Pilot Demonstration of an Impact Evaluation Protocol: NIST NCST Recommendations Arising from The Station Nightclub Fire

Final Report

Prepared by:

John R. Hall, Jr., PhD
Michael Karter
National Fire Protection Association
Quincy, MA

Amanda Kimball, P.E.
Minchao Yin
Fire Protection Research Foundation
Quincy, MA

A National Institute of Standards and Technology (NIST) Funded Study

THE FIRE PROTECTION RESEARCH FOUNDATION

FIRE RESEARCH

THE FIRE PROTECTION RESEARCH FOUNDATION
ONE BATTERYMARCH PARK
QUINCY, MASSACHUSETTS, U.S.A. 02169-7471
E-MAIL: Foundation@NFPA.org
WEB: www.nfpa.org/Foundation

FOREWORD

Under the authority of the National Construction Safety Team (NCST) Act, the National Institute of Standards and Technology (NIST) establishes a National Construction Safety Team to determine the likely technical cause(s) of building failures. These reports include recommendations, but there has been no systematic method available to evaluate the impact of these recommendations.

A general protocol for conducting such evaluations cannot be created from scratch and still be detailed and validated enough to be useful for NIST's purposes. Therefore, the Fire Protection Research Foundation and the National Fire Protection Association (NFPA) conducted an evaluation of the impact of recommendations from the NCST report on a single incident, to be documented and conducted in such a way that the specific evaluation will also form the basis for defining a general protocol.

The Research Foundation expresses gratitude to the report authors Dr. John Hall, Michael Karter, Minchao Yin, and Amanda Kimball. The Research Foundation appreciates the guidance provided by the Project Technical Panelists, and all others that contributed to this research effort. Special thanks are expressed to NIST for sponsoring this study.

The content, opinions and conclusions contained in this report are solely those of the authors.

About the Fire Protection Research Foundation

The Fire Protection Research Foundation plans, manages, and communicates research on a broad range of fire safety issues in collaboration with scientists and laboratories around the world. The Foundation is an affiliate of NFPA.

About the National Fire Protection Association (NFPA)

NFPA is a worldwide leader in fire, electrical, building, and life safety. The mission of the international nonprofit organization founded in 1896 is to reduce the worldwide burden of fire and other hazards on the quality of life by providing and advocating consensus codes and standards, research, training, and education. NFPA develops more than 300 codes and standards to minimize the possibility and effects of fire and other hazards. All NFPA codes and standards can be viewed at no cost at www.nfpa.org/freeaccess.

Keywords: NCST recommendations, NIST recommendations, building code, The Station Nightclub fire

PROJECT TECHNICAL PANEL

Scott Adams, Park City Utah Fire Service District

Ralph Gerdes, Ralph Gerdes Consultants

Harold Hansen, Venue Management Consultants Group

Bruce Johnson, ICC

Shawn Kelly, IAFC

Larry McKenna, USFA

Greg Miller, Code Consultants, Inc

Kelly Nicolello, Alaska State Fire Marshal

Jon Nisja, Minnesota State Fire Marshal Division

Jeff Tubbs, Arup

Carl Wren, Austin Fire Department

Rita Fahy, NFPA

Robert Solomon, NFPA

PROJECT SPONSOR

National Institute of Standards and Technology

Contents

Executive Summary

Under the authority of the National Construction Safety Team (NCST) Act, the National Institute of Standards and Technology (NIST) establishes a National Construction Safety Team to determine the likely technical cause(s) of building failures. These reports include recommendations, but there has been no systematic method available to evaluate the impact of these recommendations.

A general protocol for conducting such evaluations cannot be created from scratch and still be detailed and validated enough to be useful for NIST's purposes. Therefore, the Fire Protection Research Foundation and the National Fire Protection Association (NFPA) conducted this project with the goal to develop a systematic method to evaluate the impact of NCST recommendations by focusing on a single incident as an example. This specific evaluation also serves as the basis for a general protocol.

The incident chosen for the example to demonstrate the protocol was The Station Nightclub Fire, which occurred on the night of 20 February 2003 in West Warwick, Rhode Island, and resulted in 100 fatalities.

For purposes of generating a protocol, the 10 recommendations made following The Station fire can be assigned to two groups:

A. Legislation/Adoption/Enforcement (includes Report Recommendations 1-5 & 7): recommendations for changes in the rules and practices that define local environments and fire department effectiveness; and

B. Research (includes Report Recommendations 6 & 8-10): recommendations for research on fire-related phenomena and mitigation methods that will lead to recommendations for changes in rules.

Evaluation of Group A recommendations requires examination of local rules and practices. Evaluation of Group B recommendations, as those recommendations are stated, requires examination of published research results and ongoing, or planned, research programs. The following tasks were undertaken to develop a general protocol and to demonstrate the protocol by evaluating the specific impact of the Group A and Group B recommendations from The Station fire:

- Analysis of data related to fire department practices, legislation, adoption, and enforcement recommendations (Group A recommendations as described above). This task involved the analysis of data related to state and local rules and practices to assess the degree of implementation of features and practices that were recommended. The data was collected separately by NFPA through a survey of local fire departments serving communities of at least 50,000. The survey was focused on changes in laws and enforcement of those laws related to nightclub safety.

- Analysis of changes to model codes and standards for the applicable Group A recommendations listed above.
- Literature review for the Group B recommendations discussed above. A literature review was undertaken to examine published research results and ongoing, or planned, research programs related to the recommendations.
- Synergistic review of the findings from the previous tasks, which involved studying the findings for any links.

Throughout the report, at each step the general protocol developed is explained and then demonstrated using the example of The Station Nightclub.

This pilot study was undertaken to develop a general model impact evaluation protocol to be adapted to the recommendations from the other NIST NCST report and similar report. As with any pilot study, lessons were learned along the way that should apply to the model for these types of evaluations going forward. This section contains the recommended protocol for an impact evaluation that can be applied to other sets of NIST recommendations.

A general recommendation for this type of evaluation is that this analysis should be completed more than once. The reason for this is two-fold. First, it takes time for major changes to be implemented in the model codes and standards. This can sometimes take several cycles. Secondly, research takes time to conduct and consequently it takes even more time for that research to have an impact on rules in the model documents. Further, sometimes changes made to local rules and practices are rescinded due to local political environments, etc. An example of this is the Chattanooga, Tennessee City Council rescinding a prior ordinance requiring sprinklers at bars and clubs in 2013.

Another general recommendation to NIST is related to wording of the recommendations. In order to evaluate the impact of the recommendation, it is best that the recommendations made are clear and measureable. Specifically, it may be helpful to have separate recommendations relating to education and training as a bump in training may occur after an event.

Step 1: Analysis of Changes to Model Codes

The pilot study documented in this report performed the analysis of changes to model codes and standards as a second task, but ideally, this should be undertaken as a first step in the evaluation. This is because changes are usually made in the model codes as a first step and then the local jurisdictions adopt the model codes.

The general approach of this step is to analyze the requirements related to the NIST recommendations before the recommendations were issued, and compare them to later editions of the codes and standards. This should be done for all editions issued after the event because, as noted above, it sometimes takes several cycles for changes to be implemented.

Step 2: Analysis of Changes to Local Practices

The goal of this type of exercise is to provide an evaluation of the degree of implementation of features and practices that were recommended – usually in the form of a new code or standard or changes to an existing code or standard. What is sought is information on:

- *adoption* of requirements (for those features and practices), which connects the gap between impact of recommendations at the national level (on model codes and standards) and impact at the local level (on local requirements and practices);
- *compliance* with requirements (for features of properties but not for fire department practices; if fire departments report adoption of requirements for fire department practices, then there is no point in asking fire departments about inspection and enforcement activities to check compliance); and
- *timing of changes* in requirements, as this is the most accessible information indicating a role on NIST recommendations and other national changes or guidance following a major incident in changing local practices (e.g., some localities may already have local practices that match the recommendations)

An evaluation exercise can be conducted using a number of different types of information, but the best balance of affordability and useful detail will likely be achieved through a *survey*. However, it is important to check costs, response rates, design bias, and resulting statistical significance of a particular survey proposal. It is also important to check whether the level and type of detail obtainable from a survey will provide sufficient evaluative depth to be worth the cost. For this prototype application of an evaluation protocol, NFPA was able to use data collected in the earlier, independent NFPA survey as the issues addressed match well with the NIST recommendations on similar topics. In a normal application of the generic protocol, those conducting the evaluation would have to review the considerations listed here for and against a survey as a source of evaluative information. They would also have to design a survey, if they chose to conduct one. Appendix A contains the survey used by NFPA, which is offered here for its illustrative value to anyone seeking to develop a survey with the same structure for evaluation of any set of recommendations arising from investigation of a major incident.

Determining the target. The first step in implementing a survey is to determine the target for the survey. For recommendations defined by a class of properties, the first step starts with identifying the number of such establishments in the country, followed by looking for any clustering of establishments that would permit a narrower focus in the evaluation (e.g., most properties located in certain states or in communities of a certain size).

General protocol to evaluate targeted conditions. An evaluation is built around best estimates of answers to three questions, for a particular recommended feature or practice that was called for in a recommendation.

Question 1. To what extent do communities have *requirements* related to the feature or practice?

Typically, a requirement will be set forth in an adopted code provision, standard, or other legislative authorization. The "condition" could be a characteristic (e.g., system, feature) of the property that enhances safety, a practice of the fire department that reinforces the property characteristics (e.g., enforcement), or one that improves the ability to mitigate incidents when they occur. This question should also include any specific local law that may not be based on a model code or, alternatively, if the changes are being removed at the local level due to the level of resources available.

Question 2. What is the degree of *compliance* with those requirements in the communities?

For property characteristics, there may be no existing basis for direct measurement of compliance because many, possibly most, communities do not have annual fire code inspections of all properties or of a representative sample of properties. A special survey of properties could be used, but in most cases, the only practical measurement will be best estimates by community authorities.

For fire department practices to improve mitigation ability (such as communications at the fire scene, deployment and staffing, incident management), the fire department is involved directly in adoption, which means the entity that needs to implement the requirements and assure compliance is not a separate entity. As a result, they may require more persuasion or motivation to comply with a requirement in which they had nothing to do with creating.

In both cases, an audit involving direct observation of practices and conditions by an independent third party would provide more evidence of compliance, but at a considerably greater cost per community.

Question 3. Did the requirements *change after the major event* that led to the recommendations?

This is the best high-level indicator of the impact of the recommendations. It is not necessarily the case that improvements in safety introduced after a major event were made in response to that event, let alone that they were made in accordance with specific recommendations emerging from that event, but it is a reasonable premise for a first-order evaluation of the impact of recommendations. Additionally, a more detailed evaluation would be much more expensive.

Step 3: Literature Review Related to Research Recommendations

To evaluate the impact of recommendations relating to research, the recommended approach is to conduct a literature review, which should include the following types of materials:

- Published research (e.g., academia, government laboratories, private industry)

- Programs, plans, and agendas for research not yet completed;
- Research assembled or conducted as input to revisions of model codes, standards, and similar documents (e.g., ASTM, ICC, ISO, NFPA, SFPE)
- Research on the effectiveness of model codes, standards, and similar documents

The research recommendations are intended to lead to research that will in turn result in new rules and practices. To provide some assessment of the degree of progress toward this goal, the literature sources should be evaluated on the following:

- Quality (e.g., originality, peer-reviewed), including notes on availability as applicable (e.g., proprietary vs. non-proprietary)
- Relevance (e.g., relevance to topic, degree of progress toward eventual goal of recommendations on rules and practices) using a rating system

Step 4: Synergistic Review and Analysis

For the pilot study, a comparison was made between the changes in model codes and standards and the local analysis. However, as suggested above, the analysis of changes to model documents should be completed ahead of the survey used to evaluate the changes in local practice. Then, this analysis will feed into how the survey questions are formed.

Research on a topic can inform changes to model codes and standards as well as local practices. The deliverables from the literature review on any research related recommendations and the findings from the analysis of changes to model codes and local practices (Step 1 and Step 2 should be reviewed and analyzed for any links. However, this is often a long process, thus it is recommended above that this type of evaluation be completed more than once. This type of comparison can also give an idea of what changes may be on the horizon associated with more recent completed research.

Background

Under the authority of the National Construction Safety Team (NCST) Act, the National Institute of Standards and Technology (NIST) establishes a National Construction Safety Team to determine the likely technical cause(s) of building failures. These reports include recommendations, but there has been no systematic method available to evaluate the impact of these recommendations.

A general protocol for conducting such evaluations cannot be created from scratch and still be detailed and validated enough to be useful for NIST's purposes. Therefore, the Fire Protection Research Foundation and the National Fire Protection Association (NFPA) conducted this project with the goal to develop a systematic method to evaluate the impact of NCST recommendations by focusing on a single incident as an example. This specific evaluation also serves as the basis for a general protocol.

The incident chosen for the example to demonstrate the protocol was The Station Nightclub Fire, which occurred on the night of 20 February 2003 in West Warwick, Rhode Island, and resulted in 100 fatalities. A NIST NCST report was issued in June 2005 and included 10 recommendations[1]:

Recommendation 1. Model Code Adoption and Enforcement: NIST recommends that all state and local jurisdictions:

> a) adopt a building and fire code covering nightclubs based on one of the national model codes (as a minimum requirement) and update local codes as the model codes are revised;
>
> b) implement aggressive and effective fire inspection and enforcement programs that address: (i) all aspects of those codes; (ii) documentation of building permits and alterations; (iii) means of egress inspection and record keeping; (iv) frequency and rigor of fire inspections, including follow-up and auditing procedures; and (v) guidelines on recourse available to the inspector for identified deviations from code provisions; and
>
> c) ensure that enough fire inspectors and building plan examiners are on staff to do the job and that they are professionally qualified to a national standard such as NFPA 1031 (Professional Qualifications for Fire Inspector and Plan Examiner).

Recommendation 2. Sprinklers: NIST recommends that model codes require sprinkler systems according to NFPA 13 (Standard for the Installation of Sprinkler Systems) and that state and local authorities adopt and aggressively enforce this provision:

---

[1] Grosshandler, et. al., "Report of the Technical Investigation of The Station Nightclub Fire," *National Institute of Standards and Technology*, NIST NCSTAR2. June 2005.

a) for all new nightclubs regardless of size, and

b) for existing nightclubs with an occupancy limit greater than 100 people.

Recommendation 3. Finish Materials and Building Contents: NIST recommends that:

a) state and local authorities adopt and aggressively enforce the existing provisions of the model codes;

b) non-fire retarded (FR) flexible polyurethane (PU) foam, and other materials that ignite as easily and propagate flames as rapidly as non-fire retarded flexible polyurethane foam: (i) be clearly identifiable to building owners, operators, contractors, and authorities having jurisdiction (regulatory agencies); and (ii) be specifically forbidden, with no exceptions, as finish materials from all new and existing nightclubs;

c) NFPA 286 (Standard Methods of Fire Tests for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth) be modified to provide more explicit guidance for when large-scale tests are required to demonstrate that materials (other than those already forbidden in b above) do not pose an undue hazard for the use intended; and

d) ASTM E-84 (Standard Test Method for Surface Burning Characteristics of Building Materials), NFPA 255 (Standard Method of Test of Surface Burning Characteristics of Building Materials), and NFPA 286 be modified to ensure that product classification and the pass/fail criteria for flame spread tests and large-scale tests are established using the best measurement and prediction practices available.

Recommendation 4. Indoor Use of Pyrotechnics: NIST recommends that NFPA 1126 (Use of Pyrotechnics before a Proximate Audience) be strengthened, as described below, and that state and local authorities adopt and aggressively enforce the revised standard.

a) Pyrotechnic devices should be banned from indoor use in new and existing nightclubs not equipped with an NFPA 13 compliant automatic sprinkler system.

b) NFPA 1126 should be modified to include a minimum occupancy and/or area for a nightclub below which pyrotechnic devices should be banned from indoor use, irrespective of the installation of an automatic sprinkler system.

c) Plans for the use of indoor pyrotechnics in new and existing nightclubs should be posted on site; and in addition to the items listed in paragraph 4.3.2 of NFPA 1126, should describe the measures that have been established to provide crowd management, security, fire protection, and other emergency services.

d) Section 6.6.2 of NFPA 1126 should be modified to require the minimum clearance between (i) the nearest fixed or moveable contents, and (ii) any part or product (igniter, spark, projectile, or debris) of a pyrotechnic device permitted for indoor use in new and existing places of assembly, to be twice the designed projection of the device, until such time that studies show that a smaller minimum clearance can guarantee safe operation in spite of the possibility that building decorations or temporary features that greatly exceed flame spread or fire load provisions of the fire code may occur.

Recommendation 5. Occupancy Limits and Emergency Egress: NIST recommends that the factor of safety for determining occupancy limits of all new and existing nightclubs be increased in the model codes in the following manner, and that state and local authorities adopt and aggressively enforce the following provisions:

a) Within the model codes, establish the threshold building area and occupant limits for egress provisions using best practices for estimating tenability and evacuation time and, unless further studies indicate another value is more appropriate, use 1-1/2 minutes as the maximum permitted evacuation time for nightclubs similar to or smaller than The Station.

b) Compute the number of required exits and the permitted occupant loads assuming at least one exit (including the main entrance) will be inaccessible in an emergency evacuation.

c) For nightclubs with one clearly identifiable main entrance, increase the minimum capacity of the main entrance to accommodate two-thirds of the maximum permitted occupant level (based upon standing space or festival seating, if applicable) during an emergency.

d) Eliminate trade-offs between sprinkler installation and factors that impact the time to evacuate buildings.

e) Require staff training and evacuation plans for nightclubs that cannot be evacuated in less than 1-1/2 minutes.

f) Provide improved means for occupants to locate emergency routes—such as explicit evacuation directions prior to the start of any public event, exit signs near the floor, and floor lighting—for when standard exit signs become obscured by smoke.

Recommendation 6. Portable Fire Extinguishers: NIST recommends that a study be performed to determine the minimum number and appropriate placement (based upon the time required for access and application in a fully occupied building) of portable fire extinguishers for use in new and existing nightclubs, and the level of staff training required to ensure their proper use.

Recommendation 7. Emergency Response: To ensure an effective response to a rapidly developing mass casualty event, NIST recommends that state and local authorities adopt and adhere to existing model standards on communications, mutual aid, command structure, and staffing, such as:

a) NFPA 1221, *Standard for the Installation, Maintenance, and Use of Emergency Services Communications Systems*

b) NFPA 1561, *Standard on Emergency Services Incident Management Systems*

c) NFPA 1710, *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments*

d) NFPA 1720, *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Volunteer Fire Departments*

Recommendation 8. Research on Human Behavior: NIST recommends that research be conducted to better understand human behavior in emergency situations, and to predict the impact of building design on safe egress in fires and other emergencies (real or perceived), including the following:

a) the impact of fire products (gases, heat, and obscuration) on occupant decisions and egress speeds;

b) exit number, placement, size, and signage;

c) conditions leading to and mitigating crowd crush;

d) the role of crowd managers and group interactions;

e) theoretical models of group behavior suitable for coupling to fire and smoke movement simulations; and

f) the level of safety that model codes afford occupants of buildings.

Recommendation 9. Research on Fire Spread and Suppression: NIST recommends that research be conducted to understand fire spread and suppression better in order to provide the tools needed by the design profession to address recommendations 2, 3, and 5 above. The following specific capabilities require research:

a) prediction of flame spread over actual wall, ceiling and floor lining materials, and room furnishings;

b) quantification of smoke and toxic gas production in realistic room fires; and

c) development of generalized models for fire suppression with fixed sprinklers and for firefighter hose streams.

Recommendation 10. Research on Computer-aided Decision Tools: NIST recommends that research be conducted to:

a) refine computer-aided decision tools for determining the costs and benefits of alternative code changes and fire safety technologies; and

b) develop computer models to assist communities in allocating resources (money and staff) to ensure that their response to an emergency with a large number of casualties is effective.

For purposes of generating a protocol, the 10 recommendations can be assigned to two groups:

A. <u>Legislation/Adoption/Enforcement</u> (includes Report Recommendations 1-5 & 7): recommendations for changes in the rules and practices that define local environments and fire department effectiveness; and

B. <u>Research</u> (includes Report Recommendations 6 & 8-10): recommendations for research on fire-related phenomena and mitigation methods that will lead to recommendations for changes in rules.

Evaluation of Group A recommendations requires examination of local rules and practices. Evaluation of Group B recommendations, as those recommendations are stated, requires examination of published research results and ongoing, or planned, research programs. The following tasks were undertaken to develop a general protocol and to demonstrate the protocol by evaluating the specific impact of the Group A and Group B recommendations from The Station fire:

- Analysis of data related to fire department practices, legislation, adoption, and enforcement recommendations (Group A recommendations as described above). This task involved the analysis of data related to state and local rules and practices to assess the degree of implementation of features and practices that were recommended. The data was collected separately by NFPA through a survey of local fire departments serving communities of at least 50,000. The survey was focused on changes in laws and enforcement of those laws related to nightclub safety.
- Analysis of changes to model codes and standards for the applicable Group A recommendations listed above.
- Literature review for the Group B recommendations discussed above. A literature review was undertaken to examine published research results and ongoing, or planned, research programs related to the recommendations.

- Synergistic review of the findings from the previous tasks, which involved studying the findings for any links.

Throughout the report, at each step the general protocol developed is explained and then demonstrated using the example of The Station Nightclub.

Section 1: Analysis of Changes to State and Local Practices

This task was an evaluation of the Group A recommendations (Recommendations 1-5 and 7) defined in the previous section. NFPA had its own interest in these same recommendations, dating back to the NFPA findings in its own investigation of The Station nightclub fire and NFPA consideration of proposals for changes in codes and standards arising from those findings. Before the NIST project was authorized and begun, NFPA had independently developed and conducted a survey of U.S. fire departments protecting populations of at least 50,000. Although this effort was entirely separate and apart from this project as originally scoped, the information is directly applicable and therefore included within this specific study. This independent NFPA survey included questions about local practices, local codes and standards, and local enforcement activities related to those local codes and standards, for each of six groups of issues:

- Adoption of current codes and standards and activities related to general enforcement of codes and standards
- Sprinkler requirements for nightclubs
- Interior finish requirements for nightclubs
- Indoor pyrotechnic requirements for nightclubs
- Occupancy limits and egress requirements for nightclubs
- Communications, incident management, and deployment requirements for incident response

The goal of an exercise like this is to provide an evaluation of the degree of implementation of features and practices that were recommended – usually in the form of a new code or standard or changes to an existing code or standard. What is sought is information on:

- *adoption* of requirements (for those features and practices), which connects the gap between impact of recommendations at the national level (on model codes and standards) and impact at the local level (on local requirements and practices);
- *compliance* with requirements (for features of properties but not for fire department practices; if fire departments report adoption of requirements for fire department practices then there is no point in asking fire departments about inspection and enforcement activities to check compliance); and
- *timing of changes* in requirements, as this is the most accessible information indicating a role on NIST recommendations and other national changes or guidance following a major incident in changing local practices (e.g., some localities may already have local practices that match the recommendations).

An evaluation exercise can be conducted using a number of different types of information:

- The exercise can be conducted using only local *information that is already routinely collected*, recorded, and transmitted to a national body. Such an exercise will be very inexpensive, but it is very unlikely that such existing, nationally compiled data sources will be able to provide enough details for any significant evaluation.

- The exercise can be conducted using *site visits and/or special data collection protocols* that are set up to run for at least a year. Such an exercise will likely require a six-figure budget and still provide data on only a dozen or so communities. The detail obtained will be the most possible and will address the recommendations and their impacts in the greatest detail possible, but the lack of breadth of coverage will severely limit any conclusions that can be reached. Previous such studies have rarely incorporated smaller communities. Including these communities will add to the costs of the study, but not including these communities may limit the generalizability of any conclusions.
- The best balance of affordability and useful detail will probably be achieved through a *survey*. However, it is important to check costs, response rates, design bias, and resulting statistical significance of a particular survey proposal. It is also important to check whether the level and type of detail obtainable from a survey will provide sufficient evaluative depth to be worth the cost. For this prototype application of an evaluation protocol, NFPA was able to use data collected in the earlier, independent NFPA survey because the issues addressed match well with the NIST recommendations on similar topics. In a normal application of the generic protocol, the people conducting the evaluation would have to review the considerations listed here for and against a survey as a source of evaluative information. They would also have to design a survey if they chose to conduct one. Appendix A contains the survey used by NFPA, which is offered here for its illustrative value to anyone seeking to develop a survey with the same structure for evaluation of any set of recommendations arising from investigation of a major incident.

In this report, comments about the general approach and about the nightclub fire example are interwoven. Comments about the example are indented to assist the reader.

Although this protocol is limited to the evaluation of local adoption of and compliance with particular recommendations, it may be useful to include information on the degree of success in having the recommendations adopted into national model codes or recognized best practices. A lack of success at the national model code stage will likely make the downstream questions moot.

The protocol sometimes uses “the community” and “the building or fire department” interchangeably when talking about adoption and activities to check compliance. The measurement of adoption and compliance proceeds in the same manner regardless of who has what role, authority, or responsibility in achieving the desired results, but the application of the findings will depend very much on those roles and should be included in the evaluation.

The description of the protocol is fairly basic and could be refined for increased ease of use. For example, there may be value in converting the evaluation scores to letter grades, which may convey the most important summary information more quickly than the current formats.

Step 1. What is the Target?

General protocol. A recommendation needs to be translated into a desired change in conditions in the field.

Applying to the example.

In the example, the recommendations were intended to prevent or reduce the likelihood of a future multi-casualty fire at a nightclub. The target therefore is nightclubs, which should be made safer, and fire departments with nightclubs in their protected communities, which should be made better able to fight fires at nightclubs and maintain safety improvements at nightclubs. Although the target is nightclubs, it is reasonable to expect that other types of assembly occupancies would also benefit from the recommendations, whether they are aimed at changing behavior of the owners and managers (thereby increasing the safety of the buildings), the occupants (thereby reducing the risks they create or are exposed to), or the first responders (thereby better mitigating the losses in fires when they occur or reinforcing safer behaviors through inspection, enforcement, education, or other means).

General protocol: Targeting a group of properties. For recommendations defined by a class of properties, Step 1 starts with identifying the number of such establishments in the country, followed by looking for any clustering of establishments that would permit a narrower focus in the evaluation (e.g., most properties located in certain states or in communities of a certain size).

