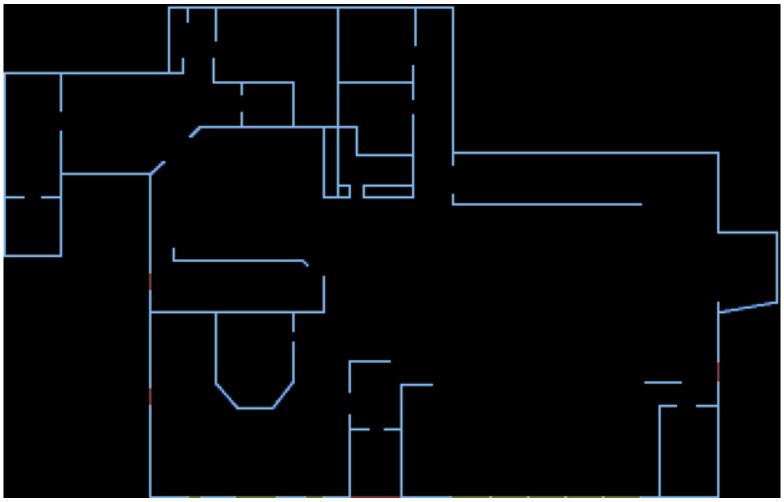


Figure 12 Appendix D Figure 2: Station nightclub layout as rendered in NetLogo

The physical environment mimics the ground level of the Station nightclub in Warwick, Rhode Island. An image of the nightclub (Figure 1) was traced to give lines usable in the simulation. The simulation treats the length of one patch as one-tenth of a meter, which is reflected throughout the model. For instance, agents have a size of 5 - meaning they take up a circle with a diameter of .5 meters around a central point. To avoid confusion, further descriptions of sizes and units will be given in meters.

Additionally, the simulation's granularity is such that one tick is equal to one second of real time. This is in part because of the extremely short time-frame of the event itself, for almost all social activity occurred in the first three minutes after ignition (Grosshandler et al. 2005).

The building had four doors (designated by red in the simulation) and eleven windows (yellow). The walls of the building (blue) remain intact throughout the fire.

Three of the windows were broken before the fire reached them and used as means of egress: this is reflected in the simulation by having the windows become exits at times that correspond with those times indicated by NIST documentation, a video of the nightclub fire, and witness accounts (Thompson 2013; Thompson 2010). In PrioritEvac, when these windows become exits, they change their color from yellow to red to signify occupants are able to leave through them. At second 94, a window in the bar was broken, as was one in the sunroom. At second 105, a second window in the bar area broke. This program component was developed by Matt Saponaro and Nihar Junagade.

2.2 Fire

The fire and smoke models are based on the temperatures within in an area provided by the NIST documentation of both the fire and the detailed simulations they did of the fire. Based on NIST's temperature model, we assume that there were fires in locations exceeding 200° Celsius. The temperatures were taken at 1.5m height for the first 90 seconds, then at .6m height for the rest of the fire, on the assumption that 1.5m would be about eye level and then when the fire progressed, people would crawl, making eye level approximately .6m.

The fire started on the stage near the pyrotechnics and eventually spread throughout the nightclub.

2.3 People

The basic agent in this agent-based model represents a single person present in the building during the fire. Most of the information about these victims come from earlier studies of the fire (Aguirre et al. 2011, 100-118 first presented the information. See also El-Tawil et al. 2017; Fang, El-Tawil, and Aguirre 2016, 40-47, Aguirre et al.

2011, 415-432). Most of their behavior is governed by the design concepts (see 6.4) included in the simulation. Agents have a) traits obtained from the input data, b) traits assigned by the simulation, and c) behavior governed by the simulation wherein an agent's behavior and its response to their environment is influenced by their personal traits.

Traits assigned by the simulation include speed limit, vision, and the path they are on. Agents are also assigned a diameter of .5 meters. This diameter relates to the physical space people take up, approximately half a meter at the widest point for an average adult (Oberhagemann 2012). This does not account for the distance people prefer to keep from each other or the density of crowds that people tend to prefer.