Applying to the example.

For the example, this means starting with an estimate of the number of nightclubs.

It will typically be the case that different data sources use different definitions or draw the boundaries differently, and that is the case in the example. In any evaluation, it will be important to examine these differences carefully so that the evaluation will be targeted on a group of properties that is appropriate for the evaluation. That is, if the evaluation is favorable or unfavorable for the group of properties selected for analysis, one can be reasonably sure that evaluation would have been similarly favorable or unfavorable for the precise group of properties targeted by the requirement or recommendation, if it had been possible to match the evaluation to that group exactly.

The industry (which refers to itself variously as the bar, nightclub and drinking establishment industry, or the nightlife and club industry trade organization industry) estimates roughly 65,000 establishments that derive their revenue primarily from the sale of alcoholic beverages.[2] However, only 8.6% of the revenue for these establishments is said to be from **nightclubs**, with taverns, bars and lounges, drinking places, and cocktail lounges accounting for the rest. There does not appear to be a formal industry definition for "nightclub". Dictionary definitions typically mention nighttime operations and music and/or dancing as defining characteristics.[3] It is reasonable to expect that a nightclub will tend to be larger than a tavern or bar, with higher revenue per establishment, which means the nightclub share of establishments is likely smaller than the nightclub share of revenue. The actual number of true nightclubs is therefore probably lower than the 5,600 establishments estimated by applying 8.6% to 65,000.

At the same time, "nightclub" also is not specifically defined or separately addressed in either the national fire incident database or the principal model codes and standards. For example, NFIRS code 162 for Property Use includes all types of drinking establishments. In NFPA 101, *Life Safety Code®*, "nightclub" is not defined and requirements are stated not only for all drinking establishments but for all assembly properties, sometimes with a minimum occupancy threshold. Therefore, changes in response to the NIST recommendations and available data on fires and on local practices may address all drinking establishments. Certain non-drinking establishments such as concert halls are also likely to be impacted by some of the NIST recommendations.

The NFPA survey asked about the number of nightclubs in the community but only surveyed fire departments protecting communities with at least 50,000 population. This provided a manageable test of the survey protocols, while also offering the possibility of capturing a large share of the nightclubs or drinking establishments in the country. NFPA had not conducted an analysis of the distribution of nightclubs and drinking establishments by size of community prior to designing the survey.

For the analysis phase of this project, estimates of total nightclubs or drinking establishments in communities with at least 50,000 population were developed from the survey and compared to the national numbers developed from industry sources above (i.e., 65,000 total drinking establishments and less than 5,600 true nightclubs). The goal was twofold:

- Try to determine whether respondents were reporting on all drinking establishments or only true nightclubs, and

---

[2] NCIAA (which claims to be the Nightlife & Club Industry's Official Trade Organization), *Our Industry*, 2011-2012 statistics from diverse sources particularly IbisWorld studies conducted by MarketResearch.com, published at http://www.nciaa.com/content.aspx?page_id=22&club_id=160641&module_id=29898.

[3] See, for example, *Merriam-Webster's Collegiate Dictionary*, Springfield (MA): Merriam-Webster, Incorporated, 10th edition, 1997.

- Estimate what share of total U.S. nightclubs or drinking establishments are located in communities with at least 50,000 population.

Responses to the survey were given in terms of ranges for the number of nightclubs in the community. To estimate the number of nightclubs in these communities, it is necessary to pick a specific number to represent a range. For the closed-end ranges (two to five and six to ten), one can run one set of analyses using the lower end of the range and one set using the upper end of the range. For the open-ended top range (11 or more), one can still run an analysis using the bottom end of the range, but it is necessary to select a number to represent the high end of the range.

An exploratory analysis was done in which the upper number for those open-ended top ranges was defined as one nightclub per 5,000 population combined with the high end of the population range. The figure of one nightclub per 5,000 population is roughly equivalent to 65,000 drinking establishments spread evenly over a U.S. population of around 320 million. For example, communities with populations in the range of 50,000 to 100,000 and reporting 11 or more nightclubs were estimated to have 20 nightclubs (20 = 100,000 x 1/5000). For the open-ended highest population range, which starts at 500,000 population, a figure of 1,000,000 population was used.

Using the bottom ends of the ranges produces an estimate of 6,700 nightclubs just from communities of 50,000 or more population, which is already higher than the nightclub-only portion of total establishments calculated above. Using the top ends of the ranges produces an estimate of 30,900 nightclubs, which is nearly half the total 65,000 drinking establishments.

It seems clear that the survey respondents were using the drinking establishment definition rather than the narrower nightclub definition, as even the lowest estimate of total nightclubs in communities of 50,000 or more population is higher than the industry's estimate of total nightclubs in the country.

Also, as the population size of the communities declines, the number of nightclubs per community declines, but the number of such communities increases. Using the bottom ends of the ranges, the smaller communities account for more total nightclubs than the larger communities. Using the higher ends of the ranges, there is no clear relationship between size of community and share of total nightclubs.

The implications of this exploratory analysis are that a full evaluation of the impact of the NIST recommendations should include communities of all sizes. As further evidence of this point, The Station nightclub fire occurred in West Warwick, Rhode Island, a community of less than 30,000 population. The deadliest nightclub fire of the past half-century – the Beverly Hills Supper Club fire in 1977 – took place in Southgate, Kentucky, a town of less than 4,000 population. On the other hand, the deadliest U.S. nightclub fire of all time took place in Boston, Massachusetts, a large city with population protected in the top population group of the NFPA survey.

General protocol. Success in implementation of recommendations will often be dependent on success in smaller communities. **Ideally, an evaluative survey should cover all sizes of communities.**

For the example, the argument in favor of including all communities is based on the fact that nightclubs can be found anywhere and appear to be very widely distributed. In general, the argument in favor of including all communities is based on the importance of capturing all or most of the targets and the fact that most of the targets may be spread across the many small communities where target density is quite low but share of total targets is collectively large.

There is a separate argument in favor of including all communities based on the possibility that new rules are less likely to be adopted, less likely to be adopted quickly, and less likely to be effectively enforced in smaller communities.

The fact that an all-community survey would be best for evaluation and may even be necessary for evaluation does not mean that such a survey will be practical or affordable.

The first concern is that response rates will drop with smaller communities.

Applying to the example.

Table A. Percent of Departments Responding to NFPA Nightclub Survey

Size of community	Percentage
500,000 or more	38%
250,000 to 499,999	42%
100,000 to 249,999	32%
50,000 to 99,999	33%
Total	34%

This looks like a fairly modest decline in response rate by size of community, but that is probably a reflection of the exclusion of communities with less than 50,000 population. For comparison's sake, consider the percent of departments responding to the third NFPA fire service needs assessment survey.[4]

[4] "Third Needs Assessment of the U.S. Fire Service". *National Fire Protection Association*, June 2011. p.179.

Table B. Percent of Departments Responding to Third Fire Service Needs Assessment Survey

Size of community	Percentage
500,000 or more	58%
250,000 to 499,999	61%
100,000 to 249,999	59%
50,000 to 99,999	59%
25,000 to 49,999	48%
10,000 to 24,999	36%
5,000 to 9,999	23%
2,500 to 4,999	19%
Under 2,500	15%
Total	23%

As with the nightclub survey, response rates change little down to 50,000 population, but they decline sharply as community size shrinks below 50,000.

In addition, the smaller the community, the less likely it is to have any nightclubs. Table C presents results from Q1 of the nightclub survey, which asked how many nightclubs a responding community has. (See Table 1 for complete results from Q1.)

Table C. Percent of Responding Departments Having No Nightclubs

Size of community	Percent
500,000 or more	0%
250,000 to 499,999	3%
100,000 to 249,999	11%
50,000 to 99,999	24%
Total	17%

As may be seen, the percentage of departments with no nightclubs rises rapidly as community size declines. Consider how this percentage might continue to decline if the survey had included smaller communities. If the national average is one nightclub per 5,000 population, then more than half of communities under 2,500 population would have no nightclubs.

Put these two factors together. The response rates for the nightclub survey were roughly 2/3 the response rates for comparable sized communities in the third fire service needs assessment survey. This means that if the nightclub survey had pursued all communities, it might have achieved only a 10% response rate for communities with less than 2,500 population (10% = 2/3 of 15% response rate for those communities in the third needs assessment survey). There are approximately 13,000 communities (defined as fire department protection areas) with less than 2,500 population, and the average population for such communities is about 1,300. Therefore, communities of that size would average about one nightclub for every four communities (4 = 5,000/1,300), and only about 2-3% of communities with less than 2,500 population would be expected to respond to the survey and report having at least one nightclub. That translates into fewer than 300 communities. Survey forms would need to be mailed to most of the 13,000 communities to hope to obtain results from 200 rural departments with nightclubs.

General protocol. These kinds of calculations would need to be made in order to determine the cost of a survey with sufficient statistical power to provide credible results for all sizes of communities.

A final consideration in determining the size of communities to be included in surveys and other research activities should be the availability of assistance from fire service associations as well as governmental associations. For example The International Association of Fire Chiefs may be able to assist through its Volunteer and Combination Officers Section as well as the Fire and Life Safety Section and the Metro Chiefs Section. Additional assistance communicating with smaller communities and rural fire departments might be obtained through the National Volunteer Fire Council and its 49 state associations, or through the International City/County Management Association and its various state associations and affiliates.

Step 2. Evaluating Targeted Conditions

General protocol. An evaluation is built around best estimates of answers to three questions for a particular recommended feature or practice that was called for in a recommendation.

Question 1. To what extent do communities have *requirements* related to the feature or practice?

Typically, a requirement will be set forth in an adopted code provision or standard or other legislative authorization. The "condition" could be a characteristic (e.g., system, feature) of the property that enhances safety, or it could be a practice of the fire department that reinforces the property characteristics (e.g., enforcement) or improves ability to mitigate incidents when they occur. This question should also include any specific local law that may not be based on a model code.

Question 2. What is the degree of *compliance* with those requirements in the communities?

For property characteristics, there may be no existing basis for direct measurement of compliance because many, possibly most, communities do not have annual fire code inspections of all properties or of a representative sample of properties. A special survey of properties could be used, but in most cases, the only practical measurement will be best estimates by community authorities.

For fire department practices to improve mitigation ability (such as communications at the fire scene, deployment and staffing, and incident management), the fire department is involved directly in adoption,. This means that the entity that needs to implement the requirements and assure compliance is not a separate entity, which might require more persuasion or motivation to comply with a requirement that they had nothing to do with creating.

In both cases, an audit involving direct observation of practices and conditions by an independent third party would provide more evidence of compliance, but at a considerably greater cost per community.

Question 3. Did the requirements *change after the major event* that led to the recommendations?

This is the best high-level indicator of impact of the recommendations. It is not necessarily the case that improvements in safety introduced after a major event were made in response to that event, let alone that they were made in accordance with specific recommendations emerging from that event. However, it is a reasonable premise for a first-order evaluation of the impact of recommendations, and a more detailed evaluation would be much more expensive.

These three questions are associated with more detailed follow-up questions:

a) For question 1, *are the requirements in place well-aligned with the requirements that were recommended*? Data on this point will allow the evaluation to estimate relative success in implementation instead of a more rigid and inflexible either/or assessment.

b) For question 2, *are communities using inspections, tests, and other means to achieve and assure compliance*? If no, then the best estimates by community authorities may not be accurate. Also if no, this points to programs where more active enforcement programs would be an obvious path to higher levels of compliance.

   Going to a deeper level of detail, are community estimates of compliance higher in places that are using particular means to achieve and assure compliance?

   If estimates are higher in places that are using more effective means, like inspections and tests, then that is evidence of the potential value of such means in improving compliance and can be used in designing follow-up programs and related advocacy arguments.

   If estimates are actually lower in places that are using more effective means, then that is evidence that community authorities may be overly optimistic about their levels of compliance, in the absence of any real data. That supports a different kind of follow-up and different kinds of related arguments.

c) For questions 1 and 3, *is adoption of requirements or full adoption of recommended requirements and practices associated more with one or another source of model codes* *and standards?* This can be useful in designing follow-up programs to improve adoption rates.

Applying the three questions to the example.

Table D shows how specific survey questions are used to provide estimates for each of the three questions (row numbers 1 to 3) and each of the four nightclub features and practices identified for evaluation.

Table D. Questions Used in Estimating Evaluative Metrics, by [Nightclub] Feature or Practice

Question to be answered	Sprinklers	Interior finish	Indoor pyrotechnics	Occupancy limits and egress requirements
#1. Do communities have requirements? Yes/No #1a. Which of several requirements do they have?	Q. 6 Q. 6, asks about occupancy threshold	Q. 9 Q. 11, on use of visual vs. testing confirmation	Q. 14 Q. 14, on use or non-use of NFPA 1126 in setting restrictions	Q. 17 Q. 17 on source of requirements, either local or a particular model code, which may imply different requirements
#2. How many [nightclubs] are in compliance? All, Most, Half, Some, None #2a. What enforcement activities with what frequencies and coverages are used to check compliance?	Q. 8 Q. 7	Q. 13 Q. 12	Q 16 Q. 15	Q. 19 Q. 18
#3. Did the requirements change after [The Station nightclub fire occurred?] Yes/No	Q. 6a	Q. 9h	Q. 14e	Q. 17f

Table E shows how specific survey questions are used to provide estimates for each of the two questions (where as noted Question #2 is moot) and each of the three fire department practices identified for evaluation.

Table E. Questions Used in Estimating Evaluative Metrics, by Fire Department Practice

Question to be answered	Adoption of model code and existence of inspection program	Public emergency services communications systems re NFPA 1221	Emergency service incident management system re NIMS or NFPA 1561	Organizational, operational and deployment procedures re NFPA 1710 or 1720
#1. Does department follow indicated practice? Yes/No	Q. 2-4	Q. 20	Q. 21	Q. 22
#3. Did the requirements change after [The Station nightclub fire occurred?] Yes/No	Q. 5	Q. 20a	Q. 21a	Q. 22a

Application of the General Protocol to Group A Recommendations

The following discussion demonstrates the general protocol developed by applying it to the Group A recommendations from The Station Nightclub fire. This includes Recommendations 1, 2, 3, 4, 5, and 7.

Recommendation 1: Adoption of Model Code and Enforcement Through Inspection

Part III in the NFPA survey asked about adoption of model codes, for new or existing occupancies, with or without amendments or other modifications, and the existence of an inspection program, for new or existing occupancies. These questions provide some information relevant to NIST Recommendation 1, which called for all state and local jurisdictions to:

a) adopt a building and fire code covering nightclubs based on one of the national model codes as a minimum requirement (and update local codes as the model codes are revised);
b) implement "aggressive and effective" fire inspection and enforcement programs that address:
   - all aspects of the codes,
   - documentation of building permits and alterations,
   - means of egress inspection and record keeping,
   - frequency and rigor of fire inspections, including follow-up and auditing procedures, and
   - guidelines on recourse available to the inspector for identified deviations from code provisions; and
c) ensure that enough fire inspectors and building plan examiners are on staff to do the job and that they are professionally qualified to a national standard such as NFPA 1031.

Question 1 (requirements) applied to code adoption and inspection program: Have building and fire codes based on national model codes been adopted? Table F is based on two columns each from Tables 2 and 3, which are based on Q's 2 and 3 from the NFPA nightclub survey. No department reported having no codes for either newly constructed or existing nightclubs, and so Table F is describing only communities with a local code not based on any national model code.

Table F. Percent of Departments Having No Local Code Based on National Model Code, for Newly Constructed and Existing Nightclubs

Size of community	Percentage of Departments Having No Code or A Local Code Not Based on a National Model Code	
	Newly Constructed Nightclubs	Existing Nightclubs
500,000 or more	15%	15%
250,000 to 499,999	0%	8%
100,000 to 249,999	7%	7%
50,000 to 99,999	8%	9%
Total	8%	9%

Note: Multiple responses were permitted, and that may affect the results. In the unlikely event that a department reported both "no code" and "local code not based on a model code", there will be double counting. This calculation also assumes that "local code not based on a model code" implies no local use of a model code, even if the department also checked off a model code as being in use.

Table 2 shows that 81% of departments (protecting communities of 50,000 or more population) use the *International Building Code*® (IBC) for newly constructed nightclubs, 35% use NFPA 101, and 30% use an "other" model code, which when specified was almost always a state code based on one of the national model codes. (Note that multiple responses were permitted and communities could and often did select more than one code.)

Table 3 shows that 66% of departments (protecting communities of 50,000 or more population) use the *International Fire Code*® (IFC) for existing nightclubs, 45% use NFPA 101, either as part of NFPA 1 (Fire Code) (22%) or not as part of NFPA 1 (23%), and 18% use an "other" model code, which when specified was almost always a state code based on one of the national model codes. (Note that multiple responses were permitted and communities could and often did select more than one code.)

Question 3 (change after the major event) for Recommendation 1a. The Station nightclub fire occurred in 2003. By the 2006 edition, both NFPA 101 and the IBC had adopted requirements consistent with the NIST recommendations for newly constructed nightclubs (sprinklers regardless of occupancy), and NFPA 101 had adopted requirements consistent with the NIST recommendations for existing nightclubs (sprinklers for occupancy of 100 or more). It should be noted that the NFPA 101 changes were actually processed as Tentative Interim Amendments (TIA) for the 2003 edition of the code, a form of emergency code changes at NFPA, in July of 2003. The survey did not ask specifically about this TIA but instead asked about any changes made after 2003.

Table 4 indicates that only 3% of departments reporting use of the IBC for newly constructed buildings were using a 2003 or earlier edition. Table 5 indicates that 28%

of departments reporting use of NFPA 101 for newly constructed buildings were using a 2003 or earlier edition. Note that 23% of departments use both documents.

Table 6 indicates that only 2% of departments reporting use of the IFC for existing buildings were using a 2003 or earlier edition. However, even the most current edition of the IFC does not include any specific sprinkler requirements for existing nightclubs. Table 7 indicates that 10% of departments reporting use of NFPA 101 for existing buildings (as part of NFPA 1) were using a 2003 or earlier edition. Note that 12% of departments use both documents.

Based on combining these results, **up to 20% of departments are in communities that have not fully implemented the NIST recommendations regarding use of an updated national model code for newly constructed buildings**, consisting of:

- 8% (from Table F) that have no local code based on a model code at all, and

- up to another 12% whose local code may reference only model code editions that precede implementation of requirements like those called for by the NIST recommendations (3% of the 81% using IBC and 28% of the 35% using NFPA 101, assuming that the departments using an older edition of either the IBC or NFPA 101 are not departments that also use an updated edition of the other code).

Also, based on combining these results, **up to 60% of departments are in communities that have not fully implemented the NIST recommendations regarding use of an updated national model code for existing buildings**, consisting of:

- 9% (from Table F) that have no local code based on a model code at all,
- another 5% using an outdated edition of NFPA 101 (10% of the 45% using NFPA 101, assuming the distribution of edition ages for departments using NFPA 101 as part of NFPA 1 is the same as the distribution of edition ages for departments using NFPA 101 not as part of NFPA 1, the latter shown in Table 7), and
- up to all of the 46% of departments whose local code is based on a model code that has not (IFC) or is not known to have ("other" code) implemented requirements like those called for by the NIST recommendations (assuming that a local code based on the IFC or an "other" code is not also based on a current edition of NFPA 101).

Table 8 indicates that 32% of departments have local amendments in place, 9% that have not been changed since 2003, the year of The Station nightclub fire, and the other 23% with local amendments that have been changed since 2003. The remaining 68% of departments have no local amendments. Local amendments can be used to remove requirements from a model code or, much less often, to provide stricter requirements. Code and standard development bodies recommend against the use of local amendments or other modifications that make the requirements less stringent.

Question 1 for Recommendation 1b: Inspections. Before examining estimates of the degree of compliance and programs intended to assure compliance for specific property requirements, it is useful to have an overview of the general provisions for compliance assurance in the communities. Specifically, it is useful to ask whether there are any provisions for inspections to check on compliance.

In the example, this is also the only information currently available for communities with less than 50,000 population. For comparison's sake, consider the percentage of departments for which no one provides fire code inspections, according to the third NFPA fire service needs assessment survey.[5]

Table G indicates that 100% of departments in communities large enough to be included in the NFPA nightclub survey (i.e., at least 50,000 population) have someone who conducts fire code inspections. For smaller communities, particularly communities under 10,000 population, this is not the case. For rural communities (under 2,500 population), more than a third of communities have no one performing fire code inspections.

Also, while not shown in Table G, for communities under 5,000 population, the most frequently cited source of fire code inspections is "Other", not the fire department, a building department, or a separate inspection department. "Other" might include inspections by the state fire marshal's office or an insurance service. "Other" might also include contract inspection personnel reporting to a local authority.

If the nightclub survey had been extended to smaller communities, it is likely that the majority of fire departments serving those communities would report no fire code inspections at all or no fire code inspections under the control and supervision of the fire department.

[5] "Third Needs Assessment of the U.S. Fire Service." *National Fire Protection Association*, June 2011. p.106.

Table G. Percent of Departments Responding to Third Fire Service Needs Assessment Survey Reporting No One Provides Fire Code Inspections

Size of community	No Fire Code Inspections
500,000 or more	0%
250,000 to 499,999	0%
100,000 to 249,999	0%
50,000 to 99,999	0%
25,000 to 49,999	1%
10,000 to 24,999	3%
5,000 to 9,999	10%
2,500 to 4,999	24%
Under 2,500	36%
Total	24%

Table 9 indicates that no departments protecting communities with at least 50,000 population report that there are no inspections in their community. For building code inspections of buildings under construction, 64% of departments reported conducting such inspections, and for the other departments, most if not all may have had inspection programs conducted by the building department, a separate inspection department, or another entity. For fire code inspections of existing buildings, 77% of departments report conducting inspections with at least annual frequency, and 23% report conducting inspections with a less-than-annual frequency. A total of 66% report conducting inspections in response to complaints, which may be instead of or in addition to inspections on a defined schedule and frequency.

NFPA has conducted two major studies of measures of fire code inspection effectiveness, one published in 1979 and the other in 2008.[6] The first study found that none of the departments studied (all protecting populations of at least 250,000), all of which claimed to be achieving annual fire code inspections, were in fact conducting inspections at least once a year. The departments that came closest were using in-service firefighters – who did not have all the training normally required of full-time fire inspectors – to conduct most inspections, which would not comply with NIST Recommendation 1c.

The second study found that requirements for professional certification of all inspectors had reduced the use of in-service firefighters, thereby sharply reducing the volume of inspections conducted. Departments also experienced reductions to inspections triggered by complaints and inspections only for special categories of properties (such

[6] *Fire Code Inspections and Fire Prevention: What Methods Lead to Success?*, NFPA and Urban Institute, 1979; and *Measuring Code Compliance Effectiveness for Fire-Related Portions of Codes*, NFPA and Fire Protection Research Foundation, 2008.

as inspections in support of permits, where there was a revenue stream associated with the permits to offset costs).

The bottom line is that Table 9 (and Q.5, which it is based on) do not show the extent of problems and shortfalls that more detailed studies have consistently and increasingly found.

Summary of evaluation of Recommendation 1.

1. At least 90% of departments protecting communities of 50,000 or more have local codes based on national model codes for both newly constructed and existing nightclubs.
2. Up to 12% of departments fall short of Recommendation 1a for newly constructed nightclubs because they are using an older edition of the code, dating from a time before restrictions based on analysis of The Station Nightclub fire became part of the code.
3. A large share of departments appear to fall short of Recommendation 1a for existing nightclubs because they are relying exclusively on a model fire code (the IFC) which had not adopted the recommended requirements for existing nightclubs. In this context, the use of outdated codes appears to be of lesser importance.
4. 100% of departments protecting communities of 50,000 or more report having some inspections for newly constructed and/or existing buildings. However, other studies have indicated that the situation is sharply different for smaller communities, which were not included in the nightclub survey, or have indicated that the coverage and frequency of inspections are often much less than fire departments believe and report. Notwithstanding the favorable data from the NFPA survey, the true rating on Recommendation 1b is probably quite low.

Summary of protocol for evaluation of recommendations like Recommendation 1.

1. Recommendations that are both very broad and very detailed are often difficult or impossible to evaluate using affordable data that can be obtained from a distance. This is especially true when the only available data consists of summary characterizations by local managers who may not have access to detailed records and analysis to support their estimates and characterizations.
2. An evaluation plan for NIST recommendations should begin by identifying data and analysis options for each recommendation and (often) each detailed sub-recommendation. For some sub-recommendations, meaningful evaluation may not be possible at any price. For others, it may be necessary to choose between (a) evaluating a less detailed version of the sub-recommendation using affordable

survey data or other remotely available data, or (b) evaluating a more detailed version of the sub-recommendation using more expensive on-site methods applied to what will inevitably be a small sample of communities.

3. In many cases, it may be possible to distinguish major versus minor obstacles to successful implementation even when direct quantification of the degree of implementation is prohibitively difficult. For example, when a NIST recommendation has not been adopted by the most widely used national model code, questions about local adoption of the national model, use of updated editions, and compliance assurance through inspections, become moot.
4. Evaluation is likely to be more expensive and more difficult in smaller communities. Programs to improve the level of implementation are also likely to be more difficult in smaller communities because of the lack of economies of scale in all aspects – much lower rates of targets per community, more distinct entities and steps to be dealt with per target reached, lower geographic density and the higher costs of contacting targets, and so forth. At the same time, smaller communities may account for a large share of the total problem to be addressed by the recommendations.
5. Therefore, an evaluation plan should be set separately for large communities (like the communities included in the example, with populations of at least 50,000 each), middle-sized communities (say, in the 10,000 to 50,000 population range), and small communities (say, under 10,000 population). It may make sense to scale back the scope of the evaluation for smaller communities and to set less ambitious goals for degree of implementation in those communities.

Recommendation 2: Sprinklers

Part IV of the NFPA survey asked about requirements for, inspection of, and usage of sprinklers in nightclubs. The data from Part IV addresses part of Recommendation 2, which was that sprinkler system requirements be adopted by national model codes and then adopted and "aggressively" enforced by state and local authorities:

a) for all new nightclubs regardless of size; and
d) for existing nightclubs with an occupancy limit greater than 100 people.

This recommendation, like Recommendations 3-5, is well structured for evaluation using the three questions, as detailed in Table D.

Question 1 (requirements) for Sprinklers: Are there sprinkler requirements, and how do they compare to Recommendation 2? Table D refers to Q.6 for an evaluation of the existence of sprinkler requirements and for characteristics of those requirements.

Q.6 does not distinguish newly constructed nightclubs from existing nightclubs. In hindsight, it would have been better to split Q.6 to provide information directly for these two situations.

For newly constructed nightclubs, the requirements in both major national model codes correspond to the NIST recommendations, requiring sprinklers in all such nightclubs. As noted in the evaluation of Recommendation 1 (Table F), only 8% of the departments have a local code that is not based on one of these two codes. Some of the 8% may have the same requirements in their local code, however, and some of the other departments may have removed that requirement through local amendment.

Table 10 shows that 9% of departments have no sprinkler requirements for nightclubs, and another 11% have requirements that do not apply below an occupancy load of 200. Therefore, 20% of departments do not have requirements that conform to the NIST recommendations. Table H provides the same statistics by size of community.

Table H. Percent of Departments
Without Sprinkler Requirements Consistent With NIST Recommendation 2

Size of community	Percentage of Departments Without Sprinkler Requirements Consistent with Recommendation 2		
	Combined No or Less Strict Requirements	No Requirements	Requirements Less Strict Than in Recommendation 2
500,000 or more	38%	9%	29%
250,000 to 499,999	12%	3%	8%
100,000 to 249,999	17%	9%	8%
50,000 to 99,999	20%	9%	11%
Total	20%	9%	11%

Question 2 (compliance) for Sprinklers: What is the perceived level of compliance with the local requirements? Table D refers to Q.8 for an evaluation of the estimated level of compliance with the requirements in place. Q.7 can be used for estimation of the extent of enforcement programs (e.g., inspections) specifically directed at compliance assurance for these requirements. Some additional analysis has been conducted to check whether the estimated level of compliance varies depending on the strictness of the requirements.

After proportional allocation of "Don't Know" responses, Table 11 shows that 81% of responding departments estimate that all or most nightclubs are in compliance with local sprinkler requirements. Table I shows that this percentage does not vary much by size of community, however there is a clear trend toward higher estimated percentages of full compliance (All but not Most) as the size of the community declines.

Table I. Percent of Departments Estimating All or Most Nightclubs
in Compliance with Sprinkler Requirements, by Size of Community

Size of community	Percentage of Departments Estimating All or Most Nightclubs in Compliance		
	All or Most	All	Most
500,000 or more	78%	33%	46%
250,000 to 499,999	65%	35%	31%
100,000 to 249,999	77%	44%	33%
50,000 to 99,999	85%	60%	25%
Total	81%	51%	30%

Table J shows that estimated compliance declines as the requirements become less strict.

Table J. Percent of Departments Estimating All or Most Nightclubs in Compliance with Sprinkler Requirements, by Requirement

	Percentage of Departments Estimating All or Most Nightclubs in Compliance		
Size of community	**All or Most**	**All**	**Most**
Regardless of occupancy	92%	67%	25%
Occupancy of 50 or more	88%	69%	19%
Occupancy of 100 or more	78%	49%	29%
Occupancy of 200 or more	81%	35%	46%
Total	81%	51%	30%

Table 12 shows that 35% of departments report that they conduct inspections "just to check compliance with sprinkler requirements", and the other 65% report that they do not. There is no clear trend up or down in the percentages conducting inspections as community size shrinks. Therefore, the increase in estimated full compliance by smaller communities in the survey is not a reflection of their having more or less direct information on compliance from inspections. It may be a reflection of smaller communities having only one or two true nightclubs (as opposed to 10-20 drinking establishments generally), making it possible for authorities to focus their attention on the status of only a couple establishments.

Question 3 (change after the major event) for Sprinklers: Did the requirements change after 2003 (the year of The Station nightclub fire)? Table D refers to Q.6a for a determination of the timing of changes to the requirements, which is the only direct information available from a distance that would suggest a change based on reaction to The Station nightclub fire and the lessons learned from it. Table 13 shows that only half of the communities changed their requirements after 2003.

The NFPA nightclub survey was designed to test the ability of generic survey questions to provide useful evaluative information for diverse findings. This particular question may illustrate the limitations of such an approach, because the communities that reported no change could be reporting at least three very different developments:

- It is possible that the local requirements changed when the referenced model code or state code changed, but because that change was not initiated by the community, they do not think of it as a change within the scope of the question.
- It is possible that the local requirements did not change because the community already had stricter requirements in place, thus the changes to the model codes

after The Station nightclub fire did not affect them and did not result in any changes to their local requirements.
- It is possible that the local requirements did not change because the community opted out of the changes to the referenced model or state code through local amendments or failure to adopt updated editions.
- It is possible that communities were aware of the numerous code violations present at the time of The Station fire and they simply redoubled their enforcement efforts for the requirements in effect in their adopted code.

In all of these situations, the issuance of the NIST requirements would not have made any direct difference in the local requirements. However, NIST's goal is to have their recommendations in place in all communities, not to be the reason why those recommendations are in place. Therefore, the evaluation should focus primarily on the answers to Questions 1 and 2, and less on the answer to Question 3.

Summary of evaluation for sprinklers

- 80% of communities with at least 50,000 population have sprinkler requirements in place that are consistent with the NIST recommendations for existing nightclubs. It is likely that 90+% have sprinkler requirements in place that are consistent with the NIST recommendations for newly constructed nightclubs.
- 81% of communities with at least 50,000 population estimate that All (51%) or Most (30%) nightclubs are in compliance with their local requirements. Most communities do not have inspections just to check on these requirements, thus the accuracy of these estimates is uncertain.
- Half of communities with at least 50,000 population and with sprinkler requirements report that their requirements changed after 2003, the year of The Station nightclub fire.

Summary of protocol for evaluation of recommendations like Recommendation 2.

1. Such evaluations are built around answers to three generic questions:
    - the existence of local requirements that are consistent with the NIST recommendations;
    - local estimates of the degree of compliance with local requirements; and
    - whether local requirements changed after the event that formed the basis for the NIST recommendations.
2. The NFPA nightclub survey represented an attempt to answer these questions for several recommendations using generic questions and affordable data collection methods.

3. Recommendation 2 is relatively short and clear-cut, which makes it relatively easy to assess the existence of local requirements that conform to NIST recommendations. Even then, going forward there should be more clear differentiation of newly constructed versus existing establishments.
4. If resources and priorities permit, there would be value in the use of a small sample of site visits or more detailed surveys (including requests for copies of supporting records) to elaborate and spot check local estimates of the degree of compliance.
5. Direct questions about changes to requirements after the precipitating event have a very limited ability to assess the impact of NIST recommendations or any other information or actions triggered by the event. If resources and priorities permit, there would be value in the use of a small sample of site visits to produce more detailed and more fully verified descriptions of how requirements and compliance with requirements developed and the role of different factors in those developments.

Recommendation 3: Interior Finish

Part V of the NFPA survey asked about requirements for, inspection of, and status of interior finish in nightclubs. The data from Part V addresses part of Recommendation 3, which recommended appropriate authorities:

a) adopt and aggressively enforce [relevant] existing provisions of model codes;
b) make sure that non-FR flexible PU foam and any materials with similar ignition or fire propagation properties are clearly identifiable to building owners, operators, contractors, and authorities, and forbid their use in all newly constructed and existing nightclubs; and
c) review and revise the standard test procedures to assure that they will identify undue hazards and will incorporate best measurement and prediction practices.

Parts of this recommendation are directed to the standards development organizations and to the researchers who support their work. This project is concerned with the evaluation of conditions in targeted properties (nightclubs) and fire departments.

Therefore, this recommendation will be evaluated here using the three questions, as detailed in Table D, solely in terms of whether local enforcement actions are well-designed to check on and remove hazardous materials even if they are not so identifiable as Recommendation 3 seeks to make them.

Question 1 (requirements) for Interior Finish: Are there interior finish requirements, and how do they compare to Recommendation 3? Table D refers to Q.9 for an evaluation of the existence of interior finish requirements and to Q.11 for analysis of the use of various measurement methods to check on compliance with the requirements.

Table 14 shows that all departments have interior finish requirements for nightclubs.

- 62% cite the IBC (which has requirements for newly constructed buildings only) as the source;
- 59% cite the IFC (which references the IBC requirements for newly constructed buildings and has nothing specific for existing buildings) as the source;
- 32% cite NFPA 101 (which has requirements for newly constructed and existing buildings) as the source;
- 17% cite NFPA 1 (which derives its requirements from NFPA 101) as the source;
- 10% cite “other” model codes as the source, and based on answers to other questions, those “other” codes are probably nearly all state codes; and
- 3% cite local requirements not based on any model code.

Table 14 provides results by community size. Table 15, based on Q.10, indicates that 93% of communities reference a standard test in their requirements. No information was requested on how the remaining 7% not referencing a standard test determine compliance, but it is possible that some or many of these communities require a certification of compliance with an appropriate test but leave the choice of test or other proof of compliance to the discretion of the parties requesting approval.

Question 2 (compliance) for Interior Finish: What is the perceived level of compliance with the local requirements? Table D refers to Q.13 for an evaluation of the estimated level of compliance with the requirements in place. Q.12 can be used for estimation of the quality of the evidence used to check compliance for these requirements. Some additional analysis has been conducted to check whether the estimated level of compliance varies depending on the type of evidence used.

After proportional allocation of "Don't Know" responses, Table 16 shows that 88% of responding departments estimate that all or most nightclubs are in compliance with local interior finish requirements. Table K shows that this percentage does not vary much by size of community, but there is a clear trend toward higher estimated percentages of full compliance (All but not Most) as the size of the community declines.

Table K. Percent of Departments Estimating All or Most Nightclubs in Compliance with Interior Finish Requirements, by Size of Community

	Percentage of Departments Estimating All or Most Nightclubs in Compliance		
Size of community	**All or Most**	**All**	**Most**
500,000 or more	90%	15%	75%
250,000 to 499,999	91%	25%	66%
100,000 to 249,999	87%	28%	58%
50,000 to 99,999	87%	42%	45%
Total	88%	34%	53%

Table 17 shows that 19% of departments report they conduct inspections "just to check compliance with interior finish requirements". There is a clear trend that conducting these inspections becomes more likely as community size shrinks.

Table 18 shows what percentage of departments are using each of four sources of fire performance information to identify compliant versus non-compliant interior finish.

- 51% of departments protecting populations of 50,000 or more report using visual inspection "only";
- 79% report using a review of specification sheets and technical data for materials;

- 15% use routine testing of materials and 12% conduct testing based on an initial visual screening, presumably of suspect materials.

A question that can likely only be answered with site visits or other more detailed conversations with communities would be how well these methods work to identify non-compliant materials that were installed in an existing nightclub, as was the case in The Station nightclub. It is not clear what would trigger visual screening or review of specification sheets and technical data if the inspectors have no indication that anything has changed.

Table L shows that estimated compliance does not vary much as the nature and quality of the evidence changes from visual inspection only for the use of testing data, specification sheets, routine testing, or testing triggered by visual observation screening.

Table L. Percent of Departments Estimating All or Most Nightclubs in Compliance with Interior Finish Requirements, by Type of Evidence of Compliance

	Percentage of Departments Estimating All or Most Nightclubs in Compliance		
Size of community	**All or Most**	**All**	**Most**
Visual inspection only	84%	32%	52%
Review of spec sheets and other technical data	90%	36%	54%
Testing based on visual screening	93%	35%	59%
Routine testing	91%	33%	58%
Total	88%	34%	53%

Question 3 (change after the major event) for Interior Finish: Did the requirements change after 2003 (the year of The Station nightclub fire)? Table D refers to Q.9h for a determination of the timing of changes to the requirements, which is the only direct information available from a distance that would suggest a change based on a reaction to The Station nightclub fire and the lessons learned from it. Table 19 shows that 29% of the communities changed their requirements after 2003.

The NFPA nightclub survey was designed to test the ability of generic survey questions to provide useful evaluative information for diverse findings. This particular question may illustrate the limitations of such an approach, as the communities that reported no change could be reporting at least three very different developments:

- It is possible that the local requirements changed when the referenced model code or state code changed, but because that change was not initiated by the community, they do not think of it as a change within the scope of the question.
- It is possible that the local requirements did not change because the community already had stricter requirements in place, thus the changes to the model codes after The Station nightclub fire did not affect them and did not result in any changes to their local requirements.
- It is possible that the local requirements did not change because the community opted out of the changes to the referenced model or state code through local amendments or failure to adopt updated editions.
- It is possible that communities were aware of the numerous code violations present at the time of The Station fire and they simply redoubled their enforcement efforts for the requirements in effect of their adopted code.

In all of these situations, the issuance of the NIST requirements would not have made any direct difference in the local requirements. However, NIST's goal is to have their recommendations in place in all communities, not to be the reason why those recommendations are in place. Therefore, the evaluation should focus primarily on the answers to Questions 1 and 2, and less on the answer to Question 3.

Summary of evaluation for interior finish:

- All communities with at least 50,000 population have interior finish requirements in place, but more than half of the departments (those not citing NFPA 101 or NFPA 1 as a source, assuming no overlap) appear to have no requirements in place for existing buildings. Nearly all (93%) reference a standard test, and the others may have requirements that indirectly reference a standard test, such as by referencing a certification requirement that will be handled by entities that use standard tests.
- 88% of communities with at least 50,000 population estimate that All (34%) or Most (53%) nightclubs are in compliance with their local requirements. Most (81%) communities do not have inspections just to check on these requirements, thus the accuracy of these estimates is uncertain. Most inspections are limited to visual inspection and/or review of specification sheets and other technical data on materials, but it is not clear that any departments have a reliable mechanism – or an applicable requirement – that will trigger identification of hazardous conditions added to an existing nightclub.
- 29% of communities with at least 50,000 population and interior finish requirements report that their requirements changed after 2003, the year of The Station nightclub fire.

Summary of protocol for evaluation of recommendations like Recommendation 3.

1. Such evaluations are built around answers to three generic questions:
   - the existence of local requirements that are consistent with the NIST recommendations;
   - local estimates of the degree of compliance with local requirements; and
   - whether local requirements changed after the event that formed the basis for the NIST recommendations.
2. The NFPA nightclub survey represented an attempt to answer these questions for several findings using generic questions and affordable data collection methods.
3. Recommendation 3 is complex in that it can only be fully assessed through data that characterizes the fire properties in all new and existing nightclubs. No community has such data or anything remotely similar. In terms of achieving the nightclub conditions intended by this recommendation, the key might be the recommendation that all interior finish materials be easily identifiable as to their compliance. Even that would not be sufficient to assure compliance in existing nightclubs unless there were a mandatory trigger – such as a permit requirement – for compliance assurance whenever an interior finish is modified. In the absence of such a trigger and of a sub-recommendation that would have that effect, it is difficult to determine, from available data, how successfully a community is in monitoring interior finish in its nightclubs.
4. If resources and priorities permit, there would be value in the use of a small sample of site visits to elaborate and spot check local estimates of the degree of compliance.
5. Direct questions about changes to requirements after the precipitating event have a very limited ability to assess the impact of NIST recommendations or any other information or actions triggered by the event. If resources and priorities permit, there would be value in the use of a small sample of site visits to produce more detailed and more fully-verified descriptions of how requirements and compliance with requirements developed and the role of different factors in those developments.

Recommendation 4: Indoor Use of Pyrotechnics

Part VI of the NFPA survey asked about requirements for, inspection of, and status of indoor use of pyrotechnics in nightclubs. The data from Part VI addresses part of Recommendation 4, which called for jurisdictions to adopt and aggressively enforce NFPA 1126. A further part of the recommendation centers on strengthening some of the provision in NFPA 1126. The recommendations for strengthening were directed at NFPA and are outside the scope of this project, which focuses on recommended changes of conditions in the field.

Therefore, this recommendation will be evaluated here using the three questions, as detailed in Table D, solely in terms of whether NFPA 1126 has been adopted and is being enforced through inspections.

Question 1 (requirements) for Indoor Pyrotechnics: Are there indoor pyrotechnics requirements, and how do they compare to Recommendation 4? Table D refers to Q.14 for an evaluation of the existence of indoor pyrotechnics requirements and for the conformance of those requirements to Recommendation 4 (i.e., specific reference to NFPA 1126).

Table 20 shows that 66% of departments protecting communities of 50,000 or more population have local restrictions based on NFPA 1126, and 98% have some kind of local restrictions on indoor use of pyrotechnics in nightclubs. Table 20 also provides results by community size.

Question 2 (compliance) for Indoor Pyrotechnics: What is the perceived level of compliance with the requirements? Table D refers to Q.16 for an evaluation of the estimated level of compliance with the requirements in place.

After proportional allocation of "Don't Know" responses, Table 21 shows that 97% of responding departments estimate that all or most nightclubs are in compliance with local indoor pyrotechnics requirements. Table M shows that this percentage does not vary much by size of community, but there is a clear trend toward higher estimated percentages of full compliance (All but not Most) as the size of the community declines.

Table M. Percent of Departments Estimating All or Most Nightclubs in Compliance with Indoor Pyrotechnics Requirements, by Size of Community

	Percentage of Departments Estimating All or Most Nightclubs in Compliance		
Size of community	**All or Most**	**All**	**Most**
500,000 or more	100%	55%	45%
250,000 to 499,999	92%	60%	32%
100,000 to 249,999	96%	81%	15%
50,000 to 99,999	98%	85%	13%
Total	97%	79%	18%

Table 22 shows that only 85% of departments report they conduct inspections "just to check compliance with indoor pyrotechnics requirements". There is a clear trend that conducting these inspections becomes more likely as community size increases.

Table 22 also shows what percentage of departments are using each of three triggers for inspections.

- 64% of departments protecting populations of 50,000 or more report conducting inspections at events;
- 50% report conducting inspections with managers in advance of events;
- 51% report conducting inspections based on complaints, concerns, or requests received in advance of or at events.

Table N shows that the estimated compliance does not vary much based on the use or non-use of inspections or the type of inspections used. Departments reporting no inspections were more likely to report "Don't Know" for compliance – 20% versus 2-4% for the three options with inspections – but when estimating, they were more likely to estimate full compliance by all nightclubs than the other three options.

Table N. Percent of Departments Estimating All or Most Nightclubs in Compliance with Interior Pyrotechnics Requirements, by When and Why Inspections Are Conducted

	Percentage of Departments Estimating All or Most Nightclubs in Compliance		
When or Why Inspection Conducted	**All or Most**	**All**	**Most**
Inspections at events	97%	75%	22%
Inspections with managers in advance of events	97%	75%	22%
Inspections based on complaints, concerns or requests	97%	72%	25%
No inspections	96%	89%	7%
Total	97%	79%	18%

Question 3 (change after the major event) for Indoor Pyrotechnics: Did the requirements change after 2003 (the year of The Station nightclub fire)? Table D refers to Q.14e for a determination of the timing of changes to the requirements, which is the only direct information available from a distance that would suggest a change based on reaction to The Station nightclub fire and the lessons learned from it. Table 23 shows that only18% of the communities changed their requirements after 2003.

The NFPA nightclub survey was designed to test the ability of generic survey questions to provide useful evaluative information for diverse recommendations. This particular question may illustrate the limitations of such an approach, because the communities that reported no change could be reporting at least three very different developments:

- It is possible that the local requirements changed when the referenced model code or state code changed, but because that change was not initiated by the community, they do not think of it as a change within the scope of the question.
- It is possible that the local requirements did not change because the community already had stricter requirements in place, thus the changes to the model codes after The Station nightclub fire did not affect them and did not result in any changes to their local requirements.
- It is possible that the local requirements did not change because the community opted out of the changes to the referenced model or state code, through local amendments or failure to adopt updated editions.
- It is possible that communities were aware of the numerous code violations present at the time of The Station fire and they simply redoubled their enforcement efforts for the requirements in effect in their adopted code.

In all of these situations, the issuance of the NIST requirements would not have made any direct difference in the local requirements. However, NIST's goal is to have their recommendations in place in all communities, not to be the reason why those recommendations are in place. Therefore, the evaluation should focus primarily on the answers to Questions 1 and 2, and less on the answer to Question 3.

Summary of evaluation for indoor pyrotechnics

- 98% of communities with at least 50,000 population have indoor pyrotechnics requirements in place, and 66% of communities specifically reference NFPA 1126.
- 97% of communities with at least 50,000 population estimate that All (79%) or Most (18%) nightclubs are in compliance with their local requirements. Most (85%) communities conduct inspections to reinforce compliance, using some combination of inspections at events, inspections with managers in advance of events, and inspections based on complaints, concerns, or requests. Estimates of

compliance show almost no difference based on the type of inspection conducted or even whether there are any inspections at all.

- 18% of communities with at least 50,000 population and indoor pyrotechnics requirements report that their requirements changed after 2003, the year of The Station nightclub fire.

Summary of protocol for evaluation of recommendations like Recommendation 4.

1. Such evaluations are built around answers to three generic questions:
   - the existence of local requirements that are consistent with the NIST recommendations;
   - local estimates of the degree of compliance with local requirements; and
   - whether local requirements changed after the event that formed the basis for the NIST recommendations.
2. The NFPA nightclub survey represented an attempt to answer these questions for several recommendations using generic questions and affordable data collection methods.
3. Recommendation 4 is complex in that it seeks to control potentially hazardous practices and not fixed, installed hazards. Communities likely do not have databases that routinely track violations by the monitoring of all or a representative sample of events, thus the direct assessment of compliance is not possible with existing data. Even site visits would be unable to acquire this kind of data.

Recommendation 5: Occupancy Limits and Egress Requirements

Part VII of the NFPA survey asked about requirements for, inspection of, and status of occupancy limits and egress requirements in nightclubs. The data from Part VII addresses part of Recommendation 5, which recommended strengthening code and standard development organizations (which is outside the scope of this project, which focuses on recommended changes of conditions in the field), adopting model code requirements, and using inspections to achieve compliance with those requirements.

Question 1 (requirements) for Occupancy Limits and Egress Requirements: Are there occupancy limits for nightclubs, and how do they compare to Recommendation 5? Table D refers to Q.17 for an evaluation of the existence of occupancy limit requirements and for the sources of those requirements, which is the only information available on how those requirements compare to Recommendation 5.

Table 24 shows that all departments have egress and/or occupancy limit requirements for nightclubs.

- 76% cite the IBC (which has requirements for newly constructed buildings only) as the source;
- 34% cite NFPA 101 (which has requirements for newly constructed and existing buildings) as the source;
- 30% cite "other" model codes as the source, and based on answers to other questions, those "other" codes are likely nearly all state codes; and
- 5% cite local requirements not based on any model code.

Question 2 (compliance) for Occupancy Limits and Egress Requirements: What is the perceived level of compliance with the requirements? Table D refers to Q.19 for an evaluation of the estimated level of compliance with the requirements in place.

After proportional allocation of "Don't Know" responses, Table 25 shows that 96% of responding departments estimate that all or most nightclubs are in compliance with local occupancy requirements.

Table O. Percent of Departments Estimating All or Most Nightclubs in Compliance with Occupancy Requirements, by Size of Community

Size of community	Percentage of Departments Estimating All or Most Nightclubs in Compliance		
	All or Most	All	Most
500,000 or more	100%	15%	85%
250,000 to 499,999	100%	33%	67%
100,000 to 249,999	92%	36%	56%
50,000 to 99,999	97%	51%	46%
Total	96%	42%	54%

Table O shows that this percentage does not vary much by size of community, but there is a clear trend toward higher estimated percentages of full compliance (All but not Most) as the size of the community declines.

Table 26 shows that 56% of departments report they conduct inspections "just to check compliance with egress requirements and/or occupancy limits for nightclubs". There is a clear trend that conducting these inspections becomes more likely as community size increases.

Table 26 also shows the frequency of these special inspections:

- 1% of departments protecting populations of 50,000 or more report conducting inspections roughly every evening;
- 6% report conducting inspections at least weekly;
- 49% report conducting inspections on a less than weekly frequency.

Table P shows that estimated compliance is lower with less frequent inspections. Departments conducting no inspections gave estimates of compliance that were similar to those from departments with weekly inspections and better than those from departments with less than weekly inspections. This appears to reveal a pattern of excessive optimism on the part of departments that do not conduct inspections. Departments reporting no inspections were more likely to report "Don't Know" for compliance – 12% versus 0-1% for the three options with inspections.

Table P. Percent of Departments Estimating All or Most Nightclubs in Compliance with Occupancy Requirements, by Frequency of Inspections

Frequency of Inspections	Percentage of Departments Estimating All or Most Nightclubs in Compliance		
	All or Most	All	Most
Inspections roughly every evening	100%	67%	33%
Inspections at least weekly	100%	54%	46%
Inspections with less than weekly frequency	95%	33%	62%
No special inspections	98%	51%	47%
Total	96%	42%	54%

Question 3 (change after the major event) for Occupancy Limits and Egress Requirements: Did the requirements change after 2003 (the year of The Station nightclub fire)? Table D refers to Q.17f for a determination of the timing of changes to the requirements, which is the only direct information available from a distance that would suggest a change based on a reaction to The Station nightclub fire and the lessons learned from it. Table 27 shows that only 12% of the communities changed their requirements after 2003.

- It is possible that communities were aware of the numerous code violations present at the time of The Station fire and they simply redoubled their enforcement efforts for the requirements in effect in their adopted code.

Summary of evaluation for occupancy limits and egress requirements

- 100% of communities with at least 50,000 population have occupancy limits in place, and 95% of communities reference a model code, either directly or indirectly. However, Recommendation 5 anticipated changes to the rules used to calculate occupancy limits, and those changes, other than sizing of the main entrance/exit to be of a width that accommodates two-thirds of the total occupant load, do not appear to have made their way into the model codes and standards, let alone local requirements and practices.

- 96% of communities with at least 50,000 population estimate that All (42%) or Most (54%) nightclubs are in compliance with their local occupancy limit requirements. The majority (56%) of communities conduct inspections to reinforce compliance, but most (49% of the 56%) conduct these inspections less often than weekly. More frequent inspections are associated with higher estimates of full compliance and departments with no inspections appear to be over-estimating levels of compliance as they are estimating compliance levels better than those with less-than-weekly special inspections.
  12% of communities with at least 50,000 population and occupancy limit requirements report that their requirements changed after 2003, the year of The Station nightclub fire.