Density of crowds tends to be measured in square feet per person, with the standard for an extremely dense crowd being 2.5 square feet (McPhail and McCarthy 2004, 12-18). Those 2.5 square feet translate to .232258 square meters, which means that a circle with that area would have a diameter of .54 meters, making social space slightly greater than physical space. Less dense crowds can take up 7.5 to 10 square feet (.7 to .9 square meters) per person. Within the Station nightclub fire, we can infer crowd density near the stage from film footage and attendance numbers as well as having a record of who was in what area of the club when the fire started; people in that area near the stage experienced high density. But the high density is not absolute, so that people's preference for personal space is able to influence their placement: thus, people are assumed to preserve some space between them as they are distributed throughout their sub-ecology. One of these sub-ecologies is a distinct area, such as the dance floor or the main bar. Social space in the more fluid and changing environment of the evacuation itself and is not pre-set by the simulation. So agents are assigned a physical size and the simulation's adaptations include a slight preference for social space. This means that, by preference, agents avoid being in the same place as other agents when possible, avoiding some crush injuries and walking into each other.

2.3.1 Speed limit

Based on Isobe et al. (2004), this program assigns a randomized speed limit of between 1.1 and 1.3 m/s to each agent. This is also congruent with NIST's (Lord et al. 2005) suggested speeds for modeling this fire, which starts with a default of 1.0 m/s and additionally assigns probabilistic speeds within different age categories, as well as Gwynne and Rosenbaum's (2016) speed assessment of approximately 1.2 m/s unimpeded. This program uses a narrower range than the .95 m/s to 1.55 m/s range used in the scalar field model developed by Fang (2015). Instead it keeps the ranges more in line with the findings of Isobe and Gwynne and Rosenbaum. Speed limits are assigned rather than speeds, because the crowd was densely packed and actual executed walking speed needed to be responsive to the walking speeds of other agents in the evacuation. The assumption is that a person cannot walk faster than the person directly in front of them. Speed limit does not change over the course of the simulation. Using speed limits allows for the possibility of scenarios in which disability or age will impact mobility and thus maximum speed not just of the person but also of agents behind them.

2.3.2 Vision

Vision is impacted by distance, angle, and smoke. It starts with agents able to

see in a cone of 10m, with an angle of 180° to include peripheral vision. These two dimensions decline linearly with the amount and proximity of smoke, to a minimum of 0, meaning that an agent would be completely blinded by smoke. This updates dynamically: agents see to their capacity whenever they need to. This means that it is not a stored variable, so that outdated values are never an issue.

2.3.3 Goals and paths

The A* pathfinding algorithm seeks the most efficient path from the existing point of a person to their goal, avoiding fire, walls, and other agents in the simulation which represent people in the precipitated gathering as much as possible. The algorithm runs as soon as a person determines that they are going to move, and then every tick thereafter until they die or exit the building.

The goal is a stored variable and updated every tick, though this does not imply that it changes every tick. If someone is seeking a loved one, they continue doing so, and only turn to an exit when there is a substantial reason to change goals. How the goals are chosen and changed is detailed below under objectives, section 6.4.4.

The next desired patch is the immediate goal towards which the person is facing. It updates every time a person moves through that space.

2.3.4 Leadership

Leadership in small groups is an essential part of group behavior. For this simulation, people are given a numerical artificially constructed leadership score, with points assigned for being an employee of the club (Chu et al. 2015) and for having previously visited the club, based on the assumption that those known to be more familiar with the club would be more trusted by their group-members to find an exit.

Also, based on Enarson (2008) and Goktepe and Schneier's (1988, 29-36) findings that men are more often leaders in responding to emergencies, male gender is also considered as contributing to likelihood of emergent leadership in groups faced with the Station emergency. This gender and other assumptions leading to this synthetic approach to leadership will be reexamined during the simulations to see if they make a significant contribution to the patterns observed, in an effort to simplify this leadership function.

People are also assigned a randomized number - less than any other single

factor - that contributes to their score. This is primarily to serve as tie-breaker when people have the same base attributes, but also mimics the more ephemeral qualities of emergent leaders who have no formal authority but may use charisma or a more goal-oriented mindset to take leadership roles in crisis (Norton, Ueltschy Murfield, and Baucus 2014, 513-529). Additionally, anyone already in the role of group leader has their leadership score doubled, both to reduce turnover (except in extenuating or extraordinary circumstances) and to reflect Best's finding that being a leader already was the highest single factor in whether or not someone was selected as a group leader (2013).