Summary of protocol for evaluation of recommendations like Recommendation 5.

1. Such evaluations are built around answers to three generic questions:
   - the existence of local requirements that are consistent with the NIST recommendations;
   - local estimates of the degree of compliance with local requirements; and
   - whether local requirements changed after the event that formed the basis for the NIST recommendations.

   When the model codes have not yet changed in all of the areas to better align with the NIST recommendations, all three of these questions about local conditions become moot.

2. Recommendation 5 is complex in that it seeks to control potentially hazardous practices and not fixed, installed hazards. Most communities do not check all or a representative sample of daily practices, thus direct assessment of compliance is not possible with existing data.

Recommendation 7: Fire Department Emergency Response

Part VIII of the NFPA survey asked about adoption of and adherence to four NFPA standards for emergency response – NFPA 1221, NFPA 1561, NFPA 1710, and NFPA 1720. Since these recommendations are for changes in fire department practices, the adoption and compliance steps are not separate.

Question 1 (requirements) for Emergency Communications Systems: Does the department adopt and adhere to NFPA 1221? Table E refers to Q.20 for information on the use of NFPA 1221. Table 28 indicates that 55% of departments protecting communities of 50,000 or more population are using NFPA 1221, and the percentage does not vary much as the size of community decreases.

Question 3 (change after the major event) for Emergency Communications Systems: Did the requirements change after 2003 (the year of The Station nightclub fire)? Table E refers to Q.20a for a determination of the timing of changes to the requirements, which is the only direct information available from a distance that would suggest a change based on reaction to The Station nightclub fire and the lessons learned from it. Table 29 shows that only 14% of the communities changed their requirements after 2003.

Question 1 (requirements) for Incident Management Systems: Does the department adopt and adhere to NFPA 1561? Table E refers to Q.21 for information on the use of NFPA 1561 or the National Emergency Management System (NIMS). Table 30 indicates that 94% of departments protecting communities of 50,000 or more population are using NFPA 1561 or NIMS, and the percentage does not vary much as the size of community decreases.

Question 3 (change after the major event) for Incident Management Systems: Did the requirements change after 2003 (the year of The Station nightclub fire)? Table E refers to Q.21a for a determination of the timing of changes to the requirements, which is the only direct information available from a distance that would suggest a change based on reaction to The Station nightclub fire and the lessons learned from it. Table 31 shows that only 15% of the communities changed their requirements after 2003.

Question 1 (requirements) for Organization and Deployment for Career and Volunteer Departments: Does the department adopt and adhere to NFPA 1710 or 1720? Table E refers to Q.22 for information on the use of NFPA 1710 or 1720. Table 32 indicates that 80% of departments protecting communities of 50,000 or more population are using NFPA 1710 or 1720, and the percentage does not vary much as the size of community decreases.

Question 3 (change after the major event) for Organization and Deployment for Career and Volunteer Departments: Did the requirements change after 2003 (the year of The Station nightclub fire)? Table E refers to Q.22a for a determination of the timing of changes to the requirements, which is the only direct information available from a distance that would suggest a change based on reaction to The Station nightclub fire and the lessons learned from it. Table 33 shows that only 12% of the communities changed their requirements after 2003.

Summary of evaluation for fire department emergency response practices

- 55% of communities with at least 50,000 population are using NFPA 1221.
- 94% of communities with at least 50,000 population are using NFPA 1561 or NIMS.
- 80% of communities with at least 50,000 population are using NFPA 1710 or 1720.
- 12-15% of communities with at least 50,000 population report that their use of these standards changed after 2003, the year of The Station nightclub fire.

Summary of protocol for evaluation of recommendations like Recommendation 7.

1. Such evaluations are built around answers to two generic questions:
   - whether local departments have adopted the standards and practices recommended by NIST (or more likely, incorporated them into fire department standard operating practices);
   - whether local requirements changed after the event that formed the basis for the NIST recommendations.

Section 2: Analysis of Changes to Model Codes and Standards

General Protocol

The impact of recommendations related to changes to laws and enforcement occurs in multiple stages. First, model codes and standards must incorporate the recommendations. Second, the codes and standards adopted by states must incorporate the changes to the model codes and standards. Finally, local practices must incorporate the changes to state codes and standards. Because of this staged approach, the changes in the model codes and standards must be analyzed first to assess the extent of changes to the model codes and standards related to the NIST recommendations. Then, state changes and local practices are assessed using the approach described in Section 1.

Applying to the Example

The purpose of this task was to evaluate the extent to which model codes and standards incorporated recommendations 2-5 of the NIST NCST Report on The Station Nightclub fire. This involved analyzing the specific changes that have been made to model codes and standards related to these recommendations.

Recommendation 2: Sprinklers

The NIST investigation report makes the following recommendations related to sprinkler protection in nightclubs:

Recommendation 2. Sprinklers: *NIST recommends that model codes require sprinkler systems according to NFPA 13 (Standard for the Installation of Sprinkler Systems), and that state and local authorities adopt and aggressively enforce this provision:*

> *a) for all new nightclubs regardless of size, and*
>
> *b) for existing nightclubs with an occupancy limit greater than 100 people.*

The model codes considered for this recommendation were the NFPA model codes (NFPA 1, , NFPA 101, and NFPA 5000) and the International Code Council's IBC, IEBC and IFC. Focus was placed on the editions of these model codes that were issued directly before The Station Nightclub fire and those issued after the fire.

In the 2003 editions, NFPA model codes required sprinklers in new assembly occupancies with occupant loads greater than 300. For existing assembly occupancies, the 2003 editions require automatic sprinkler systems in existing assembly occupancies used or capable of being used for exhibition or display purposes where the display area exceeds 15,000 square feet, but possess no specific requirements for existing nightclub occupancies.

NFPA has a process for issuing emergency code amendments called TIAs. The following TIAs went into effect August 14, 2003:

- Requirement for sprinklers to be installed in all new nightclub-type occupancies (bars, dance halls, discotheques, nightclubs, and assembly occupancies with festival seating).
- Requirement for sprinklers to be installed in existing nightclub-like assemblies with occupant loads greater than 100.

The above TIAs were issued for the 2003 editions of the NFPA 1, NFPA 101, and NFPA 5000. These new requirements were then accepted into the 2006 editions.

The 2003 editions of the IBC and IFC requires sprinklers for new Group A-2 occupancies (assembly uses intended for food and/or drink consumption) where one of the following conditions exist:

- The fire area exceeds 5,000 square feet
- The fire area has an occupant load of 300 or more
- The fire area is located on a floor other than the level of exit discharge

The 2006 editions of the IBC and IFC changed the requirements for sprinklers for new Group A-2 occupancies. Sprinklers are required where one of the following conditions exist:

- The fire area exceeds 5,000 square feet
- The fire area has an occupant load of **100 or more**
- The fire area is located on a floor other than the level of exit discharge

The IBC covers existing structures in Chapter 34, which details the requirements for alteration, repair, addition, and change of occupancy of existing structures. The evaluation process used in Chapter 34 is based on the requirements for new construction for all categories (including presence of automatic sprinklers).

The 2003, 2006, 2009, and 2012 editions of the IEBC address automatic sprinklers requirements based on the level of change occurring in the building. No change was made between the editions related to requirements for automatic sprinklers for existing assembly occupancies. For assembly occupancies undergoing Level 2 and 3 alterations, sprinklers are required when the occupant load is greater than 30, the work area exceeds 50% of the floor area, and there is sufficient municipal water supply to the floor.

In the 2006 edition of the IEBC for changes in occupancy in existing buildings, there was a change related to sprinkler systems. Where a change in occupancy occurs that requires a sprinkler system to be provided for new construction per the IBC, a sprinkler system must be installed. This is a change from the 2003 edition, which required changes in occupancy in the same manner as Level 3 alterations.

Recommendation 3: Interior Finish Materials

The NIST investigation report makes the following recommendations related to interior finish and contents in nightclubs:

Recommendation 3. Finish Materials and Building Contents: *NIST recommends that:*

> *a) state and local authorities adopt and aggressively enforce the existing provisions of the model codes;*
>
> *b) non-fire retarded flexible polyurethane foam, and other materials that ignite as easily and propagate flames as rapidly as non-fire retarded flexible polyurethane foam: (i) be clearly identifiable to building owners, operators, contractors and authorities having jurisdiction (regulatory agencies); and (ii) be specifically forbidden, with no exceptions, as finish materials from all new and existing nightclubs;*
>
> *c) NFPA 286 (Standard Methods of Fire Tests for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth) be modified to provide more explicit guidance for when large-scale tests are required to demonstrate that materials (other than those already forbidden in b above) do not pose an undue hazard for the use intended; and*
>
> *d) ASTM E-84 (Standard Test Method for Surface Burning Characteristics of Building Materials), NFPA 255 (Standard Method of Test of Surface Burning Characteristics of Building Materials), and NFPA 286 be modified to ensure that product classification and the pass/fail criteria for flame spread tests and large-scale tests are established using the best measurement and prediction practices available.*

The model codes considered for this recommendation were the NFPA model codes (NFPA 1, NFPA 101, and NFPA 5000) and the International Code Council's IBC and IFC. Focus was placed on the editions of these model codes that were issued directly before The Station Nightclub fire and those issued after the fire.

Part A of the above recommendations is covered by the analysis of state and local practices (Section 1).

Related to Part B, based on the NIST investigation report, the model codes already prohibited the use of foam plastic insulation as an interior finish material without passing a large scale test that replicates end-use conditions. There were no changes in Chapter 26 of the IBC, which regulates the use of plastics, between the 2003 and later editions (2006, 2009, and 2012 editions). There were also no changes to Chapter 48 of NFPA 5000, which regulates the use of plastics, between the 2003 and later editions.

One change was made in the 2006 edition of the IFC (from the 2003 edition). This change allows foam plastics as an interior wall or ceiling finish if separated from the interior of the building by a thermal barrier in accordance with the IBC. No changes were made between the 2003 and later editions of NFPA 1 related to use of foam plastics or interior finish requirements for assembly occupancies.

The interior finish requirements for Group A-1 and A-2 occupancies (which includes nightclubs) in the IBC did not change from the 2003 to the later editions except for one small change in the 2006 edition, which added a compliance item for those interior finish materials tested in accordance with NFPA 286. This addition requires that the peak rete of heat release throughout the NFPA 286 test not exceed 800 kW. This same change was made between the 2003 and 2006 editions of NFPA 5000 and NFPA 101. No other changes related to interior finish requirements were made between the 2003 and 2006 editions of NFPA 5000 or NFPA 101.

For Part C, no specific changes were made to NFPA 286 that included more explicit guidance for when large scale tests are required. The same applies to Part D, no specific changes as specified in the NIST recommendations were made to ASTM E-84, NFPA 255, or NFPA 286.

Recommendation 4: Indoor Use of Pyrotechnics

The NIST investigation report makes the following recommendations related to the use of indoor pyrotechnics:

Recommendation 4. Indoor Use of Pyrotechnics: *NIST recommends that NFPA 1126 (Use of Pyrotechnics before a Proximate Audience) be strengthened as described below, and that state and local authorities adopt and aggressively enforce the revised standard.*

> *a) Pyrotechnic devices should be banned from indoor use in new and existing nightclubs not equipped with an NFPA 13 compliant automatic sprinkler system.*
>
> *b) NFPA 1126 should be modified to include a minimum occupancy and/or area for a nightclub below which pyrotechnic devices should be banned from indoor use, irrespective of the installation of an automatic sprinkler system.*
>
> *c) Plans for the use of indoor pyrotechnics in new and existing nightclubs should be posted on site; and in addition to the items listed in paragraph 4.3.2 of NFPA 1126, should describe the measures that have been established to provide crowd management, security, fire protection, and other emergency services.*
>
> *d) Section 6.6.2 of NFPA 1126 should be modified to require the minimum clearance between (i) the nearest fixed or moveable contents, and (ii) any part or product (igniter, spark, projectile, or debris) of a pyrotechnic device permitted for indoor use in new and existing places of assembly, to be twice the designed projection of the device, until such time that studies show that a smaller minimum clearance can guarantee safe operation in spite of the possibility that building decorations or temporary features that greatly exceed flame spread or fire load provisions of the fire code may occur.*

No specific changes were made in NFPA 1126 owing to the NIST recommendations. The standard has requirements for permits, checklists, and demos of all effects. The separation distances also remained the same.

Recommendation 5: Occupancy Limits and Egress Requirements

The NIST investigation report makes the following recommendations related to the occupancy limits and emergency egress in nightclubs:

Recommendation 5. Occupancy Limits and Emergency Egress: *NIST recommends that the factor of safety for determining occupancy limits of all new and existing nightclubs be increased in the model codes in the following manner, and that state and local authorities adopt and aggressively enforce the following provisions:*

> *a) Within the model codes, establish the threshold building area and occupant limits for egress provisions using best practices for estimating tenability and evacuation time; and, unless further studies indicate another value is more appropriate, use 1-1/2 minutes as the maximum permitted evacuation time for nightclubs similar to or smaller than The Station.*
>
> *b) Compute the number of required exits and the permitted occupant loads assuming at least one exit (including the main entrance) will be inaccessible in an emergency evacuation.*
>
> *c) For nightclubs with one clearly identifiable main entrance, increase the minimum capacity of the main entrance to accommodate two-thirds of the maximum permitted occupant level (based upon standing space or festival seating, if applicable) during an emergency.*
>
> *d) Eliminate trade-offs between sprinkler installation and factors that impact the time to evacuate buildings.*
>
> *e) Require staff training and evacuation plans for nightclubs that cannot be evacuated in less than 1-1/2 minutes.*
>
> *f) Provide improved means for occupants to locate emergency routes—such as explicit evacuation directions prior to the start of any public event, exit signs near the floor, and floor lighting—for when standard exit signs become obscured by smoke.*

The model codes considered for this recommendation were the NFPA model codes (NFPA 1, NFPA 101, and NFPA 5000) and the International Code Council's IBC and IFC. Focus was placed on the editions of these model codes that were issued directly before The Station Nightclub fire and those issued after the fire.

For Part A and B of Recommendation 5, there are no specific requirements in the model codes on maximum permitted evacuation time for nightclubs and no provisions on computing the number of required exits assuming at least one exit is inaccessible.

A change was made to the 2006 editions of the NFPA model codes relating to Part C. Specifically, the main entrance/exit width for new nightclubs was increased from a minimum of one-half to two-thirds of the total occupant load. The other exits are still required to accommodate a minimum of one-half the total occupant load. Both the 2003 and later editions (2006, 2009, and 2012 editions) of the IBC require the main exit to accommodate not less than one-half of the total occupant load.

No specific changes were made to the model codes for Part D of the recommendation. The capacity factors used for calculating exit width remained the same in all model codes. The IBC uses different factors for sprinklered and unsprinklered buildings. NFPA uses the same factors for both. In addition, maximum travel distances remained the same in all model codes with longer distances allowed for sprinklered buildings.

Several provisions in the model codes address crowd managers, staff emergency training, and evacuation plans relating to Part E. Both the 2003 and later versions of the IFC require fire safety and evacuation plans for all assembly occupancies (other than those used for religious worship) with a requirement for training of employees in the fire emergency procedures at orientation and annually thereafter. Fire and evacuation drills are also required quarterly for employees.

NFPA model codes have similar requirements for emergency plans for assembly occupancies and include requirements for all staff of assembly occupancies to be trained and drilled in the duties they are expected to perform in the event of an emergency.

One change of note related to Part E was that the 2006 and later editions of the NFPA model codes instituted a provision that requires at least one trained crowd manager to be present for all gatherings, except religious services. For gatherings larger than 250 occupants, additional crowd managers are required at a ratio of 1:250 occupants. The 2003 NFPA model codes only require a crowd manager where the occupant load exceeds 1000. The 2009 and later editions of the IFC implemented a requirement for crowd managers where the occupant load exceeds 1000 at a ratio of 1:250 occupants.

The recommendation in Part F did not result in any specific changes in the model code requirements. Both the 2003 and later editions of the IBC require illumination of the means of egress of 1 foot candle at the walking surface and require assembly occupancies with occupant loads greater than 1,000 to have an emergency voice/alarm communication system per NFPA 72, *National Fire Alarm and Signaling Code*.

The illumination levels in the NFPA model codes also did not change from the 2003 to the later editions, which require illumination of 10 foot candle in new stairs and 1 foot candle for all other walking surfaces. In addition, both editions require floor proximity exit signs for both new and existing assemblies. For both new and existing assembly occupancies, the 2003 and later editions of the NFPA model codes require occupant notification through visible signals and by voice communication, either live or prerecorded.

Although it is not explicitly stated, the presence and training of crowd managers is an important topic related to this recommendation. As discussed above, both the NFPA model codes and IFC implemented a change related to the presence of crowd managers at large events. Further, it was noted during discussions with the Technical Panel that the addition of crowd manager training requirements to the 2015 edition of IFC is proposed. In addition, changes are being proposed to the 2015 edition of NFPA 101 related to crowd manager training. These changes are a result of the lessons learned from The Station fire.

Summary Observations: Analysis of Changes to Model Codes

General Protocol Observations

A key recommendation is that the model code analysis should be completed first for any future evaluations. This is because the changes to the model codes typically need to take place before changes are made on the local level due to the model code adoption process used by most jurisdictions. If there are no changes in the model code, there is no expected change on the local level.

Another recommendation for future studies is that this evaluation process may need to be completed more than once to capture the full impact of the recommendations. This is because occasionally it takes a few cycles for a change to get into the model codes. This can be seen with changes to the 2015 editions related to crowd managers. Following this, the states and local jurisdictions will need to adopt these editions of the codes in order for local laws to change.

Thirdly, it is recommended that all the issues related to a recommendation should be tracked individually. For example, the requirements for crowd managers should be examined separately from training requirements for crowd managers to accurately assess the impact. This may also relate to the specific wording of recommendations as well.

Observations Related to the Example

The NIST recommendations had some impact on changes in the model codes and standards. This was especially true of automatic sprinkler requirements for assembly occupancies. The 2006 editions of the IBC and IFC require sprinklers in all new nightclubs with an occupant load of 100 or more (previous editions were 300 or more). The 2006 editions of the NFPA model codes require sprinklers for all new nightclub occupancies and for existing nightclubs where the occupant load is more than 100.

Specific changes related to interior finish requirements and indoor use of pyrotechnics related to the NIST recommendations were not found.

Two changes were made to the 2006 and later editions of the NFPA model codes related to the occupancy limit and emergency egress recommendations made by NIST. Specifically, the capacity of the main exit/entrance was increased to accommodate two-thirds of the total occupant load. The second change was a requirement for crowd managers for all gatherings over 250, except religious services, at a ratio of 1:250 occupants. The 2009 and later editions of the IFC also require a crowd manager for all gatherings over 1000 at a ratio of 1:250 occupants.

Section 3: Literature Review of Research-Based Recommendations

General Protocol

To evaluate the impact of recommendations relating to research, the preferred approach is to conduct a literature review. The materials that are of interest for this type of literature review include:

- Published research (e.g., academia, government laboratories, private industry)
- Programs, plans, and agendas for research not yet completed;
- Research assembled or conducted as input to revisions of model codes, standards, and similar documents (e.g., ASTM, ICC, ISO, NFPA, SFPE)
- Research on the effectiveness of model codes, standards, and similar documents

The research recommendations are intended to lead to research that will in turn result in new rules and practices. To provide some assessment of the degree of progress toward this goal, the literature sources should be evaluated on the following:

- Quality (e.g., originality, peer-reviewed), including notes on availability as applicable (e.g., proprietary vs. non-proprietary)
- Relevance (e.g., relevance to topic, degree of progress toward eventual goal of recommendations on rules and practices) using a rating system

Applying to the Example

A literature review approach was used to address recommendations 6 & 8-10 of the NIST NCST Report on The Station Nightclub fire. These recommendations are related to research on fire-related phenomena and mitigation methods, human behavior in emergencies, and tools to aid in response to emergencies. Specifically, the sub-bullets under each recommendation were the focus of the literature review.

Each source is summarized and notes are provided related to the originality of the data for each study (i.e., original data collected or study done with existing data from other studies), whether the literature source is peer reviewed, whether the source references the NIST NCST Report on The Station Nightclub fire, and each relevant piece of literature is provided with a relevancy score. The relevancy score is based on a scale from 1 to 3 as it relates to the specific recommendation made in the NIST report. Literature that is rated a 3 has the most relevancy to the NIST recommendation, which means that it best addresses the research need identified by NIST. Since the recommendations were published in June 2005, only literature published after this publication date was considered. In addition to topical searches, a search was completed using the full report title to find all documents that cite the NIST report as a reference. Some of the sources found that cite the NIST report did not necessarily complete research on a topic recommended by NIST, but instead used data or other information from the report. These resources are included below because these are also of interest to NIST. However, these types of publications were given lower relevance ratings because they were not a direct response to research recommendations from NIST.

Recommendation 6: Portable Fire Extinguishers

Recommendation 6 of the NIST NCST investigation report relates to portable fire extinguishers:

Recommendation 6. Portable Fire Extinguishers: *NIST recommends that a study be performed to determine the minimum number and appropriate placement (based upon the time required for access and application in a fully occupied building) of portable fire extinguishers for use in new and existing nightclubs, and the level of staff training required to ensure their proper use.*

The literature was reviewed related to the use of portable fire extinguishers by the general public as literature on the use of extinguishers in nightclubs was limited. The following search terms were used:

- "placement of portable fire extinguishers",
- "portable fire extinguisher spacing",
- "minimum number of portable fire extinguishers",
- "training for portable fire extinguishers", and
- "proper use of portable fire extinguishers".

Each relevant source is listed and summarized below.

1. Grosshandler, William, Editor. "The Use of Portable Fire Extinguishers in Nightclubs: Workshop Summary." NISTIR 7419. National Institute of Standards and Technology, Gaithersburg, MD. April 2007.

Summary: This publication is a summary of a workshop that was held at NIST in Gaithersburg, MD on January 17, 2007. The following topics were discussed:

- Existence of data on the effectiveness of portable fire extinguishers
- Level of training on use of fire extinguishers that is needed and available
- Size of fire that a portable fire extinguisher can be expected to handle
- Appropriate spacing of fire extinguishers at nightclubs and other assembly occupancies
- Role of new technology in increasing effectiveness and efficiency of maintenance of portable fire extinguishers

The summary proposes actions for many groups including NFPA, ICC, NIST, UL, and others to help provide answers to the five questions discussed.

URL: http://www.nist.gov/manuscript-publication-search.cfm?pub_id=861435

2. Ghosh, Biswadeep. "Assessment of the benefits of Fire Extinguishers as fire safety precautions in New Zealand Buildings". Fire Engineering Research Project, University of Canterbury. December 2008.

Summary (excerpt from source): “This report uses historical data available from 1990 – 2007 from the New Zealand Fire Service Fire Incident Reporting System (NZFS FIRS) database and usage statistics generated from conducting a survey of fire service agencies for fire extinguishers in New Zealand. This report also evaluates prescriptive requirements existing in New Zealand and compares with prescriptive requirements outside of New Zealand.”

URL: http://www.civil.canterbury.ac.nz/fire/pdfreports/Deep%20Ghosh%20-%20project%20final.pdf

3. Poole, Brandon et al. "Ordinary People and Effective Operation of Fire Extinguishers." Worcester Polytechnic Institute/Eastern Kentucky University. April 2012.

Summary (excerpt from source): “This research investigated how effectively an untrained person would be able to extinguish a small or incipient fire. Specifically, the study posed two main questions that were answered by defining the four aspects that represent effective use of a fire extinguisher: usage, technique, safety, and extinguishment simulation. These aspects were represented by variables that can be measured.”

URL: http://www.femalifesafety.org/docs/WPIStudyFinal.pdf

4. Okimoto, Maria Lucia, Maicon Puppi, Sabrina Oliveira, and Vanessa Macedo. "Usability of portable fire extinguisher: perspectives of ergonomics and intuitive use." In Digital Human Modeling and Applications in Health, Safety, Ergonomics, and Risk Management. Healthcare and Safety of the Environment and Transport, pp. 355-364. Springer Berlin Heidelberg, 2013.

Summary (excerpt from source): “The present study aims to explore the usage of portable fire extinguishers usability from the interaction with non-specialists in emergency context. In order to simulate the emergency context, a usability test was applied with addition stress stimuli. The study allows to conclude that the portable fire extinguisher evaluated present a low level of intuitive use induction, revealing the need to state better standards from Brazilian authorities towards the label and handles of this product. This paper presents the importance of evaluating ergonomic and intuitive factors related to products required on emergency contexts. This study conducted in Brazil is the starting point for other research that explore the theme and aim to improve these devices, assisting designers to take into account aspects of intuitive use and ergonomic principles during the configuration of industrial products.”

5. Tasmania Fire Service. “Guide to the Selection and Location of Portable Fire Extinguishers and Fire Blankets.” April 2007.

Summary: This guide provides advice to aid in the selection and location of extinguishers and fire blankets in and around buildings. The focus of this guide is on new buildings, but also provides guidance for identification of suitable fire extinguishers for existing buildings.

URL: http://www.fire.tas.gov.au/publications/fireExtinguisherGuide.pdf

Table 1: Literature Summary for Recommendation 6

Source	**Data Source**	**Peer reviewed?**	**References NIST report?**	**Relevancy Score**
1	Existing data	No	Yes	3
2	Original data (survey)	No	No	2
3	Original data	No	No	2
4	Original data	Yes	No	2
5	Existing data	No	No	1

Recommendation 8: Human Behavior in Emergency Situations

Recommendation 8 of the report focuses on several aspects related to better understanding human behavior in emergency situations:

Recommendation 8. Research on Human Behavior: *NIST recommends that research be conducted to better understand human behavior in emergency situations, and to predict the impact of building design on safe egress in fires and other emergencies (real or perceived), including the following:*

> *a) the impact of fire products (gases, heat, and obscuration) on occupant decisions and egress speeds;*
>
> *b) exit number, placement, size and signage;*
>
> *c) conditions leading to and mitigating crowd crush;*
>
> *d) the role of crowd managers and group interactions;*
>
> *e) theoretical models of group behavior suitable for coupling to fire and smoke movement simulations; and*
>
> *f) the level of safety that model codes afford occupants of buildings.*

Literature was reviewed for each of the above sub-categories for this recommendation, so the discussion below is split into six sections.

For recommendation 8a related to the impact of fire products on occupant decisions and egress speeds, the search terms included:

- "impact of smoke on evacuation",
- "impact of gas on evacuation",
- "impact of heat on evacuation", and
- "impact of obscuration on evacuation".

The following relevant literature was identified.

URL: http://www.iafss.org/publications/fss/10/197/view

1. Ohmiya, Yoshifumi and Sano, Tomonori. "Experimental Study on Accident Perception by Smoke at An Initial Fire." Proceedings of the 5th International Symposium on Human Behavior in Fire, 2012.

Summary (excerpted from text): "In 2000, in accordance with newly provided fire prevention guidelines under the Building Standards Law, the Verification Method of Evacuation Safety was introduced. This method is used to verify if people in buildings can evacuate considering heat and smoke of fire by making use of technical prediction methods. In this method, the total time from breaking out of fire to completion of evacuation is calculated by adding time to start evacuation (time from breaking out of a fire to starting of evacuation action), walking time, and time spent to go out of exit. The time to start evacuation is generally estimated depending on room area. However, it is pointed out that this calculation method lacks clear technical basis. For this reason, focusing on visual perception of smoke, this study conducts a series of experiments with the purpose of understanding the relation between reasons of accident perception and brightness, smoke density or luminance in the room by varying space factors."

2. Fang, Z., Song, W., and Wu, H. "A Multi-Grid Model for Evacuation Coupling With the Effects of Fire Products." Proceedings of Pedestrian and Evacuation Dynamics, 2011.

Summary (excerpted from text): "In the study, influences of fire products on pedestrians are introduced into a multi-grid evacuation model, in which the space is discretized into small grids with the size of 0.1 m × 0.1 m and each pedestrian occupies 5 × 5 grid sites. The fire products affect two walking parameters of pedestrians: the desired movement direction and the step frequency. The data of fire products are obtained from the simulation results of the Fire Dynamics Simulator (FDS), a well-founded computational fluid dynamic (CFD) program, developed by the National Institute of Standards and Technology (NIST). With this model, we investigated the routes of pedestrians in fires, and the evacuation times in scenarios with different fire intensities, pre-movement times or door widths. The results indicate that pedestrians will avoid moving towards the fire source, small fire may make egress process faster while large fire may reduce evacuation efficiency significantly, the movement time increases rapidly with the increasing pre-movement time, and the door width plays a more important role for evacuation in fire than normal condition. Furthermore, for the evacuation from a hall with two exits our model can reproduce the inefficient use of exits and predict the optimal condition that results in least evacuation time."

3. Ronchi, E., Gwynne, S. M. V., Purser, D. A., and Colonna, P., "Representation of the Impact of Smoke on Agent Walking Speeds in Evacuation Models". *Fire Technology*, 49:2, 411-431, April 2013.

Summary (excerpted from text): "This paper addresses the problem of reproducing the effect of different visibility conditions on people's walking speed when using evacuation models. Currently, the correlation between smoke and walking speed is typically based on two different sets of experimental data produced by (1) Jin and (2) Frantzich and Nilsson. The two data-sets present different experimental conditions, but are often applied as if equivalent. To test the impact of this representation within evacuation tools, the authors have employed six evacuation models, making different assumptions and employing different data-sets (FDS+EVAC, Gridflow, buildingEXODUS, STEPS, Pathfinder and Simulex). A simple case-study is simulated in order to investigate the sensitivity of the representation of two key variables: (1) initial occupant speeds in clear conditions, (2) extinction coefficients."

4. Nguyen, Manh Hung, Hoa, Tuong Vinh, and Zucker, Jean-Daniel. "Integration of Smoke Effect and Blind Evacuation Strategy (SEBES) within fire evacuation simulation", *Simulation Modelling Practice and Theory*, 36, 44–59, 2013.

Summary (excerpted from text): "This paper presents an agent-based evacuation model with Smoke Effect and Blind Evacuation Strategy (SEBES) which respects that recommendation by integrating a model of smoke diffusion and its effect on the evacuee's visibility, speed, and evacuation strategy. The implementation of this model enables us to optimise the evacuation strategies taking into account the level of visibility. The obtained simulation results on a realistic model of the Metro supermarket of Hanoi confirm the important impact of smoke effect and blind evacuation strategy on the number of casualties."

5. Fahy, Rita F. and Proulx, Guylene, "Human behavior and evacuation movement in smoke", *ASHRAE Transactions*, July 2008.

Summary (excerpted from text): "Codes and standards are developed on the premise that occupants of a building that meets relevant requirements should not have to evacuate through smoke during a fire. Investigations of actual fires demonstrate, however, that occupants often move through smoke during a fire evacuation. This paper will review common behaviors observed during fire emergencies, particularly those that have been observed in the pre-movement phase of the evacuation. Three case studies are presented to illustrate occupant movement through smoke in fires in office and apartment buildings. Two new technologies that can support occupants' evacuation through smoke are described: directional alarm sounders and photoluminescent wayguidance systems."

6. Ferreira, M. J., Strege, S. M., Peacock, R. D., and Averill, J. D. "Smoke Control and Occupant Evacuation at the World Trade Center." American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) Proceedings. Salt Lake City, UT, pp. 1-8, June 21-25, 2008.

Summary (excerpted from text): "This paper examines smoke control and occupant evacuation in WTC 1 and WTC 2 on September 11, 2001 focusing on the impact region and above for each tower. Approximately 2,000 individuals were at or above the area of impact in WTC 1 and WTC 2 who did not successfully evacuate. NIST found that the smoke management (smoke purge) systems in WTC 1 and WTC 2 were not initiated on September 11,2001. Had the smoke purge sequence (required by the BCNYC for post-fire smoke venting) been initiated in WTC 1or WTC 2, it is unlikely the system would have been capable of operation, due to damage caused by aircraft impacts. Even if fully operational, none of the hypothetical potential smoke management approaches evaluated would have prevented smoke spread given the damage caused by aircraft impact. During the events occurring on September 11, 2001 stair pressurization would have been ineffective in improving conditions for occupants trying to exit the building due to the extensive damage to the stair shafts. Installation of combination fire/smoke dampers in HVAC ductwork, which was not required in WTC 1or WTC 2 at the time the WTC was constructed, may have acted to slow the development of hazardous conditions on the uppermost floors of the building, but would likely not have had a significant effect on the ability of occupants to egress the building due to the impassibility of the exit stairways."

Link: http://fire.nist.gov/bfrlpubs/build08/PDF/b08012.pdf

7. Fridolf, Karl, Andrée, Kristin, Nilsson, Daniel, and Frantzich, Håkan, "The impact of smoke on walking speed", *Fire and Materials*, December 2013.

Summary (excerpted from text): "In fire safety engineering, information about the expected walking speed of occupants through smoke is often one factor that is of interest to the designer. However, despite the fact that research already in the 1970s demonstrated that people tend to evacuate through smoke, little research has been performed on the topic since, and evidently, there is a lack of data on walking speed in smoke. This has created a situation where fire safety engineering assessments of the required safe escape time may be intimately associated with high uncertainties, especially for buildings in which people can be expected to evacuate long distances through smoke, for example, underground transportation systems. In order to address the lack of data on movement through smoke, 133 data points on individual walking speed in smoke are presented in this paper. The data lie within an extinction coefficient range of 1.2–7.5 m^{-1}. In line with previous studies, it is demonstrated that the level of smoke density has a negative impact on the walking speed, whereas no significant effects of inclination, type of floor material, gender, age and height could be found in the data. In this paper, recommendations are also provided on how designers should treat the data in their fire safety risk assessments, depending on the type of risk analysis method, that is, if the designer is performing a deterministic analysis or a quantitative risk analysis. It is argued that this information can be used to reduce the uncertainty in future risk analyses involving egress calculations."

8. Gershon, Robyn R. M, Magda, Lori A., Riley, Halley E. M., and Sherman, Martin F. "The World Trade Center evacuation study: Factors associated with initiation and length of time for evacuation." *Fire and Materials*, Volume 36, Issue 5-6, pp. 481-500, August-October 2012.

Summary (excerpted from text): "On 11 September 2001, one of the largest workplace evacuations in the U.S. history took place. The evacuation was largely successful: an estimated 87% of all occupants in World Trade Center (WTC) Towers 1 and 2 exited in less than two hours. Evacuation times, however, were highly variable and not entirely explained by the engineering parameters of the buildings. To understand the complexity of factors that potentially influenced the evacuation time on 11 September, 2001, an interdisciplinary research study was conducted by public health scientists from the Mailman School of Public Health at the Columbia University in the New York City. Analysis of survey data collected from a sample of 1444 evacuees identified several facilitators and barriers to length of time to initiate and fully evacuate from WTC Towers 1 and 2. At the individual level, these included sociodemographic and occupational variables, health status, sensory cues, risk perception, delaying behaviors, and following a group or an emergent leader. At the organizational level, factors included emergency preparedness safety climate variables. Structural (environmental) factors included egress route barriers, poor signage, congestion, and communication system failures. Many factors identified in the study are modifiable. Therefore, these data have the potential to inform high-rise preparedness and response policies and procedures."

9. Su, Joseph Z., Bénichou, Noureddine, Bwalya, Alex, Lougheed, Gary, Taber, Bruce, and Leroux, Patrice. "Unprotected Floor Assemblies and Tenability Conditions in a Test House Under Two Basement Fire Scenarios." *Fire Technology*, Volume 47, Issue 3, pp 631-664, July 2011.

Summary (excerpted from text): "A full-scale experimental program was undertaken to study the impact of two basement fire scenarios on the structural integrity of unprotected floor assemblies above a basement and the tenability conditions in a test facility representing a typical two-storey detached single-family house with a basement. The experiments utilized relatively severe, fast-growing fires set in the basement, which had an unprotected (unfinished) ceiling, to challenge the structural integrity of the floor system above the basement, which provides the normal egress route on the first storey for occupants. Potential exposure to toxic gases, heat and smoke obscuration under the test conditions was analyzed to estimate the time available for escape. The results help establish the sequence of fire events such as fire initiation, smoke alarm activation, onset of untenable conditions, and structural failure of the floor assembly above the basement to understand how these factors affect the ability of occupants on the upper storeys to escape in the event of a basement fire."

10. Akizuki, Yuki, Hara, Naoya, and Tanaka, Takeyoshi. "Calculating Methods of Evacuee's Behavior Based on the Floor Illumiance in Fire Smoke Estimated by Two Layer Zone Mode." Proceedings of the 4th International Symposium on Human Behavior in Fire, 2009.

Summary (excerpted from text): "In making a plan for safe evacuation under smoke in fire, visibility of escape routes is of crucial importance Therefore it is necessary to establish a calculation method of evacuee's behaviour in fire smoke to evaluate evacuee's visibility quantitatively. Emergency lights are designed only for electric blackout, which are caused by damage due to high temperature smoke in fire room, therefore they cannot ensure sufficient lightness for visibility of evacuation against fire smoke. This paper proposes a calculation model of evacuee's behaviour based on the floor illuminance in fire taking into account of smoke filling and adhesion, the conditions of smoke in building fire were estimated using a two layer zone model. Additionally we show the change of floor illuminance and evacuee's behaviour, such as travel speed and psychological states, in an example case of a vehicle fire in a car park at an underground mall in Japan."

11. Kady, Rani A. and Davis, Jerry. "The effect of occupant characteristics on crawling speed in evacuation." *Fire Safety Journal*, Volume 44, Issue 4, Pages 451–457, May 2009.

Summary (excerpted from text): "The movement of occupants is a key element in the development of evacuation models, which estimate the required evacuation time to reach an exit. The deterioration of environmental conditions influences occupants to adopt new responses. This study investigates crawling movement as a physical response to environmental conditions during a fire. The study investigates occupant crawling speed compared with walking speed, and the effect of occupant characteristics; gender and body composition (BMI), on crawling during an evacuation. Eighteen subjects (nine males and nine females) within the 19–29 age stratum participated in the study (normal, overweight, and obese body composition). The findings indicate a statistical significance between normal walking and crawling speeds. Further, the study statistically demonstrates that both gender and body composition significantly impact individual crawling speed as they are unique individual characteristics. More research is needed to better understand the effect of age group, mobility capabilities, and fatigue on crawling speed. The study concludes that the development of crawling data and its representation in evacuation models will enhance the accuracy of evacuation models, and better evaluate the safety of evacuees."

12. Fahy, R., Proulx, G., and Flynn, J. "The Station Nightclub Fire – An Analysis of Witness Statements". Proceedings of the 10th International Symposium for Fire Safety Science, pp. 197-210. 2011.

Summary: This paper describes a joint project of the NFPA and the National Research Council of Canada (NRCC) to study the behavior of the building occupants of The Station as they evacuated. The analysis presented is based on analysis of witness statements available from 355 survivors, collected by various police agencies. This paper summarizes the occupant responses as well as exit route choices and egress paths. This research uses information from the NIST NCST investigation and thus cites the report. However, it was not done in response to the NIST research recommendation and has a lower relevance rating.

Table 2: Literature Summary for Recommendation 8a

Source	Data Source	Peer reviewed?	References NIST report?	Relevancy Score
1	Original Data	Yes (conference)	No	3
2	Existing Data	Yes (conference)	No	3

Source	Data Source	Peer reviewed?	References NIST report?	Relevancy Score
3	Existing Data	Yes	No	3
4	Existing Data	Yes	No	3
5	Original Data	Yes	No	3
6	Existing Data	Yes	No	3
7	Original Data	Yes	No	3
8	Existing Data	Yes	No	2
9	Original Data	Yes	No	1
10	Existing Data	Yes (conference)	No	1
11	Original Data	Yes	No	1
12	Existing Data	Yes (conference)	Yes	1

For recommendation 8b related to exit number, placement, size, and signage the search terms included:

- "exit number on evacuation",
- "exit placement on evacuation",
- "exit size on evacuation", and
- "signage on evacuation".

The following relevant literature was identified.

1. Rubini, P. A. and Zhang, Q. "Simulation of Perceived Visibility in Smoke Laden Environment", Proceedings of the 4th International Symposium on Human Behavior in Fire, 2009.

Summary (excerpted from text): "A considerable body of research has been accumulated regarding human behaviour in fires and the simulation of the movement of individuals in smoke laden environments. A necessary input to such models is the perceived visibility of the surroundings, whether hazards, obstructions or safe exits. This paper introduces the methodology and presents initial results from the quantitative simulation of visibility through a smoke laden environment. The simulations account of direct illumination, indirect illumination from surfaces and particular scattering. The underlying smoke movement is obtained from a prior time dependent CFD simulation and, with appropriate assumptions on soot particle properties, post-processed in a second phase to determine the visibility of, for example, an illuminated exit sign."

2. Schneider, Volker. “Modeling the Visibility of Emergency Signs in Smoke and Smoke-Free Conditions.” Proceedings of the 4th International Symposium on Human Behavior in Fire, 2009.

Summary (excerpted from text): “In case of a fire smoke spread and its impact on visibility is a major hazard for occupant safety. Deteriorating conditions due to increasing smoke optical density can cause a variety of effects that impair the efficiency of an evacuation. These effects include the reduction of walking speed, turn-back behaviour or loss of orientation. Especially people in complex building spaces not familiar with the surrounding are usually dependent on signage providing the necessary wayfinding information. The visibility of egress signs is thus a crucial parameter in an evacuation analysis. Most guidelines that address performance based safety concepts or fire engineering methods consequently include sections on tenability limits and methods to evaluate the conditions for safe egress in smoke laden environments. The German Guideline “Methods of Fire Safety Engineering” includes lower limits of optical density per path length in the range of 0.1 to 0.2 m-1 acceptable for safe egress. In the second edition of the Guideline released in May 2009 the fundamental and pioneering work of Jin and Rasbash on visibility is supplemented by references to more recent studies, both theoretical and experimental, on the visibility of emergency exit signs. These concepts that focus on basic sign parameter like size, luminance and contrast and the illumination of the respective scenario are now also included in the microscopic ASERI evacuation model.”

3. Galea, E.R., Xie, H., and Lawrence, P. “Experimental Study of the Effectiveness of Emergency Signage.” Proceedings of the 4th International Symposium on Human Behavior in Fire, 2009.

Summary (excerpted from text): “Signage systems are widely used in the built environment to aid occupant wayfinding during both circulation and evacuation. Recent research conducted by the authors shows that only 38% of people ‘see’ conventional static emergency signage in presumed emergency situations in an unfamiliar built environment, even if the sign is located directly in front of them and their vision is unobstructed. However, most people who see the sign follow the sign. These results suggest that current emergency guidance signs are less effective as an aid to wayfinding than they potentially can be and that signs are likely to become more effective if their detectability can be improved while upholding the comprehensibility of the guidance information they provide. A novel dynamic signage design is proposed to address this issue by enhancing the affordance of the sign, while maintaining the simplicity and clarity of the information conveyed by the sign and the code compliance of the sign. The effectiveness of the new sign is tested under the same experimental settings and conditions as in previous experiments examining conventional, static signs. The results show that 77% of people ‘see’ the dynamic sign and 100% of them go on to follow the sign.”

4. Galea, E.R., Xie, H., and Lawrence, P. "*Experimental and Survey Studies on the Effectiveness of Dynamic Signage System*". Draft Proceedings of the 11th International Symposium on Fire Safety Science, February 2014.

Summary (excerpted from text): "Recent research conducted by the authors shows that only 38% of people 'see' conventional static emergency signage in presumed emergency situations in an unfamiliar built environment, even if the sign is located directly in front of them and their vision is unobstructed. However, most people who see the sign follow the sign. These results suggest that current emergency guidance signs are less effective as an aid to wayfinding than they potentially can be and that signs are likely to become more effective if their detectability can be improved while upholding the comprehensibility of the guidance information they provide. A novel dynamic signage design is proposed to address this issue. The effectiveness of the new sign is tested under almost identical experimental settings and conditions as in the previous experiments examining conventional, static signs. In addition, a dynamic method to identify that an exit route is no longer viable is tested using an international survey to gauge understanding of the new signage concept."

5. Filippidis, L., Galea, E. R., Gwynne, S., and Lawrence, P. J. "Representing the Influence of Signage on Evacuation Behavior within an Evacuation Model." *Journal of Fire Protection Engineering*, Volume 16, No. 1, pp. 37-73, February 2006.

Summary (excerpted from text): "Occupant interaction with signage systems is being introduced into evacuation simulations through the newly developed concept of the Visibility Catchment Area or VCA. In this article, we describe the concept of VCA and how it has been extended to incorporate the presence of physical obstructions and termination distance. The VCA concept is then linked to a prototype behavior model intended to represent the occupant's interaction with the signage system. The functionality and performance of the newly developed model is then demonstrated through the simulation of various evacuation scenarios within a hypothetical supermarket layout."

6. Xie, Hui, Filippidis, Lazaros, Galea, Edwin R., Blackshields, Darren, and Lawrence, Peter J. "Experimental analysis of the effectiveness of emergency signage and its implementation in evacuation simulation." *Fire and Materials*, Volume 36, Issue 5-6, pages 367–382, August-October 2012.

Summary (excerpted from text): "Despite the fact that signage systems are an important component in building wayfinding systems, there is a lack of relevant data regarding how occupants perceive, interpret and use the information conveyed by emergency signage. The effectiveness of signage systems is therefore difficult to assess. This paper addresses this issue through experimentation. The experiment involved measuring the impact of a signage system on a population of 68 test subjects who were instructed to individually vacate a building as quickly as possible via any means they thought appropriate. The evacuation path involved a number of decision points at which emergency signage was available to identify the appropriate path. Through analysis of video footage and data derived from questionnaires, the number of people who saw and utilised the signage information to assist their egress is determined."

7. Filippidis, Lazaros, Lawrence, Peter J., Galea, Edwin R., and Blackshields, Darren. "Simulating the Interaction of Occupants with Signage Systems", Fire Safety Science, Proceedings of the Ninth International Symposium, pp. 389-400, 2008.

Summary (excerpted from text): "This paper describes the introduction of chained signage systems into evacuation simulation models. Signage systems are widely used in buildings to provide information for wayfinding, thereby providing exiting information during emergencies and assisting in navigation during normal circulation of pedestrians. Recently a system was developed to introduce simple signs into egress models. The system, known as Visibility Catchment Area or VCA, allowed simulated agents to interact with signs which point directly to an exit and signs which are located directly above the exit. However, this approach was not able to represent the more general situation of a sign network within an arbitrarily complex building. In this paper we extend the method to include chained signage systems which provides simulated agents that are unfamiliar with the structure a means by which to navigate to an emergency exit. The model includes the associated navigation behaviours exhibited by occupants that rely on a signage system for navigation including: Searching behaviours, Backtracking behaviours, Lost behaviours and Communication behaviours. The new features are demonstrated through a series of demonstration cases and are shown to produce plausible results."

URL: http://www.iafss.org/publications/fss/9/389/view

8. Nilsson, D., Frantzich, H. and Saunders, W.L. "Coloured Flashing Lights To Mark Emergency Exits – Experiences From Evacuation Experiments". Proceedings of the 8th International Symposium of Fire Safety Science, 2005.

Summary (excerpted from text): "Three evacuation experiments were performed to investigate how emergency exits should be designed. In the first two experiments coloured flashing lights and strobe lights at emergency exits were tested and compared to a standard emergency exit design. In the third experiment green, blue, orange and red lights were compared to determine which colour was the most appropriate for use in emergencies. Results of the studies show that flashing lights and strobe lights, compared to the standard emergency exit design, increase the use of emergency exits. Furthermore, it is recommended that green lights should be used at emergency exits."

URL: http://www.iafss.org/publications/fss/8/569/view

9. Ronchi, Enrico, Nilsson, D., and Gwynne, S. M. V. "Modelling the Impact of Emergency Exit Signs in Tunnels." *Fire Technology*, Volume 48, Issue 4, pp 961-988. October 2012.

Summary (excerpted from text): "This paper addresses the problem of representing the impact of different emergency exit signs during the evacuation of a tunnel when using two different evacuation models (i.e. FDS+Evac and buildingEXODUS). Both models allow the user to represent the impact of smoke upon the evacuee. The models are calibrated (1) considering the nature of the models themselves, (2) by deriving assumptions from previous experiments and literature, (3) using new data produced from experimental work performed by Lund University. The purpose of this paper is to demonstrate the activities required of the user to configure sophisticated egress tools given the scenario examined and the alternatives available in representing evacuee beehavior."

10. Kady, Rani A. "The Impact of Exit Route Designs on Evacuation Time for Crawling Occupants." *Journal of Fire Sciences*, Volume 27, pg. 481, September 2009.

Summary (excerpted from text): "According to the Life Safety Code, the distance between the exit access and the exit is a function of the occupants, type and number of obstructions, and the type of hazard. This study investigates the impact of route design on evacuation times for crawling movements. The study compares evacuation time for a straight route to an indirect route design, and the influence of occupant characteristics, in terms of gender and BMI, on evacuation time for occupants crawling an indirect route. Eighteen subjects (9 males and 9 females) in the 19–29 age stratum participated in the study (normal, overweight, and obese). The findings indicate a statistical difference between evacuation time for crawling in a straight route and an indirect one. Furthermore, the study reveals that both gender and BMI are major physical determinants of evacuation time of crawlers in an indirect route. The study is an attempt to provide data on occupant movement in unique circumstances (such as crawling an indirect route). Such data will contribute to enhance the ability of evacuation models to better represent occupant movement in different building enclosures."

11. Filippidis, L., Galea, E. R., Gwynne, S., and Lawrence, P.J. "Representing the Influence of Signage on Evacuation Behavior within an Evacuation Model." *Journal of Fire Protection Engineering,* 16:37, 2006.

Summary (excerpted from text): "Occupant interaction with signage systems is being introduced into evacuation simulations through the newly developed concept of the Visibility Catchment Area or VCA. In this article, we describe the concept of VCA and how it has been extended to incorporate the presence of physical obstructions and termination distance. The VCA concept is then linked to a prototype behavior model intended to represent the occupant's interaction with the signage system. The functionality and performance of the newly developed model is then demonstrated through the simulation of various evacuation scenarios within a hypothetical supermarket layout."

URL: http://jfe.sagepub.com/content/16/1/37.full.pdf

12. Horasan, Mahmut and Kilmartin, Russell. “Analysis of Egress Calculation Assumptions and Findings for Large Shopping Center Life Safety Assessments.” Proceedings for the 5th International Symposium on Human Behavior in Fire, 2012.

Summary (excerpted from text): “A significant collection of shopping center fire safety engineering assessment data related to 60 projects conducted over the last 15 years was analyzed from the perspective of egress calculation assumptions and findings. The evolution of mostly explicit pre-movement time recommendations from key guideline and reference documents was reviewed and compared in relation to the analysis. Occupant density and pre-movement times were identified as the two key factors influencing the overall Required Safe Egress Time (RSET). One of the findings of the analysis presented in the paper is that overall movement times are not a function of the shopping centre floor area and population as expected. This is a consequence of a trend observed with almost all assessments analysed, where highly conservative and generous aggregate egress widths were enforced by the prescriptive codes and adopted in the architectural design. The paper also goes on to identify a simple relationship between overall RSET and pre-movement times based on explicit values. A significant conclusion of the analysis is that despite the presence of some misgivings towards the use of explicit pre-movement times, the resulting RSET values are observed to be consistent and reliable for the purposes of fire safety engineering assessments.”

13. Guo, Xiwei, Chen, Jianqiao, Zheng, Yaochen, and Wei, Junhong. “A heterogeneous lattice gas model for simulating pedestrian evacuation.” *Physica A: Statistical Mechanics and its Applications*. Volume 391, Issue 3, pp. 582–592, February 2012.

Summary (excerpted from text): “Based on the cellular automata method (CA model) and the mobile lattice gas model (MLG model), we have developed a heterogeneous lattice gas model for simulating pedestrian evacuation processes in an emergency. A local population density concept is introduced first. The update rule in the new model depends on the local population density and the exit crowded degree factor. The drift D, which is one of the key parameters influencing the evacuation process, is allowed to change according to the local population density of the pedestrians. Interactions including attraction, repulsion, and friction between every two pedestrians and those between a pedestrian and the building wall are described by a nonlinear function of the corresponding distance, and the repulsion forces increase sharply as the distances get small. A critical force of injury is introduced into the model, and its effects on the evacuation process are investigated. The model proposed has heterogeneous features as compared to the MLG model or the basic CA model. Numerical examples show that the model proposed can capture the basic features of pedestrian evacuation, such as clogging and arching phenomena.”