3 Process Overview

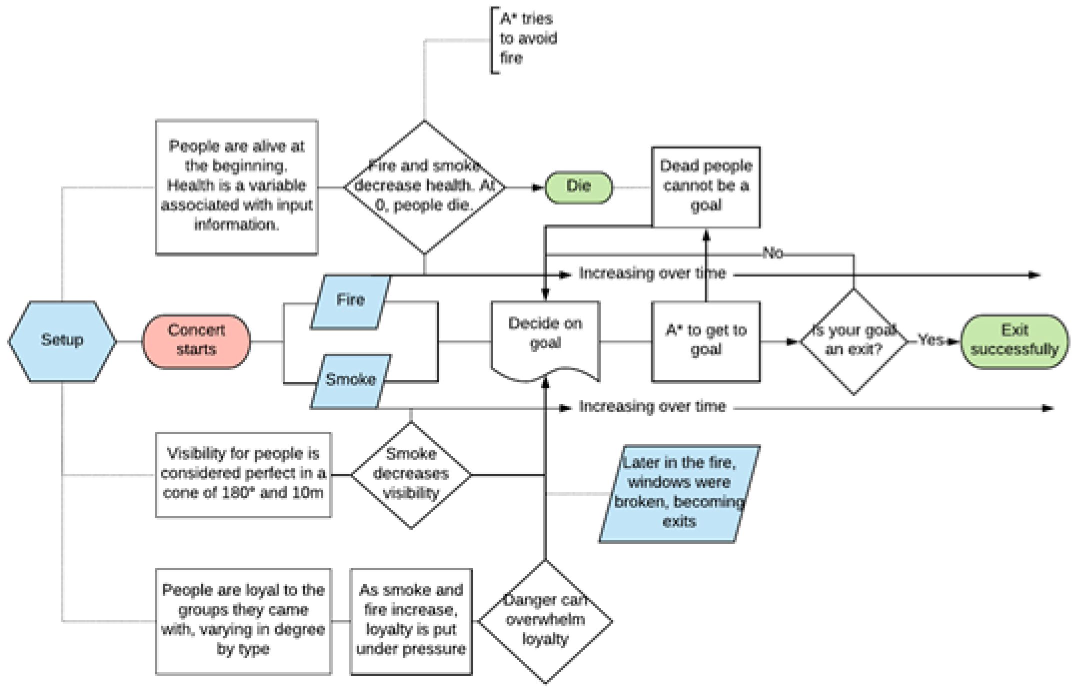


Figure 13 Appendix D Figure 3: Overall process flowchart

The Figure 3 flowchart represents the overall flow of logic through the simulation, starting with the setup and moving through both the simulation and time as read from left to right. The setup function calls in external .csvs that establish the physical environment, smoke, fire, and agents. More details are in section 6.6.2.

to setup

Clear-all

reset-ticks

set-default-shapes

```
 Read-data-from-files “file-name.csv”
 set max-wall-distance (max [size] of walls) / 2
soclink
 ask people [preferreddirection
set-speed-limit
set speed 1 + random-float 4
set leadership-quality 0
set-group-constant]
 ask patches [set values to 0]
end
```

Figure 14 Appendix D Figure 4: Setup Command

The setup is the basis for everything that comes next, and so the code in Figure 4 is here elaborated upon. First, the setup clears everything else: all of the data and changes from previous runs, so that they will not influence the new run of the simulation. This means that there is no carry-over or learning on the agents' part between runs.

Time, as represented by ticks, needs to be reset separately. It is reset to 0 by the setup command. This allows the simulation itself to be run for an arbitrary number of seconds before the operator decides that a particular simulation instance is done.

Next, default shapes are assigned to all of the components. Walls, windows, and doors are set as lines, since that is the shape they take. Fire and smoke are both assigned the shape “square” so that they visually overlap with the patch that they occupy. Agents are assigned a default shape of a circle to represent an approximation of a top-down view.

Once these default shapes are assigned, the fire, smoke, building, and agents can be read in from .csv. More details about that are in section 6.6.2.

```
to go
tick
set fire heuristics
 ask people [prioritize-group
  ifelse alarmed? != true        [alert]
                                 [move]
      experience injury]
 if ticks = 94 [ ask windows with [who = 57 or who = 34] [ set as exits]]
 if ticks = 105 [ ask windows with [who = 59] [ set as exits]]
 recolor-patches
end
```

Figure 15	Appendix D Figure 5: Master Command

Figure 5 is the overall primary command to run the simulation.

The physical environment changes first, so that agents are responding to changes that they can perceive. First, a second advances.

The fire spreads, and so the heuristic of danger associated with each patch updates.

Agents will determine whether the danger they perceive and other factors overwhelm their group loyalty - group loyalty being the default if they came with a group. The level of group loyalty is one of the experimental variables assigned in the interface, to test which levels most closely correspond with reality. This line of code tells them how much they currently are prioritizing their group, and orients them to the people around them.

The next line determines if agents are alarmed. Agents do not begin to evacuate unless they are alarmed by their surroundings; that is unless they perceive some threat. The 'alert' function allows agents to assess their surroundings. Things which are considered alarming are fire, smoke, and nearby agents who are alarmed. Agents require multiple of those inputs to become alarmed themselves - smoke without fire might be ignored, particularly in context of a concert, in which the fire itself was initially considered a regular part of the show's pyrotechnics. Furthermore, a single person becoming alarmed might be dismissed as irrelevant. So the program requires that agents notice multiple alarming sources before they become alarmed and start attempts to escape.

Once they are alarmed, though, they start to move, and remain alarmed for the duration of the simulation. They select a goal according to the objectives and process in 6.4.4 and their goal is stored. Then, using the A* search algorithm, agents find a path to their goal. Movement is accomplished in stages. The next desired patch is the first patch beyond the one where the agent is standing that is on the path to their goal. A person then travels to their next desired patch. They travel at their set speed in meters per second, but the code is phrased as:

```
repeat speed [move-to next-desired-patch set-next-desired-patch]
```

This allows agents to follow the paths they set, avoiding obstacles.

Agents then experience injury from the smoke and fire in their environment.

The windows break in accordance with records and NIST documentation. Even though they were broken by people, they are treated as part of the environment and not as a result of behavior.

They break at two different times, in accordance with the best documentation available.

'Recolor patches' is a final step that functions primarily for visual examination of the model and generating images. Patches that have fire are recolored red, patches that have smoke are recolored a shade of grey on a gradient that corresponds to the local density of smoke, with white indicating smoke dense enough to occlude any vision.

4 Design concepts

4.1 Basic principles

The basic principles of the model are that agents behave in predictable ways based on individual imperatives that can be determined using sociological principles. Those individual imperatives are broken down into, first and foremost, the desire to live. This is expressed in the desire to not be in a burning building and the preference to be far away from fire. Agents are also expected to have interpersonal relationships that they value - they want those agents to live as well.

Additional principles include that smoke makes it hard to see: it restricts both the depth and field of vision in a linear fashion as it accumulates over time.

4.2 Emergence

Group behaviors are an emergent phenomenon. Those facets of code contributing to emergence are expressed in the movement of individuals; the results of that emergence will be addressed in the evaluation section.

4.3 Adaptation

The A* search algorithm is the primary way agents adapt to their environment. The basic A* algorithm uses two different components that make it ideal for pathfinding. The first component is equivalent to counting the steps to a destination: the more steps between the starting point and ending point, the more a path 'costs.' The second component is a heuristic, of which the basic building block is distance: paths that minimize that distance are preferred. A* selects the next possible place to go that has the lowest total steps plus heuristic. It then only explores additional possible places to go from it to the next place, rather than exploring in all directions like some other search algorithms. Since it explores a limited number of places A* is faster and takes less computing power than other search algorithms, which is important for the overall simulation. A* is also fairly accurate to human behavior, since humans use similar heuristics.