14. Li, Xiaomeng, Chen, Tao, Pan, Lili, Shen, Shifei, and Yuan, Hongyong. “Lattice gas simulation and experiment study of evacuation dynamics.” *Physica A: Statistical Mechanics and its Applications*. Volume 387, Issue 22, pp. 5457–5465, September 2008.

Summary (excerpted from text): “In this paper, evacuation dynamics in an office building is studied by experiment and simulation. A lattice gas (LG) model is developed. A parameter called ‘exit bias’ is introduced into the model to describe the occupants’ familiarity with different exits in a building. The evacuation experiment, which consists of seven scenarios under various conditions, is conducted to verify the model and calibrate the model’s input parameters such as pedestrian speed and exit bias. The effect of exit width on flow rate, and the effect of occupants’ familiarity with the building on their route selections, are studied. It is found that the accuracy of simulation depends a lot on the model’s pedestrian speed. The optimal pedestrian speed is decided by not only occupant characteristics, but also flow features determined by people distribution, building structure, environment pressure, etc. LG models with proper pedestrian speed are capable of simulating the dynamic process of orderly emergency evacuations.”

15. Daoliang, Zhao, Lizhong, Yang, and Jian, Li. “Exit dynamics of occupant evacuation in an emergency.” *Physica A: Statistical Mechanics and its Applications*, Volume 363, Issue 2, pp. 501–511, May 2006.

Summary (excerpted from text): “A two-dimensional Cellular Automata model is proposed to simulate the exit dynamics of occupant evacuation. Concerning the exit width and the door separation, we put forward some useful standpoints: (1) exit width should be bigger than a critical value, and the door separation should be neither too small nor too big; (2) for single-exit door, with the increase of exit width, the flux per unit width will decrease but the total flux will always increase; (3) the total flux of the exit is an increasing nonlinear function of the exit width; (4) the optimal value of the door separation does not vary with the value of exit width; (5) the layout of exits should be symmetry. Those results are helpful in performance-based design of building.”

16. Spearpoint, MJ. “Network Modeling of The Station Nightclub Fire Evacuation”. *Journal of Fire Protection Engineering*, Volume 22, Number 3, pp. 157-181. Sage Publications, August 2012.

Summary: The network model EvacuatioNZ was used to study the evacuation of The Station Nightclub. Evacuation times and exit door use were compared to results obtained by NIST and subsequent modeling by others. Sensitivity analysis included study of the impact of changing the probability assigned to the preferred exit. This work illustrates the capability of EvacuatioNZ as well as other network models. This research uses information from the NIST NCST investigation and thus cites the report. However, it was not done in response to the NIST research recommendation and has a lower relevance rating.

Table 3: Literature Summary for Recommendation 8b

Source	**Data Source**	**Peer reviewed?**	**References NIST report?**	**Relevancy Score**
1	Existing Data	Yes (conference)	No	3
2	Existing Data	Yes (conference)	No	3
3	Original Data	Yes (conference)	No	3
4	Original Data	Yes (conference)	No	3
5	Existing Data	Yes	No	3
6	Original Data	Yes	No	3
7	Existing Data	Yes (conference)	No	3
8	Original Data	Yes (conference)	No	2
9	Original Data	Yes	No	2
10	Original Data	Yes	No	2
11	Existing Data	Yes	No	2
12	Existing Data	Yes (conference)	No	1
13	Existing Data	Yes	No	1
14	Existing Data	Yes	No	1
15	Existing Data	Yes	No	1
16	Existing Data	Yes	Yes	1

For recommendation 8c related to conditions leading to and mitigating crowd crush, the search terms included:

- "crowd crush conditions",
- "occupant gathering", and
- "occupant merging".

The following relevant literature was identified.

1. Luh, Peter B., et. al. "Modeling and Optimization of Building Emergency Evacuation Considering Blocking Effects on Crowd Movement". IEEE Transactions on Automation Science and Engineering, Volume 9, Issue 4, October 2012.

Summary: This paper establishes a new macroscopic network-flow model that incorporates fire, smoke, and psychological factors. The crowd evacuation behaviors are based on previous psychological findings and simulation studies. The paper then presents optimization techniques for evacuation of crowds based on numerical results from computer modeling. Additional research on validation of the model is suggested.

URL: http://recipe.ee.ntu.edu.tw/C&D/Frame/paper/LWC12.pdf

2. Cui, Q., Ichikawa, M., Kaneda, T., and Deguchi, H. "A Dynamic Simulation on Crowd Congestion in Large-Scale Terminal Station Complex in an Official Announcement Advisory Information." *Pedestrian and Evacuation Dynamics*, pp. 375-387, 2011.

Summary (excerpted from text): "On the assumption of advisory information concerning an imminent Tokai earthquake being officially announced, as a case example this study developed a spatial-spot type agent-based simulation model for the Nagoya Station area, where several terminal stations are concentrated; in the model, agents played people on their way home, and such factors as the routes selected by agents and the spatial restrictions, e.g. passages, were taken into consideration. Basic on SOARS (Spot Oriented Agent Role Simulator) platform, we conducted a large-scale crowd simulation with 160,000 agents and analysis the change of space density in one hour to compare to the estimates given by Nagoya City, we analysis the result and also refer to this kind of project for implementing much higher functions."

3. Kadokura, Hiroyuki, Sekizawa, Ai, Sano, Tomonori, Yajima, Masanori, and Masuda, Satomi. "Study on Congestion in Stairs During Phased Evacuation in a High-Rise Building – Analysis Based on the Observational Data of a Real Total Evacuation Drill." Proceedings of the 5th International Symposium on Human Behavior in Fire, 2012.

Summary (excerpted from text): "If a large fire or other serious emergency occurs in a high-rise building, all occupants would be forced to evacuate the building under such an extreme event. Also, it would be quite probable that that on this occasion many occupants in the building start to evacuate at the same time. Further, the staircase would become very congested and chaotic, if all occupants try to evacuate via a limited number of staircases concurrently. In such a case, it may cause considerable delay of the evacuation time or influence on walking speed of evacuees. To explore the potential availability of phased evacuation, this study analyzes the data obtained by videotaping and measuring the walking speed of evacuees during a total evacuation drill held by a high-rise office building in Tokyo."

4. Sano, Tomonori, Jo, Akihide, and Ikehata, Yuka. "Experimental Study on Crowd Flow Through an Opening Connected to a Crowded Corridor: A Comparison of Experiment and Multi-agent Simulation." Proceedings of the 5th International Symposium on Human Behavior in Fire, 2012.

Summary (excerpted from text): "This paper presents the characteristics of the pedestrian movement around the door connected to corridor. It focused on the flow rate where a door connects to corridor to verify evacuation safety, based on performance-based design. Full-scale evacuation experiments were conducted to confirm that a decrease in flow rate would occur when passing through an opening. In addition to this, the process of selecting a door to exit a room is influenced by the relative position of the final destination. Furthermore, the differences between this experiment and "SimTread" (a multi-agent pedestrian simulator) were investigated to examine the validity of the simulation."

5. Harding, Peter J., Amos, Martyn, and Gwynne, Steve. "Prediction and Mitigation of Crush Conditions in Emergency Evacuations." *Pedestrian and Evacuation Dynamics*, pp. 233-246, 2008.

Summary (excerpted from text): "This paper describes a methodology for the prediction and mitigation of crush conditions. The paper is organised as follows. We first establish the need for such a model, defining the main factors that lead to crush conditions, and describing several exemplar case studies. We then examine current methods for studying crush, and describe their limitations. From this, we develop a three-stage hybrid approach, using a combination of techniques. We conclude with a brief discussion of the potential benefits of our approach."

6. Korhonen, T. and Heliövaara, S. "FDS+Evac: Herding Behavior and Exit Selection". Proceedings of the 10th International Symposium of Fire Safety Science, 2011.

Summary (excerpted from text): "The behavior of the occupants is one major factor determining the outcome of building evacuations. Two different occupants may make very different decisions in similar situations. Evacuation simulation models should consider this factor and enable simulations with different behavioral scenarios. We present how three different behavioral types have been implemented in the agent based evacuation model FDS+Evac. The considered types are "conservative", "active", and "herding" agents and they differ in the way they select their target exits. Conservative agents prefer familiar routes, active agents actively observe their environment to find the fastest exit route, and herding agents tend to follow others. The factors affecting the exit selections include the distance to the exit, the behavior of the other agents, visibility and familiarity of the exits, and the smokiness along the exit routes. Some verification simulations are made and the presented model is seen to work as intended. A larger scale evacuation scenario is analyzed to illustrate the effect of the agent types on the outcome of evacuations. The analysis shows that the presence of active agents decreases the average egress time even if there is a large number of herding agents present. Active agents discover the less used, faster exit routes, like emergency exits, and lead the following herding agents also to these routes. This results in more even exit usage and speeds up the whole evacuation."

URL: http://www.iafss.org/publications/fss/10/723/view

7. Crowd Management Strategies. Rock Concert Safety Survey Annual Reports. Multiple Editions.

Summary: Annual reports review popular concert and festival crowd safety incidents, trends, and issues internationally.

URL: http://www.crowdsafe.com/reports.html

8. Al Bosta, S. "Crowd Management Based on Scientific Research to Prevent Crowd Panic and Disasters." *Pedestrian and Evacuation Dynamics*, pp. 747-746, 2011.

Summary (excerpted from text): "This paper presents the developed concept of management of and control to the pedestrian flow movements at Jamarat in the regular annual pilgrimage to Makkah (Hajj) season in Saudi Arabia. Every Year, 3 to 4 millions of pilgrims perform their rituals in the course of extensively high restrictions, in the midst of a climax of limited/narrow space and time constraint. The Jamarat where pilgrims gather to perform a ritual stoning of pillars symbolizing the devil as part of the Hajj. The new Jamarat leveled building replaced the old ones. The project objective is to prevent crowd panic and to minimize the risk of crowd disasters. Management and control of pedestrian group movement to and/or inside Jamarat leveled building and area, using new experimental knowledge methodologies observed from the science of crowd dynamics, throughout anticipation and analysis of the pilgrim flow from low crowd density to extremely high crowd density, accompanied, attended, and escorted with an insider real-time-life video-scrutiny/observation/analysis."

9. Zhang, P., Huang, X., Wan, H. and Liu, M, "Agent-based Dynamic Model For Pedestrian Counter Flow". Proceedings of the 8th International Symposium of Fire Safety Science, 2005.

Summary (excerpted from text): "This paper presents the establishment of the Agent-based Dynamic Model for Pedestrian counter flow (ADMP). It was shown that a rule set of pedestrian behaviors and its combination with a dynamic model for pedestrian flow was capable of effectively capturing the crowd flow rules of pedestrians using agent-based technology. Two digital tests of bottlenecks of evacuation passage in counter flow are presented, in which 200 and 300 pedestrians were stochastically distributed in a space measuring 40000 x 10000 (mm). From a comparison of the two digital tests, it could be seen that, with an increase in pedestrian density, the counter flow became more and more disorderly, and the two different directions of flow struggled more excitedly as a result."

URL: http://www.iafss.org/publications/fss/8/581/view

10. Hayward, Rebecca K., Castellanos, Alex, Brocklehurst, David, and Sharma, Shrikant B. "Investigating Stair-floor merging phenomena and the impact of single and multiple entry points." Proceedings of the 5th International Symposium on Human Behavior in Fire, 2012.

Summary (excerpted from text): "In this article the merging flow phenomena at the floor-stair interface is examined using a parametric modelling approach, building upon a number of previous studies notably the work of Galea on the influence of architectural layout on the merging behaviour at the floor–stair interfaces. A common case of stair configuration is assumed where there are one or two entry points from each floor to the stair landing. The first connection point provides merging on the landing at the base of the stair flight approaching the landing, whilst the second connection point provides merging on the landing at the head of the flight descending down to the lower levels. These phenomena are studied using experimental data gathered during office departure flows, extending the experimental and simulation work by the authors previously reported. The model uses a proportionate merging parameter to investigate the sensitivity of deference on evacuation times, validated using previous and newly gathered data."

11. Boyce, K. E., et. al. "Experimental Studies to Investigate Merging Behavior in a Staircase". *Fire and Materials*, Volume 36, Issue 5-6, pp. 383-398. August-October 2012.

Summary (excerpted from text): "The quantification of merging flows and the factors that influence evacuee merging behaviour are important considerations in our understanding of emergency evacuation of particularly high-rise buildings, and essential for better escape route design and evacuation modelling. This paper presents the results of three evacuation studies to investigate merging flows and behaviours on stairs. Stair:floor merging ratios are provided together with specific flows from the floor and stair. The potential influence of the geometrical location of the floor relative to the stair and the occupant population is discussed. The results indicate that, despite differences in the geometrical location of the door in relation to the stair and the relative stair/door width, the merging was approximately 50:50 across the duration of the merge period in each of the buildings studied. Differences in merge patterns were however evident throughout the merge periods in each of the buildings, particularly in the case where the floor occupants approached from a corridor adjacent to the incoming stair, in which case floor occupants took priority during periods of slower movement. There were also suggestions that some occupant characteristics such as gender or role may have a potential influence on merging, with very obvious deference behaviour of a few individuals dictating the merging in a mixed occupancy building. The studies highlight the potential influence of geometrical location of floor relative to the stair, relative door/stair widths and population characteristics on merge patterns and indicate that much more work is required in this area."

12. Ding, Yuanchun, et. al. "Investigating the Merging Behavior at the Floor-stair Interface of High-rise Building Based on Computer Simulations". 9th Asia-Oceania Symposium on Fire Science and Technology. *Procedia Engineering*, Volume 62, pp. 463-469. 2013.

Summary (excerpted from text): "The merging behavior at the floor-stair interface of high-rise building based on computer simulations is investigated in this paper. A landing with dogleg stairs is adopted in this research. Four different configurations show that the evacuation time is almost a linear function to the number of storeys. Furthermore, the door from the floor to landing, which is on the opposite side of the landing to the incoming stair, is the best situation to improve the upper floors' evacuation effect, and restrain the lower floors' evacuation. At the same time, the door from the floor, which is adjacent to the incoming stair, is the worst situation to improve the lower floors' evacuation, and restrain the upper floors' evacuation. Additionally, with these results obtained in this paper, the building designer can select a more suitable position to place the evacuation doors."

URL: http://ac.els-cdn.com/S1877705813012708/1-s2.0-S1877705813012708-main.pdf?_tid=1b1374de-1cbd-11e4-85d7-00000aacb361&acdnat=1407256105_f464455ec6cd30192cf6d75ee8d5fa55

13. Galea, E. R., et. al. "Investigating the Representation of Merging Behavior at the Floor-Stair Interface in Computer Simulations of Multi-Floor Building Evacuations". *Journal of Fire Protection Engineering*, Volume 18, Number 4, pp. 291-316. October 2008.

Summary (excerpted from text): "In this article, the representation of the merging process at the floor— stair interface is examined within a comprehensive evacuation model and trends found in experimental data are compared with model predictions. The analysis suggests that the representation of floor—stair merging within the comprehensive model appears to be consistent with trends observed within several published experiments of the merging process. In particular: (a) The floor flow rate onto the stairs decreases as the stair population density increases. (b) For a given stair population density, the floor population's flow rate onto the stairs can be maximized by connecting the floor to the landing adjacent to the incoming stair. (c) In situations where the floor is connected adjacent to the incoming stair, the merging process appears to be biased in favor of the floor population. It is further conjectured that when the floor is connected opposite the incoming stair, the merging process between the stair and floor streams is almost in balance for high stair population densities, with a slight bias in favor of the floor stream at low population densities. A key practical finding of this analysis is that the speed at which a floor can be emptied onto a stair can be enhanced simply by connecting the floor to the landing at a location adjacent to the incoming stair rather than opposite the stair. Configuring the stair in this way, while reducing the floor emptying time, results in a corresponding decrease in the descent flow rate of those already on the stairs. While this is expected to have a negligible impact on the overall time to evacuate the building, the evacuation time for those higher up in the building is extended while those on the lower flows is reduced. It is thus suggested that in high-rise buildings, floors should be connected to the landing on the opposite side to the incoming stair. Information of this type will allow engineers to better design stair—floor interfaces to meet specific design objectives."

14. Collier, P. C. R. "Emergency Egress – Merging Flows at Floor Stairway Interfaces". BRANZ Study Report 251. BRANZ Ltd, Judgeford, New Zealand. 2011.

Summary (excerpted from text): "This is a report prepared from a literature search of merging behaviour observed in trial evacuations and studies following the World Trade Center (WTC) evacuations. Validated merging behaviour and occupant behaviour in general is incorporated into egress models to demonstrate that delays in the merge process do not adversely affect egress times in the current building regulation environment."

URL:
http://www.branz.co.nz/cms_show_download.php?id=418f22d4cd22ffa299a6546fce1ac3fe930329a7

15. Dixon, A. J. P. "Experimental Studies on Crowd Flow Merging on Evacuation Stairs". The British Psychological Society. 2010 Northern Ireland Branch Annual Conference. April 2010.

Summary (excerpted from text): "**Purpose:** This paper reviews the literature on crowd merging on building evacuation stairs and the research being undertaken.
Background: An important parameter of fire engineering is merging behaviour of occupants onto building evacuation stairs. This affects time taken to escape the fire floor. Hitherto this has been seen as a physical phenomenon with scant human behaviour. Socio-psychological factors to be researched include deference behaviour, group factors, personal space, perceptions of crowding and risk, role and occupancy-type.
Methods/Key Points: Observations of psychological, behavioural and social factors that affect merging behaviour on evacuation stairs form the cornerstone of the research. Ethical and practical obstacles to subjecting participants to emergency conditions to obtain such information will be discussed. As a result of these objections, video footage of unannounced fire drills augmented by controlled experiments under safe conditions is the preferred method, in addition to comprehensive literature review.
Conclusions: Preliminary analyses indicate that a 'psychologising' of the merging flow problem is warranted and that quantitative data with fire engineering application is likely to ensue from the research."

16. Purser, David. "Implications of Modelling and Experimental Studies of Evacuation Behavior on Stairs for Multistorey Building Design". Proceedings of the 4th International Symposium on Human Behavior in Fire, 2009.

Summary (excerpted from text): "Prescriptive guidance for exits and stair widths in buildings is based on a floor clearance flow time into a protected stair of 2.5 minutes. GridFlow computer evacuation simulations have been used for a performance-based analysis of the guidance (England and Wales) for generic multi-storey office buildings with up to 10-storey served (designed both for simultaneous and phased evacuation). Assuming zero pre-movement times, floor clearance patterns and times for maximum design populations were found to depend on three main parameters: maximum specific flow rates through storey exits and on stairs, occupant capacity (standing area and occupant density) on the stair between floors, and merge ratio at the storey exits. With a standard emergency stair configuration GridFlow simulations gave a 50:50 merge ratio, and at maximum densities of 2 or 4 persons/m2 on the stair this led to floor clearance rates halving at each successively higher floor with clearance times exceeding the 2.5 minute target value, often by a significant margin, on higher floors. In order to examine actual merging behaviour and to provide validation data for the parameters used for the simulations, a series of experimental evacuations was carried out in five separate buildings in London and Northern Ireland, with different exit and stair widths, and stair layouts. The results confirmed the GridFlow results, with average merge ratios of 50.6:49.4 (stair:floor), densities of 2.08 persons/m2 on the stair under crowded conditions and maximum unrestricted specific flow rates in unannounced evacuations of 86.7 and 60.1 persons/minute/metre effective width at exits and on stairs."

17. Campbell, Chris and Milke, Jim. "Observed Trends in Human Behavior Phenomena within High-Rise Stairwells". Presentation at the 2012 SFPE Engineering Technology Conference, October 2012.

Summary: Presentation covers the findings from a 3 year study funded by NIST to assess characteristics of occupant movement on stairs to improve prediction tools for evacuation analyses. This was done by analyzing movement on stairs in several experiments and comparing against modeling results.

Table 4: Literature Summary for Recommendation 8c

Source	Data Source	Peer reviewed?	References NIST report?	Relevancy Score
1	Existing Data	Yes	Yes	3
2	Existing Data	Yes	No	3
3	Original Data	Yes (conference)	No	3
4	Original Data	Yes (conference)	No	3
5	Existing Data	Yes	Yes	3
6	Existing Data	Yes (conference)	No	3
7	Existing Data	No	No	3
8	Existing Data	Yes	No	1
9	Existing Data	Yes (conference)	No	1
10	Original Data	Yes (conference)	No	1
11	Original Data	Yes	No	1
12	Existing Data	Yes (conference)	No	1
13	Existing Data	Yes	No	1
14	Existing Data	No	No	1
15	Existing Data	Yes (conference)	No	1
16	Original Data	Yes (conference)	No	1

Source	Data Source	Peer reviewed?	References NIST report?	Relevancy Score
17	Original Data	Yes (conference)	No	1

For recommendation 8d related to the role of crowd managers and group interactions, the search terms included:

- “crowd managers in evacuation”,
- “crowd management in evacuation”,
- ”group interactions in evacuation”, and
- “occupant behavior in evacuation”.

The following relevant literature was identified.

1. Feng, L., Miller-Hooks, E., and Brannigan, V. “Mathematical Modeling of Command and Control in Evacuation Involving Large Public Gatherings.” Proceedings of the 5th International Symposium on Human Behavior in Fire, 2012.

Summary (excerpted from text): “This paper is a preliminary attempt to model the introduction of command and control in the building environment. The effectiveness of strategies ranging from providing information only to reconfiguring the built environment through architectural design changes and forcing pedestrians to follow system optimally designed evacuation routes are investigated and compared using proposed mathematical formulations and computational methodologies.”

2. Al Bosta, S. “Crowd Management Based on Scientific Research to Prevent Crowd Panic and Disaster.” *Pedestrian and Evacuation Dynamics*, pp. 741-746, 2011.

Summary (excerpted from text): “This paper presents the developed concept of management and control to the pedestrian flow movements at Jamarat in the regular annual pilgrimage to Makkah (Hajj) season in Saudi Arabia. Every year, 3 to 4 millions of pilgrims perform their rituals in the course of extensively high restrictions, in the midst of a climax of limited/narrow space and time constraint. The Jamarat where pilgrims gather to perform a ritual stoning of pillars symbolizing the devil as part of the Hajj. The new Jamarat leveled building replaced the old ones. The project objective is to prevent crowd panic and to minimize the risk of crowd disasters. Management and control of pedestrian group movement to and/or inside Jamarat leveled building and area, using new experimental knowledge methodologies observed from the science of crowd dynamics, throughout anticipation and analysis of the pilgrim flow from low crowd density to extremely high crowd density, accompanied, attended, and escorted with an insider real-time-life video-scrutiny/observation/analysis.”

3. Borch, Christian. “Crowd theory and the management of crowds: A controversial relationship.” *Current Sociology*, Vol. 61, No. 5-6, pp. 584-601, September 2013.

Summary (excerpted from text): “Sociologists of policing and collective protest have made a plea for eradicating from police literature and training programmes which aim to provide guidelines for crowd management any references to classical crowd theory where crowds are depicted as irrational entities. Instead, these scholars suggest, rational conceptions of crowds should inform contemporary crowd management. This article questions this plea on two grounds. First, it demonstrates that there is no unidirectional connection between sociological crowd theory (whatever its content) and practical strategies for governing crowds. The tactical polyvalence of crowd theory is illustrated by showing how the irrational conception of crowds has given rise to very different strategies for the management of crowds (urban reform programmes in the Progressive Era and Hitler’s mobilization strategies, respectively). Second, the article argues that, in spite of its current scholarly popularity, there is no guarantee that the call for a practical employment of the rational notion of crowds will necessarily be successful. This is demonstrated by stressing, on the one hand, that irrational notions of crowds continue to thrive, thereby rendering a turn towards rational approaches difficult, and, on the other hand, that the rational approaches in their ignorance of collective emotional arousal present an inadequate picture of crowds and consequently have limited scope as guidelines for crowd management strategies.”

4. Bonkiewicz, Luke and Ruback, R. Barry. “The Role of the Police in Evacuations Responding to the Social Impact of a Disaster.” *Police Quarterly,* Volume 15: 137, June 2012.

Summary (excerpted from text): “Disaster evacuations are stressful events in which citizens and law enforcement frequently interact with each other. Most emergency response plans are based on military strategies that operate independent of the general public, but we argue that the police must be cognizant of several social psychological factors that affect citizens’ behavior during evacuations, including risk perception, social networks, and access to resources. Drawing from social psychological, criminal justice, and disaster research, we propose a model that (a) describes how citizens’ priorities and behaviors change as a disaster evolves and (b) identifies policing strategies that accommodate these changing behaviors and facilitate a successful evacuation. Our model, embedded in how people behave and what police are taught, can increase citizen compliance with law enforcement during disaster evacuations, remove more citizens from harm, save lives, and improve the relationship between communities and the police.”

5. Zhana, Xin, Yanga, Lizhong, Zhua, Kongjin, Kongb, Xiaoming, Raoa, Ping, and Zhang, Taolin. “Experimental Study of the Impact of Personality Traits on Occupant Exit Choice During Building Evacuation.” 9th Asia-Oceania Symposium on Fire Science and Technology, *Procedia Engineering*, Volume 62, pp. 548-553, 2013.

Summary (excerpted from text): "How do evacuees choose egress route and final exit during an emergency evacuation? This is an essential question within which human factors should be taken into account. Human factors, including personality, age and gender, play an important role during an emergency evacuation. Especially, personality trait varies among individuals. This paper focuses on the potential relationship between the occupants' choice of egress route and final exit and their personality traits (mainly about conscientiousness). We carried out 8 evacuation trials in a school building using a group of students. A survey was conducted to qualitatively analyse the students' evacuation behavior. A simplified Chinese version of NEO-FFI (Neuroticism Extraversion Openness Five-Factor Inventory) was also used to assess the students' personality. The results show that: the participants' choice of classroom exit is unbiased; Conscientiousness influences the way in which students decide their choice of classroom exit. Highly conscientiousness people are more rational when making a decision."