This implementation of A* tries to be more accurate to human behavior by using an enhanced heuristic. The heuristic is enhanced by taking into account not just distance to the goal but also distance to fire and smoke and level of crowdedness. So a person will end up preferring to go to a place that is primarily closer to their goal, but also one that is farther from fire and less crowded. This becomes important because the nightclub did not operate like a maze, where the right path would be closely delineated. Instead, it had a lot of open ground, allowing for different degrees of preference to provide nuance in regards to the paths agents took.

It's important to note that A* does not impact objectives. Instead, A* is the mechanical way agents pursue those objectives and adapt to their environment as they try to accomplish them.

Objectives being so intimately tied to groups, it's worth explicating the mechanics of groups. There are several types of groups for those who did not come alone. There are coworkers, friends, dating partners, family members or spouses, and agents with multiple types of relationships. This last would be typified by, for example, someone who were in the company of family and work associates, making their group at the Station both business associates and family.

Group prioritization is managed in a multi-tiered way, and it does impact objectives. For each type of group, there is a preliminary value assigned indicating level of commitment to the group. That level is adjusted in the interface, to allow for ease of testing with the finalized software.

The group constant is the numerical measure of a person's loyalty. That constant is then impacted by proximity to fire and degree of smoke - basically, how dangerous a situation seems. The higher the danger, the more it will impact the group loyalty number. When that number, multiplied by the group constant, reaches a certain threshold (which threshold is an experimental variable controlled in the interface) agents stop prioritizing their group and act as individuals. Subsequent analysis will examine the extent to which types of relationships among group members, such as married couples, dating pairs, friendships, and work associates affect the results. The code that defines loyalty can be expressed:

When (group-constant * perceived-danger) < threshold, ties break

So agents are all responding to the same stimulus, with variations in response based on their loyalty. Their individual exposure will depend partly on their location in the building, but the expectation is that the outcomes will primarily differ based on their group ties. Loyalty to group members is an experimental variable, with a preliminary number set by group type in the interface. This can be varied between individual runs of the simulation. The hypothesis is that the more loyal they are to their particular group, the more danger it will take before they decide to prioritize themselves instead of their group. Some of agents may never shift their priorities to themselves away from their groups - whether this is true and if so on what contexts will be part of the results.

The expectation is that as fire and smoke increase, agents become alarmed, and as the distance to their group leaders increase the agents will eventually decide that they care more about getting out themselves than making sure other members of their group do. Presumably a group of coworkers will default to self-preservation much more quickly and abandon their group-mates as compared to a group consisting of a married couple. Each group will disintegrate at a different point - if they do disintegrate - but it is theoretically possible for it to happen at any time. Figuring out whether they are still prioritizing their group, and what the stressors are, is the first thing agents do every second - before they decide whether they're moving and where they're moving and before they take a step. It should be stressed, however, that these substantive questions will not be addressed in this master's thesis but will be pursued later on during my doctoral work.

4.4 Objectives

The various components of agents' decision-making processes are all triggered when agents start to move. They move when they notice fire, smoke, or agents around them moving. Figure 6 demonstrates the logic at play.