Link: http://ac.els-cdn.com/S1877705813012812/1-s2.0-S1877705813012812-main.pdf?_tid=7507e33e-02ce-11e4-9ce3-00000aab0f01&acdnat=1404404827_7d1f1ad7d0cf8b83d862522671831079

6. Hunt, Aoife, Galea, Edwin R., and Lawrence, Peter J. "An Analysis of the Performance of Trained Staff Using Movement Assist Devices to Evacuate the Non-ambulant." Proceedings of the 5th International Symposium on Human Behavior in Fire, 2012.

Summary (excerpted from text): "This paper describes work undertaken to quantify the performance of trained hospital staff in evacuating people with reduced mobility. Data were collected from 32 trials in which a test subject was evacuated through 11 floors of Ghent University Hospital using four commonly used movement assistance devices: stretcher, carry chair, evacuation chair and rescue sheet. Presented in the paper are performance results for both male and female assist teams, including device preparation time, horizontal speeds, vertical speeds and overtaking potential in stairwells. These data form the basis of the device performance evaluation presented in this paper. A comparative methodology is derived to assess the efficiency of the devices and enable performance differences to be established. Finally, the data collected are used in a numerical simulation of the evacuation of a ward, located on the 11th floor of a hospital, containing 28 non-ambulant patients. The scenarios investigate the time required to evacuate the ward using each of the four assist devices, assuming only the day or night shift staff are available. Furthermore, the scenarios consider the performance of all-male and all-female handlers and also take into consideration the impact of fatigue on the handlers."

Table 5: Literature Summary for Recommendation 8d

Source	Data Source	Peer reviewed?	References NIST report?	Relevancy Score
1	Existing Data	Yes (conference)	No	3
2	Existing Data	Yes	No	3
3	Existing Data	Yes	No	2
4	Existing Data	Yes	No	2
5	Original Data	Yes (conference)	No	2
6	Original Data	Yes (conference)	No	1

For recommendation 8e related to theoretical models of group behavior suitable for coupling to fire and smoke movement simulations, the search terms included:

- "group behavior model",
- "occupant behavior model", and
- "evacuation model".

The following relevant literature was identified.

1. Chaturvedi, Alok, et. al. "DDDAS for Fire and Agent Evacuation Modeling of the Rhode Island Nightclub Fire". Lecture Notes in Computer Science, Volume 3993, pp. 433-439, 2006.

Summary: The paper describes a Dynamic Data Driven Application System (DDDAS) developed to study the interaction between agent models and fire during an evacuation. Two separate models were used to simulate the components of the emergency situation using data from the other interaction models, allowing evaluation of real-time interactions. The result is a better understanding of how individual variables impact the evacuation process.

2. Chu, Mei Lin, Law, Kincho, and Latombe, Jean-Claude. "A Computational Framework for Egress Analysis with Realistic Human Behaviors". CIFE Technical Report #TR209. Center for Integrated Facility Engineering, Stanford University, September 2012.

Summary: This paper provides information on a multi-agent based simulation tool. The tool enables the modeling of social behaviors during evacuation. It presents the basic framework used and the implementation of social behaviors based on recent social science studies regarding response in emergencies. In the modeling framework presented, users can incorporate individual, group, and crowd behavioral rules in simulation. Simulation results show that social behaviors can lead to changes in the overall egress times and patterns.

Link: http://cife.stanford.edu/sites/default/files/TR209_0.pdf

3. Pan, Xiaoshan. "Computational Modeling of Human and Social Behaviors for Emergency Egress Analysis". Ph.D. Dissertation, Department of Civil and Environmental Engineering, Stanford University, June 2006.

Summary: The dissertation addresses the issue of incorporating the impact of psychology and sociology in emergencies into computational models. The author incorporated human behavioral characteristics into a Multi-Agent Simulation System for Egress analysis (MASSEgress). The social behavior is simulated through the modeling of both individual behavior and group interactions. A set of methods were incorporated into MASSEgress to simulate the sensing, decision-making, behavior selection, and motor control of evacuees. Comparisons of MASSEgress to other evacuation models were performed in addition to simulation of The Station Nightclub event.

Link: http://minoe.stanford.edu/publications/xiaoshan_pan/PhD_Thesis_Pan_CIFE.pdf

4. Wassim, Abu Abed and Berkhahn, V. "Towards Perceptually Driven Simulations of Pedestrian Dynamics in Fire: A Cognitive Modeling Approach." Proceedings of the 5th International Symposium on Human Behavior in Fire, 2012.

Summary (excerpted from text): "In this paper, a cognition-oriented approach to modelling movement dynamics of pedestrians will be presented. The focus will be on the following three focal points in simulating evacuation behaviour in fire: Modelling pedestrian behaviour in dark and smoke- filled environment, modelling pedestrian behaviour under stress, fear and anxiety and analysing acoustic-signals-supported evacuation strategies.All the mentioned problems are involving pedestrians' behaviour that is greatly influenced by the cognitive abilities of the individual, especially her perception of the surrounding."

5. Veeraswamy, Anand, Lawrence, Peter J., and Galea, Edwin R. "Implementation of cognitive mapping, spatial representation and wayfinding behaviors of people within evacuation modeling tools." Proceedings of the 4th International Symposium on Human Behavior in Fire, 2009.

Summary (excerpted from text): "In this paper a novel wayfinding technique that attempts to represent the manner in which people wayfind within structures is introduced and demonstrated through two examples. The first step is to encode the spatial information of the enclosure in terms of a graph. The second step is to apply search algorithms to the graph to find possible routes to the destination and assign a cost to the routes based on their personal route preferences such as "least time" or "least distance" or a combination of criteria. The third step is the route execution and refinement. In this step, the agent moves along the chosen route and reassess the route at regular intervals and may decide to take an alternative path if the agent determines that an alternate route is more favorable e.g. initial path is highly congested or is blocked due to fire."

6. Papelis, Y. E., Bair, L. J., Manepalli, S., Madhavan, P., Kady, R., and Weisel, E. "A Multi-Grid Model for Evacuation Coupling With the Effects of Fire Products." *Pedestrian and Evacuation Dynamics*, pp. 349-359, 2011.

Summary (excerpted from text): "This study presents a real-time agent-based approach to modeling crowd behavior that is based on complementary psychological and engineering principles. The application focus is for developing realistic models that address not only the physical but also the psychological aspects of crowd behavior. Our approach to modeling the psychology of a crowd is based on the principle of emotional reflection. According to this principle, our emotions are evoked in response to our perception of other people's emotions; hence emotions propagate through a crowd as a result of each person's perception of other crowd member's emotions as well as external factors. The emotional model is coupled with a movement model that is based on the social forces formulation, but with parameters modified to represent the current emotional state of each crowd member. We present the model along with results of how different emotional levels can affect the movement dynamics of crowds."

7. Kneidl, A., Thiemann, M., Borrmann, A., Ruzika, S., Hamacher, H.W., Köster, G., and Rank, E. "Bidirectional Coupling of Macroscopic and Microscopic Approaches for Pedestrian Behavior Prediction." *Pedestrian and Evacuation Dynamics*, pp. 459-470, 2011.

Summary (excerpted from text): "This study combines a macroscopic and a microscopic model of pedestrian dynamics with a bidirectional coupling technique to obtain realistic predictions for evacuation times. While the macroscopic model is derived from dynamic network flow theory, the microscopic model is based on a cellular automaton. Output from each model is fed into the other, thus establishing a control cycle. As a result, the gap between the evacuation times computed by both models is narrowed down: the microscopic approach benefits from route optimization resulting in lower evacuation times. The network flow approach is enriched by including data of microscopic pedestrian behavior, thus reducing the underestimation of evacuation times."

8. Radianti, Jaziar and Granmo, Ole-Christoffer. "A Framework for Assessing the Condition of Crowds Exposed to a Fire Hazard Using a Probabilistic Model." *International Journal of Machine Learning and Computing*, Vol. 4, No. 1, February 2014.

Summary (excerpted from text): "Allocating limited resources in an optimal manner when rescuing victims from a hazard is a complex and error prone task, because the involved hazards are typically evolving over time; stagnating, building up or diminishing. Typical error sources are: miscalculation of resource availability and the victims' condition. Thus, there is a need for decision support when it comes to rapidly predicting where the human fatalities are likely to occur to ensure timely rescue."

“This paper proposes a probabilistic model for tracking the condition of victims when exposed to fire hazards, using a Bayesian Network. The model is extracted from safety literature on human physiological and psychological responses against heat, thermal radiation and smoke. We simulate the state of victims under different fire scenarios and observe the likelihood of fatalities due to fire exposure. We show how our probabilistic approach can serve as the basis for improved decision support, providing real-time hazard and health assessments to the decision makers.”

Link: http://www.ijmlc.org/papers/379-H0005.pdf

9. Hu, Jun, Sun, Huijun, Gao, Ge, Wei, Juan, and You, Lei. “The Group Evacuation Behavior Based on Fire Effect in the Complicated Three-Dimensional Space.” *Mathematical Problems in Engineering*, Volume 2014, 2014.

Summary (excerpted from text): “In order to effectively depict the group evacuation behavior in the complicated three-dimensional space, a novel pedestrian flow model is proposed with three-dimensional cellular automata. In this model the calculation methods of floor field and fire gain are elaborated at first, and the transition gain of target position at the next moment is defined. Then, in consideration of pedestrian intimacy and velocity change, the group evacuation strategy and evolution rules are given. Finally, the experiments were conducted with the simulation platform to study the relationships of evacuation time, pedestrian density, average system velocity, and smoke spreading velocity. The results had shown that large-scale group evacuation should be avoided, and in case of large pedestrian density, the shortest route of evacuation strategy would extend system evacuation time.”

Link: http://www.hindawi.com/journals/mpe/2014/949280/

10. Guo, Ren-Yong and Huang, Hai-Jun. “Route choice in pedestrian evacuation: formulated using a potential field.” *Journal of Statistical Mechanics: Theory and Experiment*, Issue 4, pg. 4018, April 2011.

Summary (excerpted from text): “A method for formulating the route choice behavior of pedestrians in evacuation in closed areas with internal obstacles is proposed. The method is implemented in a pedestrian model, in which the route choice is determined by the potential of discrete space. The potential measures the total effect of such factors affecting route choice as route distance, pedestrian congestion and route capacity. Using scenario simulations, the proposed method is compared with several existing methods. Simulation results indicate that the proposed method can simulate two classes of phenomena that cannot be reproduced accurately by those existing methods. In addition, two examples of inefficient evacuation as regards route choice are given. The two examples illustrate that, for improving the efficiency of evacuation, excessive or limited sensitivity of pedestrians to the route capacity may be unhelpful, and adding an extra route may be inefficient.”

11. Zhang, Xia, Li, Xiao, and Hadjisophocleous, George. "A probabilistic occupant evacuation model for fire emergencies using Monte Carlo methods." *Fire Safety Journal*, Volume 58, pp. 15–24, May 2013.

Summary (excerpted from text): "The paper proposes a probabilistic occupant evacuation model for fire emergencies using Monte Carlo methods and then integrates the model into the fire risk analysis model CUrisk. The evacuation model uses a coarse network approach to describe a building and an individual perspective to represent occupants. The Monte Carlo methods repeat random variables including the occupants' gender, age, speed, exit selection, pre-evacuation time, and distance to be traveled to exit the initial compartment with uniform distributions. The model produces results similar to those generated by deterministic models for cases dominated by deterministic factors, and gives results covering the possible ranges of outputs for cases controlled by random characteristics. The validation of the model against Test 9 in Guidelines for Evacuation Analysis for New and Existing Passenger Ships shows that predicted evacuation times are between the results given by Pathfinder 2009 and FDS+EVAC. They are also in agreement with the expectations for the test. The application of the model to the Station nightclub fire produces evacuation times covering or similar to those given by Pathfinder 2009, buildingEXODUS, and Simulex for the fire drill mode, and the percentages of remaining occupants in good agreement with the real fire consequences."

12. Akizuki, Y., Tanaka, T. and Yamao, K. "Calculation Model for Travel Speed and Psychological State in Escape Route considering Luminous Condition, Smoke Density and Evacuee's Visual Acuity". Proceedings of the 9th International Symposium of Fire Safety Science, 2008.

Summary (excerpted from text): "In this research, we define subject's visual acuity as recognizable threshold of form perception using Landolt Ring. Visual acuity is a person's ability to see distinctly the details of an object. We set eight levels of floor illuminance, complete or incomplete adaptation conditions and luminous conditions with or without smoke. Since the travel speed of the younger group was faster than that of the older group, regardless of illuminance level or smoke density, the difference in travel speed can be predicted by visual acuity. In this report, we constructed a calculation model to predict travel speed as functions of the luminous environment (incorporating illuminance level, adaptation condition, and smoke density) and evacuee's visual acuity. This model helps us predict performance of evacuees under fire, smoke or blackout conditions."

13. Zhaoa, Daoliang, Yangb, Lizhong, and Lib, Jian. "Occupants' behavior of going with the crowd based on cellular automata occupant evacuation model." *Physica A: Statistical Mechanics and its Applications*, Volume 387, Issue 14, pp. 3708–3718, June 2008.

Summary (excerpted from text): "Occupant behavior which is very complex affects evacuation efficiency and route choice a lot. The psychology and behavior of going with the crowd is very common in daily life and also in occupant evacuation. In this paper, a two-dimensional Cellular Automata model is applied to simulate the process of evacuation considering the psychology of going with the crowd with different room structure or occupant density. The psychology of going with the crowd (the abbreviation is GWC) is classified into directional GWC (DGWC) and spatial GWC (SGWC). The influence of two such kinds of psychology on occupant evacuation is discussed in order to provide some useful guidance on the emergency management of evacuation."

14. Wu, Guan-Yuan, Chien, Shen-Wen, and Huang, Yuan-Ting, "Modeling the occupant evacuation of the mass rapid transit station using the control volume model." *Building and Environment*, Volume 45, Issue 10, Pages 2280–2288, October 2010.

Summary (excerpted from text): "In this study, a control volume model is applied to simulate the process of evacuation in mass rapid transit (MRT) station using different scenarios. The control volume model assumes that each individual is an independent particle. When the evacuation occupant flow is larger than the capacity of the exit so that a virtual closed surface called the control surface that can be formed by connecting the waiting occupants at the exit. The change of the control volume is dependent on the transient number of the waiting occupants only. Based on the homogeneous flow with neglecting the behavior of the individual, the dynamic change of the evacuation occupant at the exit of the platform and the concourse can be formulated and analyzed. In addition, the number and capacity of the exits used in the total evacuation time analysis were measured with the aid of video recording and on-site observations. Using the control volume model, the dynamic characteristics of the evacuation process at each time-step for each of the exits are calculated and discussed. Comparisons are also made with the results found from other studies and NFPA 130."

15. Kuligowski, Erica. "Theory Building: An Examination of The Pre-Evacuation Period of The 2001 WTC Disaster." Proceedings of the 5th International Symposium on Human Behavior in Fire, 2012.

Summary (excerpted from text): "This paper presents a qualitative study of occupant behavior in response to the September 11, 2001 World Trade Center disaster. Through social science-based analyses of transcripts from 245 face-to-face interviews with survivors from both World Trade Center towers, collected by project High-rise Evacuation Evaluation Database, a conceptual model was developed to describe the pre-evacuation period in what became the largest full-scale building evacuation in history. The objectives of this study were to understand the types of actions performed before occupants began evacuation via stairs and elevators, and why those actions were taken to improve techniques used in evacuation modeling tools."

16. Wang, Jing-hong, Lo, Siu-ming, Sun, Jin-hua, Wang, Qing-song, and Mu, Hong-lin. "Qualitative simulation of the panic spread in large-scale evacuation." *Simulation*, Vol. 88, No. 12, pp. 1465-1474, November 2012.

Summary (excerpted from text): "In this paper, a qualitatively simulated approach to model and study the panic spread is proposed. First, the internal structure of the evacuation system is described and various internal and external phenomena related to the change of evacuees' behaviors in the evacuation process are qualitatively interpreted. Based on the qualitative knowledge, a qualitative simulation model of a large-scale evacuation system is established. The calculation results of inverse group matrix verify the rationality and stability of our model. According to the implementation of a series of scenarios with different input, some uncertainty factors that can affect the panic spread in the evacuation process are analyzed, in which the spread of disaster, the rescue guidance, and the normal emotional evacuees are mainly considered. This model reproduces a well-known phenomenon in crowd evacuation, namely "fast is slow", and confirms that the severity of disaster exponentially positively correlates with the panic spread, and the effectiveness of rescue guidance is influenced by the leading emotion in the crowds as a whole."

17. Cocking, Chris, Drury, John, and Reicher, Steve. "The psychology of crowd behaviour in emergency evacuations: Results from two interview studies and implications for the Fire and Rescue Services." *The Irish Journal of Psychology*, Vol. 30, No. 1-2, pp. 64-73, 2009.

Summary (excerpted from text): "Existing psychological models of crowd behaviour were applied to examine emergency egress behaviour, and how this could facilitate the safe management of mass evacuations. Two interview-based studies of survivors' experiences of different emergencies were conducted. It was found that far from mass panic occurring, being in an emergency can create a common identity amongst those affected. A consequence of this is that people are cooperative and altruistic towards others - even when amongst strangers, and/or in life-threatening situations. The analysis has direct implications for how the Fire and Rescue Services manage mass evacuations. In line with earlier critiques, the concept of mass panic is considered to be a myth unsupported by existing evidence. Crowds in emergencies can be trusted to behave in more social ways than previously expected by some involved in emergency planning."

18. Papelis, Y. E., Bair, L. J., Manepalli, S., Madhavan, P., Kady, R., and Weisel, E. "Modeling of Human Behavior in Crowds Using a Cognitive Feedback". *Pedestrian and Evacuation Dynamics*, pp. 265-273, 2011

Summary (excerpted from text): "This paper presents a real-time agent-based approach to modeling crowd behavior that is based on complementary psychological and engineering principles. The application focus is for developing realistic models that address not only the physical but also the psychological aspects of crowd behavior. Our approach to modeling the psychology of a crowd is based on the principle of emotional reflection. According to this principle, our emotions are evoked in response to our perception of other people's emotions; hence emotions propagate through a crowd as a result of each person's perception of other crowd member's emotions as well as external factors. The emotional model is coupled with a movement model that is based on the social forces formulation, but with parameters modified to represent the current emotional state of each crowd member. We present the model along with results of how different emotional levels can affect the movement dynamics of crowds."

19. Machado, R. and Anderson, M. "Emergency Situations in Nightclubs: A Discussion on How to Improve the Fire Safety Strategies Through The Use of Evacuation Modeling Analysis". *Pedestrian and Evacuation Dynamics*, pp.851-854, 2011.

Summary (excerpted from text): "In the past few years, the world has witnessed severe fires in nightclubs, which have caused many human losses. This paper promotes a methodology which uses evacuation modeling analysis for improving the fire safety strategies (FSS) in nightclubs. The methodology is presented through a study case which represents a nightclub scenario. The results have shown that the use of evacuation modeling analysis can help immensely fire protection engineers to develop their FSS reports, incorporating the human behavior factor; rather than only considering the standard safety factors, such as travel distance. The same methodology can be also applied for fire safety management, which is another key-issue to be properly addressed for fire safety purposes in nightclubs. It is expected that this paper can bring some additional light to the way emergency evacuations are planned and addressed is in nightclubs."

20. Weifeng Yuan and Kang Hai Tan, "An evacuation model using cellular automata", Physica A: Statistical Mechanics and its Applications, Volume 384, Issue 2, pp. 549–566, October 2007.

Summary (excerpted from text): "In order to simulate evacuation from a room with multiple exits, a two-dimensional basic cellular automata (CA) model is proposed based on human behavior. In this model, two factors are taken into account, viz. spatial distance and occupant density. To make the simulation more reasonable, human behavior including inertial effect, group effect and unadventurous effect are considered in an extended model. Numerical results show that the proposed CA model is realistic and robust. A parametric study reveals the potential application of CA model in the assessment of fire safety."

21. Samoshin, D., Kholshchevnikov, V., Serkov, B., and Kosatchey, A. "Psychophysical Relation Laws for Pedestrian Flows Parameters". Proceedings of the 5th International Symposium on Human Behavior in Fire, 2012.

Summary: The authors analyzed data from more than 70 series of observations on human flow in various types of buildings in Russia with similar observational studies done internationally. They found that pedestrian flow should be considered a random process instead of a set of separate empirical relations.

Table 6: Literature Summary for Recommendation 8e

Source	Data Source	Peer reviewed?	References NIST report?	Relevancy Score
1	Existing Data	Yes	Yes	3
2	Existing Data	No	Yes	3
3	Existing Data	No	Yes	3
4	Existing Data	Yes (conference)	No	3
5	Existing Data	Yes (conference)	No	3
6	Existing Data	Yes	No	3
7	Existing Data	Yes	No	3
8	Existing Data	Yes	No	3
9	Existing Data	Yes	No	3
10	Existing Data	Yes	No	3
11	Existing Data	Yes	No	3
12	Original Data	Yes (conference)	No	3
13	Existing Data	Yes	No	2
14	Existing Data	Yes	No	2
15	Existing Data	Yes (conference)	No	2
16	Existing Data	Yes	No	2
17	Existing Data	Yes	No	2
18	Existing Data	Yes	No	1
19	Existing Data	Yes	No	1
20	Existing Data	Yes	No	1
21	Existing Data	Yes (conference)	No	1

For recommendation 8f related to the level of safety that model codes afford occupants in buildings, the search terms included:

- "level of safety of model codes",
- "level of safety of building codes",
- "measuring effectiveness of fire prevention", and
- "measuring effectiveness of code compliance".

The following relevant literature was identified.

1. Crawford, Jim. "Updated Codes Save Lives: Lessons Learned from a Seattle Nightclub Fire". *FireRescue*. May 2014.

Summary: This article discusses the successful outcome of a fire during a New Year's Eve celebration at a Seattle nightclub fire where the fire was extinguished by automatic sprinklers and fire extinguishers, wherein there were no injuries. Following The Station nightclub fire, both Seattle and Washington State took steps to adopt the updated model code requirements that were a result of The Station fire. The nightclub in Seattle met those updated requirements.

2. Hall, John R., et. al. "Measuring Code Compliance Effectiveness for Fire-Related Portions of Codes". Fire Protection Research Foundation, Quincy, MA, July 2008.

Summary: This report contains the findings from a study completed by NFPA and the Foundation with the goals to "develop tools to measure how fire prevention activities of fire safety enforcement organizations can reduce fire risk in communities" and "develop a refined methodology to measure fire prevention inspection effectiveness, to meet the needs to today's state and local fire prevention personnel". A portion of the project also gives an overview of Leadership in Life Safety Design (LLSD), which is a potential management tool to measure enhanced life safety features in a building.

URL: http://www.nfpa.org/research/fire-protection-research-foundation/reports-and-proceedings/for-emergency-responders/fire-prevention-and-administration/measuring-code-compliance-effectiveness-for-fire-related-portions-of-codes

3. Solomon, Robert. "Measuring Optimum and Code-Plus Design Criteria for the High Rise Environment". CTBUH 8th World Congress, March 2008.

Summary: This paper presents the concept of Leadership in Life Safety Design (LLSD). LLSD is a building evaluation tool to categorize and quantify the impact design features that enhance life safety. These features are beyond the code requirements and would be voluntarily incorporated. The system focuses on high rise buildings and was developed by the NFPA High Rise Building Safety Advisory Committee (HRBSAC).

URL: http://www.ctbuh.org/LinkClick.aspx?fileticket=frnYNQFF1aQ%3D&tabid=1323&language=en-US

4. Cobin, John M., "Theory review: Does fire safety regulation work? Lessons from Turin, Italy", *Planning Theory,* Vol. 13 No. 2, pp. 189-209, May 2014.

Summary (excerpted from text): "The general theory of regulation and then 10 theories related to safety regulation are summarized, explaining why regulation is or is not beneficial, or why negative externalities like building fires might increase. As an example, evidence from regulation and planning to enhance fire safety in Turin, Italy, is included, which shows apparent regulatory failure due to public choice and knowledge problems. Regulators there apparently failed to meet their public interest objective: the "control of safety conditions to prevent fires" and to "minimize the causes of fire." Thus, planning theory should endeavor to better incorporate government failure theories into its models. These theories at times provide better explanatory and predictive power than traditional market failure models."

5. National Fallen Firefighters Foundation. "Report of the 2nd National Fire Service Research Agenda Symposium". National Fire Academy. May 2011.

Summary: The research agenda highlights the need for research to support community risk reduction. The specific research recommendations include the development of tools to quantify the impact of building and fire code adoption in the community, developing a scientifically-based tool for evaluating the effectiveness of fire prevention and risk reduction programs. Additionally, it identifies a need for tools to assist company officers and incident commanders with risk assessments.

URL: http://www.everyonegoeshome.com/symposium/report2.pdf

6. De Sanctus, Gianluca, et. al. "Assessing the Level of Safety for Performance Based and Prescriptive Structural Fire Design of Steel Structures". Draft Proceedings of the 11th International Symposium for Fire Safety Science. 2014.

Summary (excerpted from text): "The level of safety in structural fire safety is implemented by combining passive and active fire safety measures. Prescriptive and some performance based codes provide requirements to achieve this level of safety without explicitly quantifying it. Here, a reliability based method is used to quantify the level of safety of a design. A generic representation of the building facilitates the application of the methodology on different buildings and to consider the requirements of the codes. Engineering models are used to consider the effect of fire safety measures including the fire brigade intervention under realistic fire conditions. The uncertainties associated with these engineering models are considered through a probabilistic approach. The reliability of the structure is assessed through an advanced Monte Carlo technique called subset simulation. The methodology is applied for retail buildings. The benefits using performance based codes are addressed and compared with the results of prescriptive codes. The methodology can be used for verifying equivalency in fire safety design as well."

URL: http://www.iafss.org/publications/fss/11/88/view

7. Insurance Services Office, Inc. "Building Code Effectiveness Grading Schedule (BCEGS)". 2014.

Summary: The BCEGS assesses the building codes adopted by a community and how the community enforces the requirements. The program assigns communities with a grade from 1 to 10.

URL: http://www.isomitigation.com/bcegs/0000/bcegs0001.html

8. Vaughan, Ellen and Turner, Jim. "The Value and Impact of Building Codes". Coalition for Current Safety Codes. December 2013.