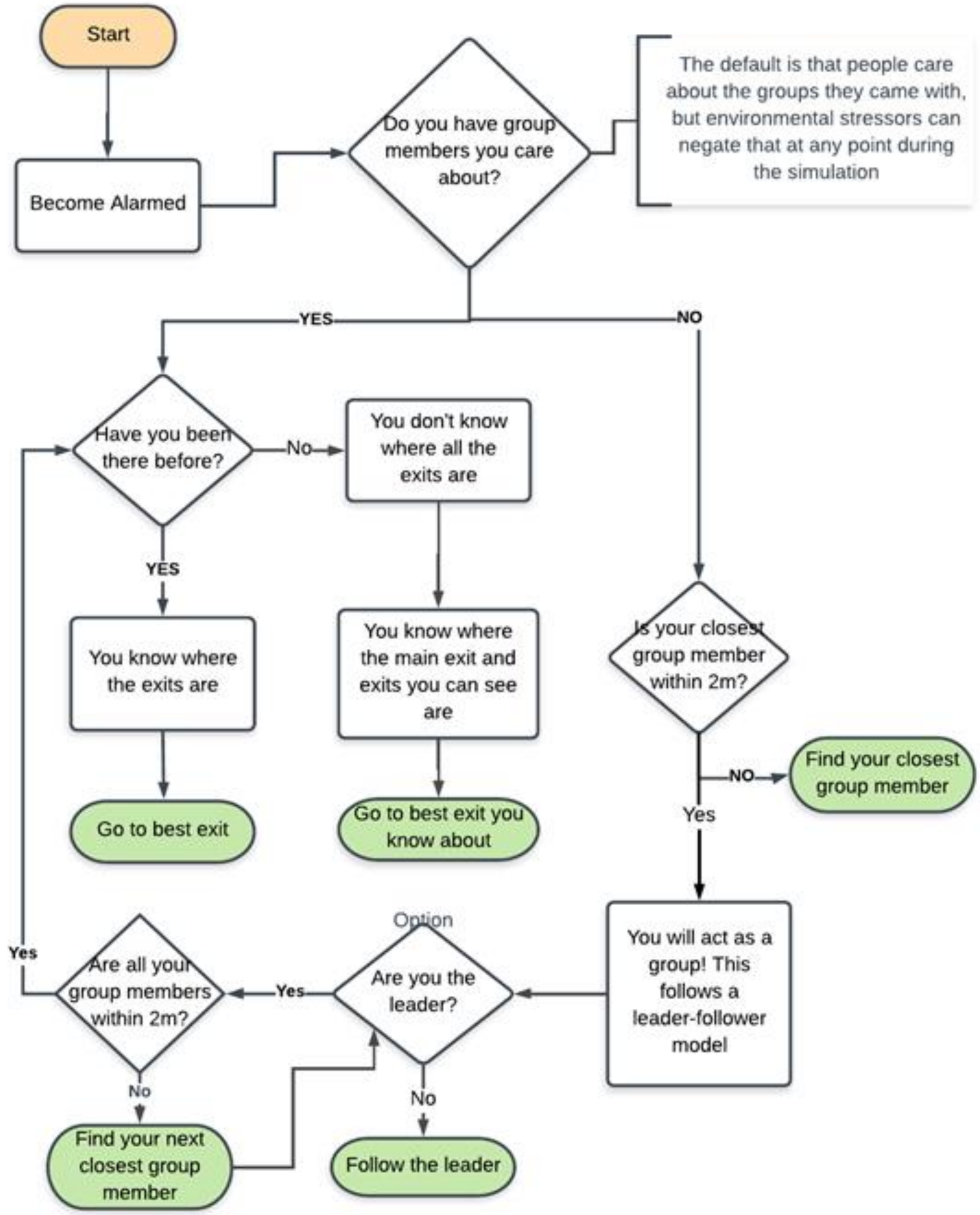


Figure 16 Appendix D Figure 6: Decision-making flowchart

First, agents need to decide what their goal is: where they're heading. There are a number of factors that determine this, reflected in the decision-making flowchart in figure 6.

The primary determinant is whether agents came by themselves, because there is evidence that those who came alone had a higher rate of survival (Aguirre et al. 2011, 100-118). If someone came alone, they then set a goal based on whether or not they have previous familiarity with the building. Those who had previously visited the nightclub are assumed to be familiar with its layout and use the best exit (based on proximity and lack of danger), regardless of whether or not they can see it. Those who had not previously visited then seek either the closest visible exit in a cone of visibility that is impacted by smoke or, if they are unable to see a close exit, the main entrance. It is assumed that people would have entered through the main entrance and therefore remember approximately where it is.

For agents who came in groups, their goals are more complicated. At the outset, agents search for their nearest group-member, and so that person becomes their goal. However, group members already in close proximity to each other - roughly arm's length, 2m - are considered to be able to act as a group: they know where that group-member is and so no longer have to seek them. At that point, those group members in proximity to each other transition to leader-follower behavior. The leader decides the subsequent goal and the followers keep the leader as their goal, setting up a follow-the-leader pattern. The way leadership is determined is explained in section 6.2.3.4. A group leader will continue to try to locate and accumulate group members until all are in close proximity, and then will search for either the closest or closest visible exit. If two sub-groups are formed out of one group that is searching for each other, when the groups meet up, leadership will be reassessed and the person with the highest leadership score will become the overall leader.

Because we are using a limited number of traits to identify the leaders, there is also a random number generator that assigns a value greater than zero but always less than even one of the other factors. The range lets the random number serve as a tie-breaker in groups in which two or more members have the same score while not letting it be the primary determinant of the leader. To guard against the potential volatility of leadership within a group, the leadership score of agents who are already leaders is doubled, to allow groups to move with greater stability (Best 2013).

4.5 Learning

Agents do not learn from previous iterations of the program. It was deemed nonsensical to have agents learn from multiple iterations of one simulation.

4.6 Prediction

A* is inherently predictive; it chooses the best path to a destination. One of its shortfalls is that it does not account for where the fire and smoke will be, only where it is at a given moment. It is a shortfall that very often also plagues humans, and so we treat it as a feature and not a bug.

4.7 Sensing

Those agents in the simulation which represent people have vision: they are assumed to see things around them, including fire, smoke, exits, and other agents. Their default field of vision includes peripheral vision in a 180 degree cone that extends 10m. This decreases with increased smoke.

There are also more inexpressible events that agents sense: agents can tell when agents around them are alarmed, with no further qualification. This is assumed to be communicated through visual, auditory, and haptic feedback, such as shuffling in the crowd or cries of alarm, but individual factors are not represented in the code. In this simulation, agents just know.

4.8 Interaction

Agents are assumed to decide collectively who is going to act as leader of their mostly small groups, based on which member fulfills the most qualities itemized in section 6.2.3.4. That is, specific leadership is not pre-set as part of the input variables, and is generated within the simulation.

Agents modulate their speeds based on the speeds of those in front of them. Agents also interact when within 2m of their group members, which in Fang's (2015) work it is referred to as a "conferral zone" in which people can more easily communicate. When this distance is accomplished with all group members, then the goal of finding the other agents is considered accomplished and the group members move to the next goal.

Agents are assigned an initial health level based on Best (2013), and being in close proximity to fire and smoke reduces their energy. This applies in and around smoke and fire. More dense smoke reduces energy levels more quickly. When energy reaches 0, agents are assumed to die of injury. Dying removes agents from the simulation and outputs the relevant information at that point in time.

4.9 Stochasticity

The simulation is stochastic in that none of the code contains a predetermined destination. Agents have goals based on internal rules, but those rules are not generated directly by input data. This means that the average results of multiple simulations will be used to determine whether the results are significant.

4.10 Collectives

Collectives are both emergent and pre-set in the simulation: people who came as a group with other people are considered to still belong to that group - they are a kind of collective.

They have links to each other which are articulated in the code but not visible in the display. Emergent collectives happen when agents are seeking their group members or the exits from the building. They are people who form groups that seek either other group members or the exits. There are also knots of people that are a form of collective as the members of the collectivity try to escape the fire.

4.11 Observation

Currently, observation can be done visually, though it takes a significant amount of time at the full scale, or by running a procedure called ‘master-run’. ‘Master-run’ runs the simulation for 180 seconds of simulated time and then exports all the results to a .csv with a random numeric ending so that files are not overwritten. The .csv can then be analyzed in a number of different ways; the ones used for calibration are in Table 1.

5 Initialization

The simulation requires NetLogo to be installed to run. When NetLogo is installed and open, it can be used to open the program file 'prioritevac.nlogo.' The program and other files need to be downloaded locally, in the same subfolder. The easiest way to accomplish this is by importing the Git from either Github or Bitbucket. Once prioritEvac is open, “Setup” will set up the simulation.

6 Input data

An in-depth description of the original effort to get the input data for the Station fire is in Aguirre et al., 2011. It involved collecting data from reports by the state attorney's office, the sheriff’s department, and the local newspaper.

NISTs Fire Dynamic Simulator (FDS) simulation for the Station nightclub fire provided the data used for the smoke and fire inputs. Because FDS is computationally intensive and high-detail, the inputs have been simplified to .csvs and are granular to a tenth of meter, not the significantly more detailed information FDS produces as a default. The .csv provides location and the time at which that location exceeded 200 degrees. 200° is considered the cutoff point at which point that location is on fire.

All of the relevant input data can be swapped for files from other fires. To perform the substitution, make sure the relevant files are in the same folder prioritevac.nlogo is loading from, then change the file names in the code and the size that the canvas needs to be. Details such as the main entrance and any broken windows would also need to be adjusted.

6.1 People

The People .csv has data pulled together from various interviews and other official sources (Torres 2010, Aguirre et al., 2011). All of the data has been anonymized: there are no names or other information identifying the victims of this fire in the .csv that is used for the simulation.

6.1.1 Location

Location in the building at the start of the fire is part of the input data, drawn from the information available and then with agents randomly placed within their initial sub-ecology. That is, if someone stated that they were in the bar area when the concert started, they will still be located in the bar area, but randomly placed within that area.

6.1.2 Basic Biometric Data

Gender and age are included because they allow for greater ease of searching for the same person in the non-anonymized data file if anything needs to be cross-checked. Their inclusion also allows for observation of emergent trends that might relate to either trait.

6.1.3 Visited?

Whether someone had previously been to the nightclub impacted their survival and ability to find exits, and so impacts behavior (Best 2013). People who had previously been to the club are supposed to be more familiar with the placement of exits, so the program assumes that agents know the locations of all exits and can choose the closest, while agents who did not previously visit only know the locations of those exits they could see before the fire started (as dictated by their position and field of vision) and of the main entrance which they are presumed to know from using it to enter.

6.1.4 Group-number and group-type

These two variables are considered in tandem to make links to connect agents who came together to the nightclub. Groups are differentiated by type. Coworker bonds are different from familial bonds, for example. The types of groups are coworker, friend, dating partner, familial (including married couples), and agents who have multiple kinds of relationships. These classifications are based on Fahy et al. (2011) and culturally-based assumptions on the types of groups that would be most relevant.

6.2 Smoke and Fire

Smoke and fire are input in separate csvs, based on FDS results as they were converted to video. Fire is structured as having locations and arrival times – that is, times at which a location is considered as being on fire - and was based on a top-down video sliced from a three-dimensional simulation in NIST's Fire Dynamic Simulator. These slices were taken at 1.5m height for the first 90 seconds of the simulation, then at .6m height for the rest of the simulation, with the idea that it is roughly head height at first and then lowers at the point when agents are expected to largely be crawling.

Smoke is structured along the same lines, with not only arrival times but five degrees of gradation, for 0%, 25%, 50%, 75%, and 100% smoke density. The 0% gradation denotes absence of smoke, and 100% smoke density means a completely opaque smokescreen. Higher density causes more injury more rapidly.

The videos for smoke were split into sections rather than the whole-building top-down view of fire, and they were categorized according to their corresponding locations within the nightclub and in our schematic.

6.3 Building

A layout of the Station nightclub was acquired from NIST, and then the location of walls, windows, and exits was input into a .csv, using the beginning and endpoints of the straight lines that comprised those aspects of the building. That .csv is read into the simulation, and the composition of the resultant physical environment is addressed in 6.2.1.

Additionally, a PNG with only the walls in the floorplan was uploaded to make them a feature of the map in addition to agents. This will need to be revisited for simulations where structural integrity is compromised. The size of doors and windows is accurate to those in the building.

7 Submodels

In addition to the setup and go functions, there are a number of submodels that contribute to the overall function of the simulation. The submodels can be roughly grouped by category, which corresponds to the file in which they can be found in the program.

7.1 Heuristics

The various heuristics submodels cover factors in judgement and preference. The first of these is the alert function, which has agents assess their surroundings and become alarmed enough to evacuate if there are sufficient warning signs.

Heuristics also include assessing how dangerous a particular direction is, including crowdedness and proximity to smoke and fire. The final and most important submodel in the heuristic section is that which governs group loyalty, discussed in 6.4.3.

7.2 Leave simulation

Agents can leave the simulation in two ways: through overwhelming injury or through reaching an exit. These submodels track how and where and when agents exit.

7.3 Speed

The speed submodel is taken directly from the NetLogo model library - specifically a network traffic model (Wilensky 2003). Agents match the speed of the agent in front of them, if there is one, or accelerate if there is not.