Summary: The paper looks at the big picture of building codes and why they are valuable. Also, it discusses why the three-year cycle of updating model codes and strong enforcement of the building codes are important.

URL: https://www.disastersafety.org/wp-content/uploads/The-Value-and-Impact-of-Building-Codes-by-Ellen-Vaughn-Jim-Turner.pdf

9. Meacham, Brian et. al. "Adaptive Management in Fire Regulation and Emergency Response". Fire Safety Science, Proceedings of the 9th International Symposium, pp. 317-328, 2008.

Summary: This paper discusses how adaptive management techniques may be applied to fire in buildings. The analysis completed indicates that adaptive approaches may be helpful for identifying better regulatory processes, design concepts, and emergency planning and response requirements. However, the authors indicate that adaptive management techniques may not be suitable for all types of disaster mitigation and emergency planning. They specify that further work is necessary to analyze where it is best used.

URL: http://www.iafss.org/publications/fss/9/317/view

10. King, Martin. "Demonstrating Your Fire Prevention Program's Worth – Part 1". Firehouse. August 2011.

Summary: This article is part one in a four-part series discussing the importance of measuring the effectiveness of fire prevention and public education programs. The article gives several different resources that are available to educate on evaluation.

URL: http://www.firehouse.com/article/10461687/demonstrating-your-fire-prevention-programs-worth-part-1

11. Vision 20/20. "Model Performance Measures for Fire Prevention Programs". March 2009.

Summary: This document covers a project with the purpose to "outline model performance measures for local, state, and national fire prevention program managers". The overarching goal is to reach a point where fire prevention efforts are being reported in a consistent fashion to allow for accurate program comparisons and establishment of baselines. The document also contains example evaluation measures.

URL:
http://strategicfire.org/ckfinder/userfiles/files/Model%20Performance%20Measures%20revised%201-09.pdf

12. NFPA. "NFPA 1730, Standard on Organization and Deployment of Fire Prevention Inspection and Code Enforcement, Plan Review, Investigation, and Public Education Operations to the Public". National Fire Protection Association, Quincy, MA.

Summary: Proposed standard NFPA 1730 is scheduled to be available in 2016. This standard includes a methodology for a community risk assessment to aid in establishing the necessary level of fire prevention resources.

13. May, Peter J. "Regulatory Regimes and Accountability". Regulation and Governance, Volume 1, pp. 8-26, 2007.

Summary (excerpted from text): "This research considers accountability issues for new forms of regulation that shift the emphasis from prescribing actions to regulating system or regulating for results. Shortfalls at various levels of accountability are identified from experiences with these regimes in the regulation of building and fire safety, food safety and nuclear power plant safety. These experiences illustrate how accountability shortfalls can undermine regulatory performance and introduce a potential for subtle forms of regulatory capture. These concerns underscore the importance of finding the right fit between regulatory circumstances and the design of regulatory regimes."

URL: http://onlinelibrary.wiley.com/doi/10.1111/j.1748-5991.2007.00002.x/pdf

14. Health and Safety Executive. "Example Risk Assessment for a Nightclub". July 2013

Summary: This document provides a case study of a risk assessment for a nightclub, serving as an example on how to document the hazards. It also functions as a guide to think though the steps that need to be taken to control these risks.

URL: http://www.hse.gov.uk/risk/casestudies/pdf/nightclub.pdf

15. Noonan, F. "Risk Assessment using Scoring System Methodology (SSM) as holistic substitute for IBC Height & Area Table". Alliance for Smoke Containment and Control, Chicago, 3 Aug 2007.

Summary: This presentation, given at the Alliance for Smoke Containment and Control, gives an overview of a possible holistic approach to building height and area. The methodology proposed is Scoring System Methodology (SSM), which is used throughout the global economy for risk assessment. At the time of the presentation, a prototype model was being developed for input by building safety professionals.

16. IBHS. "Fortified… for safer living® (Fortified) Program Standards". Institute for Business & Home Safety, Tampa FL, 2008.

Summary: This document, developed by the Institute for Business and Home Safety (IBHS), provides standards for the Fortified program. The Fortified program is a code plus

homebuilding program. The program standards specify construction, design, and landscaping guidelines with the goal to increase a new home's resistance to natural disasters and reduce damage by other events, such as fire.

URL: http://www.disastersafety.org/wp-content/uploads/fortified-safer-living-standards-IBHS.pdf

17. Fire Department of New York (FDNY). "FireCast".

Summary: Following the Deutsche Bank fire in New York in 2007, the FireCast program was initiated. This program developed a risk based approach to inspections based on analyzing available data.

Table 7: Literature Summary for Recommendation 8f

Source	Data Source	Peer reviewed?	References NIST report?	Relevancy Score
1	Existing Data	No	No	3
2	Existing Data	Yes	No	3
3	Existing Data	Yes (conference)	No	3
4	Existing Data	Yes	No	3
5	Existing Data	No (research agenda)	No	3
6	Existing Data	Yes (conference)	No	3
7	Existing Data	No	No	3
8	Existing Data	No	No	3
9	Existing Data	Yes (conference)	Yes	2
10	Existing Data	No	No	2
11	Existing Data	No	No	2
12	Existing Data	No	No	2
13	Existing Data	No	No	1
14	Existing Data	Yes	No	1
15	Existing Data	No	No	1
16	Existing Data	No	No	1
17	Existing Data	No	No	1

Recommendation 9: Fire Spread and Suppression

Recommendation 9 relates to research recommendations aimed to better understand fire spread and suppression in order to provide tools to designers:

Recommendation 9. Research on Fire Spread and Suppression: *NIST recommends that research be conducted to understand fire spread and suppression better in order to provide the tools needed by the design profession to address recommendations 2, 3 and 5, above. The following specific capabilities require research:*

> *a) prediction of flame spread over actual wall, ceiling and floor lining materials, and room furnishings;*
>
> *b) quantification of smoke and toxic gas production in realistic room fires; and*
>
> *c) development of generalized models for fire suppression with fixed sprinklers and for firefighter hose streams.*

Literature was reviewed for each of the above sub-categories for this recommendation, so the discussion below is split into three sections.

For recommendation 9a related to prediction of flame spread over wall, ceiling, and floor lining materials, the following relevant literature was identified. The following search terms were used:

- "flame (fire) spread (growth) over wall",
- "flame (fire) spread (growth) over ceiling",
- "flame (fire) spread (growth) over floor",
- "flame (fire) spread (growth) on furnishings",
- "room fire spread prediction", and
- "room fire growth".

1. Liang, Canjun, Cheng, Xudong, Li, Kaiyuan, Yang, Hui, Zhang, Heping and Yuen, Kwok K. "Experimental study on flame spread behavior along poly(methyl methacrylate) corner walls at different altitudes". *Journal of Fire Sciences*, Volume 32, Number 84, 2014.

Summary (excerpted from text): "The effects of altitude and intersection angle on the flame spread behavior and pyrolysis front characteristics along corner walls were experimentally studied. The experiments were conducted using mock corners made of poly(methyl methacrylate) slabs with intersection angles varying from 60to 120 at two altitudes of 29.8 and 3658.0 m. Measurements were taken for the upward and lateral flame spread rates, the flame heights, the flame heat flux to the fuel surface, and the mass loss rates of the tested slabs."

2. Hjohlman, Maria, Andersson, Petra, van Hees, Patrick. "Flame Spread Modelling of Complex Textile Materials". *Fire Technology*, 47, 85–106, 2011.

Summary (excerpted from text): "Flame spread in textile materials was modelled using two different simulation programs: the semi-empirical area-based code ConeTools, and the computational fluid dynamics, CFD, code Fire Dynamics Simulator, FDS, (version 5). Two textile products were selected for study, they show a large difference in composition and application area, one material is developed to function as a protecting layer for the underlying structure in case of fire while the other is an insulating material with no requirements on fire performance. Two FDS-models were developed for the simulations."

3. Tsai, Kuang-Chung. "Using cone calorimeter data for the prediction of upward flame spread rate". *Journal of Thermal Analysis and Caliorimetry*, Volume 112, Issue 3, pp 1601-1606.

Summary (excerpted from text): "In a cone calorimeter, the specimen receives uniformly distributed irradiance from the cone heater. Producing a heating environment simulating the heating intensity in real fires, this apparatus consequently is capable of providing information of materials relevant to their fire performance. This study introduces an alternative protocol of the cone calorimeter and a sample holder by which the following differences were made, including specimen turned 42° before ignition, lower ignition source before ignition, heater removed after ignition, and specimen moved back to vertical orientation after ignition. The prediction of flame spread rate using the alternative test protocol is closer to the measured flame spread rate than standard test methods."

4. Ren, Ning, Wang, Yi, Trouvé, Arnaud. "Large eddy simulation of vertical turbulent wall fires". 9th Asia-Oceania Symposium on Fire Science and Technology. *Procedia Engineering* 62, pp 443- 452. 2013.

Summary (excerpted from text): "The objective of the present study is to evaluate the ability of wall-resolved large eddy simulations (LES) to accurately simulate wall fires. The focus of the study is on the flame-to-wall heat transfer. The LES performance is evaluated via comparisons with a previously developed experimental database. LES simulations are performed using FireFOAM."

URL: http://www.sciencedirect.com/science/article/pii/S187770581301268X

5. Weng, W. G. and Hasemi, Y. "A numerical model for flame spread along combustible flat solid with charring material with experimental validation of ceiling flame spread and upward flame spread." *Fire and Materials*, Volume 32, Issue 2, pp 87-102. March 2008.

Summary (excerpted from text): "This paper gives a numerical model for flame spread along combustible flat solid with charring materials. The presented model consists of a one-dimensional flame spread model coupled with a one-dimensional pyrolysis model. The existing experimental data (the ceiling flame spread beneath medium density fibreboard) are used for comparison to validate the model. In addition, the model can also be used to predict upward flame spread."

6. Shih, Hsin-Yi and Wu, Hong-Chih. "An Experimental Study of Upward Flame Spread and Interactions Over Multiple Solid Fuels". *Journal of Fire Sciences*, Volume 26, Number 5, pp 435-453. September 2008.

Summary (excerpted from text): "Upward flame spread and flame interactions over multiple solid fuels are experimentally studied, and the effects of flame interactions on the flame spreading rates are analyzed. Flame spreading characteristics and spreading rates are measured and compared for six different geometric arrangements of thin solids at different solid width and separation distance between solids."

7. Mangs, J. and Hostikka, S. "*Experiments and Numerical Simulations of Vertical Flame Spread on Charring Materials at Different Ambient Temperatures*". Proceedings of the 10th International Symposium for Fire Safety Science, pp. 499-512. 2011.

Summary (excerpted from text): "A new experimental apparatus for measuring flame spread rates at different ambient temperatures is presented. The 2-m long sample is pre-heated with air to desired temperature, ignited from below with a small propane burner, and flame spread is monitored with thermocouples at the surface of the sample. Rate of vertical concurrent flame spread as a function of ambient temperature is determined on cylindrical birch rod samples and on PVC cable samples. Corresponding flame spread scenarios are numerically simulated using axi-symmetric solution of the flow field and a pyrolysis model with parameters estimated from thermogravimetric and cone calorimeter experiments. The simulation model was able to predict the flame spread rates within the uncertainties associated with the experiments and post-simulation analysis of the spread rate."

URL: http://www.iafss.org/publications/fss/10/499/view

8. Weng, W. and Hasemi, Y. "*A Numerical Model For Ceiling Flame Spread Beneath A Combustible Board With Charring Material*". Proceedings of the 8th International Symposium for Fire Safety Science, pp. 385-396. 2005.

Summary (excerpted from text): "In this paper, an approach for modeling ceiling flame spread beneath a combustible board is developed. The presented model consists of a one-dimensional flame spread model coupled with a one-dimensional pyrolysis model. Firstly, the pyrolysis model is validated against the experimental data from the literature. In addition, the existing experimental data (the ceiling flame spread beneath medium density fibreboard (MDF)) are used for comparison to validate the numerical model. The results obtained from numerical simulations using the presented model are consistent with the experimental tests."

URL: http://www.iafss.org/publications/fss/8/385/view

9. Consalvi, J.L., Porterie, B., Coutin, M., Audouin, L., Casselman, C., Rangwala, A., Buckley, S.G. and Torero, J.L. "*Diffusion Flames Upwardly Propagating Over Pmma: Theory, Experiment And Numerical Modeling*". Proceedings of the 8th International Symposium for Fire Safety Science, pp. 397-408. 2005.

Summary (excerpted from text): "A numerical model and experiments over PMMA are used to evaluate the main assumptions used in the theoretical description of a diffusion flame established in a natural boundary layer. Flow characteristics (2-D Boundary Layer) and surface thermal balance are identified as the critical assumptions to be evaluated. Comparison of experiments, numerical results, and theoretical model serve to validate the assumptions leading to the definition of a mass transfer number but establish the need to model all three-dimensional features of the flow."

URL: http://www.iafss.org/publications/fss/8/397/view

10. Kudo, Y., Itakura, M., Fujita, Y. and Ito, A., "*Flame Spread And Extinction Over Thermally Thick Pmma In Low Oxygen Concentration Flow*". Proceedings of the 8th International Symposium for Fire Safety Science, pp. 457-468. 2005.

Summary (excerpted from text): "This report discusses the mechanisms of flame spread and extinction over a thermally thick PMMA surface in a low-oxygen-concentration flow, based on experimental investigations. The temperature distribution in the condensed phase when the oxygen concentration in an air current decreases was measured in detail using holographic interferometry and thermography. The energy balance in the condensed phase was investigated based on the detailed temperature distribution, and the dominant heat transfer path in a low-oxygen-concentration flow was clarified."

URL: http://www.iafss.org/publications/fss/8/457/view

11. Galea, Edwin R., Wang, Zhaozhi, Veeraswamy, Anand, Jia Fuchen, Lawrence, Peter J., and Ewer, John. "Coupled Fire/Evacuation Analysis of the Station Nightclub Fire". Fire Safety Science, Proceedings of the Ninth International Symposium, pp 465-476. 2008.

Summary (excerpted from text): "In this paper, coupled fire and evacuation simulation tools are used to simulate the Station Nightclub fire. This study differs from the analysis conducted by NIST in three key areas; (1) an enhanced flame spread model and (2) a toxicity generation model are used, (3) the evacuation is coupled to the fire simulation. Three evacuation scenarios are then considered, two of which are coupled with the fire simulation. The coupled fire and evacuation simulation suggests that 180 fatalities result from a building population of 460. With a 15 sec delay in the fire timeline, the evacuation simulation produces 84 fatalities which are in good agreement with actual number of fatalities. An important observation resulting from this work is that traditional fire engineering ASET/RSET calculations which do not couple the fire and evacuation simulations have the potential to be considerably over optimistic in terms of the level of safety achieved by building designs."

URL: http://www.iafss.org/publications/fss/9/465/view

12. Lai, Chi-Ming, Ho, Ming-Chin, and Lin, Ta-Hui. "Experimental Investigations of Fire Spread and Flashover Time in Office Fires". *Journal of Fire Sciences*, Volume 28, pp 279-302. May 2010.

Summary (excerpted from text): "The characteristics of, prediction models for, and experimental data pertaining to flashover in full-scale room fires were first reviewed. Then, initiation, growth, full development, and decay of three office fire scenarios were experimentally explored using a 10 MW fire test facility and continuous online combustion gas analysis. The conditions for flashover were investigated and compared with correlations in the literature. The model office compartment is an aerated lightweight concrete structure with dimensions of 5 m × 6 m and with a net room height of 2.4—3.3 m."

13. Consalvia, J. L., Pizzoa, B., Porterie, B. "Numerical analysis of the heating process in upward flame spread over thick PMMA slabs". *Fire Safety Journal*, Volume 43, pp 351–362. 2008.

Summary (excerpted from text): "A detailed analysis of the unburned material heat-up during upward flame spread over small slabs of PMMA is provided using a numerical model. The two-dimensional time-dependent Favre-averaged Navier–Stokes equations coupled with sub-models for turbulence, combustion, soot formation, and radiation are solved for the gas phase. The modelling of condensed phase processes is based on the one-dimensional heat conduction equation and pyrolysis is treated as a phase change using the latent heat approach."

14. Kwon, Jae-Wook, Dembsey, Nicholas A., and Lautenberger, Christopher W. "Evaluation of FDS v. 4: upward flame spread". *Fire Technology*, Volume 43, No. 4, pp 255-284. 2008.

Summary (excerpted from text): "In this work three simulations are conducted to evaluate FDS V.4's capabilities for predicting upward flame spread. The FDS predictions are compared with empirical correlations and experimental data for upward flame spread on a 5 m PMMA panel. A simplified flame spread model is also applied to assess the FDS simulation results. Capabilities and limitations of FDS V.4 for upward flame spread predictions are addressed, and recommendations for improvements of FDS and practical use of FDS for fire spread are presented."

15. Cheng, Hao and Hadjisophocleous, George V. "Dynamic modeling of fire spread in building". *Fire Safety Journal*, Volume 46, pp 211–224. 2011.

Summary (excerpted from text): "In this paper, a dynamic model of fire spread considering fire spread in both horizontal and vertical directions is described. The algorithms for simulating the fire spread process in buildings and calculating dynamic probability of fire spread for each compartment at each time step of simulation are proposed. The formulae used in calculating the input data for the dynamic fire spread model are derived. The dynamic fire spread model can easily be applied for any building including high-rise buildings. A detailed example of calculation of fire spread in a two-storey office building is described."

16. Li, Liming, Zhang, Heping, Xie, Qiyuan, Chen, Long, and Xu, Chunming. "Experimental study on fire hazard of typical curtain materials in ISO 9705 fire test room". *Fire and Materials*, Volume 36, pp 85-96. 2012.

Summary (excerpted from text): "In this paper, fire hazard of three typical curtain materials with different pleat rates were tested in an ISO 9705 fire test room. Fire parameters such as temperature field, flame spread rate, heat release rate (HRR), and emitted gases, and the influences of pleat rate and cotton content on flame spread rate were investigated. The correlation between flame spread rate and HRR was discussed. Fire parameters such as temperature field, flame spread rate, heat release rate (HRR), and emitted gases, and the influences of pleat rate and cotton content on flame spread rate were investigated. The correlation between flame spread rate and HRR was discussed."

17. Hofmann, Anja and Muediger, Muehlnikel. "Experimental and numerical investigation of fire development in a real fire in a five-storey apartment building". *Fire and Materials*, Volume 35, pp 453-462. 2011.

Summary (excerpted from text): "A fire in a five-storey apartment building was investigated experimentally and numerically. The room of origin of the fire was a living room in the second floor and the fire was started by a candle on a television set. The fire spread externally over the building façade and internally along the staircase and affected all the flats above leading to two fatalities. By this time large sections of the façade were on fire already. The rapid fire that spread over the façade and the staircase necessitated detailed investigations."

18. Chen, Chien-Jung, Hsieh, Wie-Dong, Hub, Wei-Cheh, Lai, Chi-Ming, and Lin, Ta-Hui. "Experimental investigation and numerical simulation of a furnished office fire". *Building and Environment*, Volume 45, pp 2735-2742. 2010.

Summary (excerpted from text): "Experiments were conducted in a full-scale model room equipped with both movable and fixed fire loads to explore fire growth and spread via heat release rates, indoor air temperature and species concentration. Numerical simulations with parameter adaptation were carried out using FDS software to predict the fire features and were compared with the experimental results. In this study, the material properties and oxygen limit settings in the FDS software were tested to explore their influence on the tendency of heat release rate and on the total amount of heat release. The results show that the heat release rate from the FDS simulations is comparable to the full-scale experiment results during the fire growth period. Temperature profile near ceiling can be modeled well. In the full-involvement burning and decaying periods, the qualitative trends were identical, although the simulated value differed greatly from the experimental result."

19. Sunahara, Hiroyuki, Ishihara, Takahiro, Kikkawa, Akimitsu, Mizuno, Masayuki, Ohmiya, Yoshifumi, and Morita, Masahiro. "Fire Behavior under a Ceiling in Growing Fire Part 1 Fire Spread and Ceiling Temperature Distribution". *Fire Science and Technology*, Volume 26, Number 4, Special Issue, pp. 473-478. 2007.

Summary (excerpted from text): "In general, a fire develops gradually from the smallest source of a fire to a fully developed fire. The growth in this period is commonly described with a model in the form of αt2. When a fire develops in a general building, it reaches the ceiling at a certain point and spreads beneath the ceiling horizontally. However, in the most experiments, a fire is steadily ignited by a burner, and therefore, there are only few full scale experiments conducted with respect to the ceiling temperature and flame length in growing fire that has reached the ceiling. Therefore, an experiment was conducted to measure the spreading speed of fire, ceiling temperature, air velocity and flame length with an actual-sized fire experiment using a wood crib."

20. Harish, K. and Venkatasubbaiah, K. "Numerical simulation of turbulent plume spread in ceiling vented enclosure". *European Journal of Mechanics B/Fluids*, Volume 42, pp 142-158. 2013.

Summary (excerpted from text): "The buoyancy-induced turbulent flow generated by a heat source in a square enclosure with single and multiple ceiling vents has been studied numerically. A two-dimensional, turbulent natural convection flow is investigated in stream function and vorticity formulation approach. The effects of heat source location, vent location and multiple vents on flow characteristics in enclosure are presented. The heat transfer characteristics, ambient entrainment flow rate and the oscillatory nature of the penetrative and recirculating flow inside the vented enclosure are reported."

21. Zhang, Xia and Yu, Yong. "Experimental studies on the three-dimensional effects of opposed-flow flame spread over thin solid materials". *Combustion and Flame*, Volume 158, Issue 6, pp 1193–1200. June 2011.

Summary: The paper presents an experimental study of the three-dimensional effects of flame spread over thin solid materials using a natural-convection-suppressing horizontal narrow-channel. The effects of gas flow speed, oxygen concentration, material width, and flow tunnel size on flame spread are considered.

22. Xie, Wei and DesJardin, Paul E. “An embedded upward flame spread model using 2D direct numerical simulations”. *Combustion and Flame*, Volume 156, Number 2, pp 522-530. 2009.

Summary (excerpted from text): “A fully coupled 2D fluid–solid direct numerical simulation (DNS) approach is used to simulate co-flow flame spread over poly(methyl methacrylate) (PMMA) at different angles of inclination. Comparison of simulations and experimental measurements are conducted over a range of flame spread rates. Results show that the heat flux to the preheating region varies considerably in time — contradicting often employed assumptions used in established flame spread theories. Accounting for the time dependent behavior is essential in accurate predictions of flame spread, however, a universal characterization in terms of easily defined parameters is not found. Alternatively, a reaction progress variable based embedded flame model is developed using mixture fraction, total enthalpy and surface temperature. State maps of the gas-phase properties and surface heat flux are constructed and stored in pre-computed lookup tables. The resulting model provides a computationally efficient and a local formulation to determine the flame heat flux to the surface resulting in excellent agreement to DNS and experiments for predictions of flame spread rate and position of the pyrolysis front.”

23. Pizzo, Y., Consalvi, J. L., and Porterie, B. “A transient pyrolysis model based on the *B*-number for gravity-assisted flame spread over thick PMMA slabs”. *Combustion and Flame*, Volume 156, Number 9, pp 1856-1859. September 2009.

Summary (excerpted from text): “This work developed a transient pyrolysis model based on the modified mass transfer number determined from experiments on the steady-state burning rate of vertical PMMA slabs. It allowed satisfactory concordance with experiments on upward flame spread. A good agreement for the rate of spread was also observed for inclination angles below the critical angle.”

24. Olson, S. L., Miller, F. J., Jahangirian, S., and Wichman, I. S. “Flame spread over thin fuels in actual and simulated microgravity conditions”. *Combustion and Flame*, Volume 156, Number 6, pp 1214-1226. June 2009.

Summary (excerpted from text): “In this study, the flame spreads in a narrow gap, as occurs in fires behind walls or inside electronic equipment. Two sets of experiments are described, one involving flame spread in a Narrow Channel Apparatus (NCA) in normal gravity, and the others taking place in actual microgravity. Three primary variables are considered: flow velocity, oxygen concentration, and gap size (or effect of heat loss). Flammability maps are constructed that delineate the uniform regime, the flamelet regime, and extinction limits for thin cellulose samples. Good agreement is found between flame and flamelet spread rate and flamelet size between the two facilities. The experiments show that in normal gravity the flamelets are a fire hazard since they can persist in small gaps where they are hard to detect.

The results also indicate that the NCA quantitatively captures the essential features of the microgravity tests for thin fuels in opposed flow."

25. Jiang, Yun. "Decomposition, Ignition, and flame spread on furnishing materials", Yun Jiang, Ph.D. Thesis, Centre for Environment Safety and Risk Engineering, Victoria University, Australia. 2006.

Summary (excerpted from text): "The general aim of this research is to find an effective and applicable method for prediction of pyrolysis and ignition of certain furnishing materials in a real fire environment. In current study, certain furnishing materials, timbers, polyurethane foams and fabrics, were chosen for research purpose. Series of bench-scale tests were carried out to construct a physical platform for modelling and provide test results for validating of the modeling. Through modelling, various criteria for ignition were investigated and compared with the test results."

URL: http://vuir.vu.edu.au/481/1/02whole.pdf

26. Huang, X. and Gollner M.J., "*Correlations for Evaluation of Flame Spread over an Inclined Fuel Surface*". Draft Proceedings of the 11th International Symposium for Fire Safety Science, 2014.

Summary (excerpted from text): "The time-dependent flame spread process over thermally thick slabs of polymethyl methacrylate (PMMA) is investigated with particular emphasis on the burning behavior and geometry of the flame. Correlations between the flame length and the fuel mass-loss rate have revealed a delayed transition to turbulence for flames residing on the underside of fuel samples, and an earlier transition to turbulence for flames on the topside of these samples, compared to traditional vertical wall flames. As the fuel inclination increases, the relationship between the flame length and fuel mass-loss rate ranges between a recent theoretical prediction for a laminar wall plume dominated by diffusion and the traditional prediction for a turbulent wall plume dominated by convective mixing."

URL: http://www.iafss.org/publications/fss/11/173/view

27. Zhang, Ying, Huang, Xinjie, Wang, Quigsong, Ji, Jie, Sun, Jinhua, and Yin, Yi. "Experimental study on the characteristics of horizontal flame spread over XPS surface on plateau". *Journal of Hazardous Materials*, Volume 189, pp 34–39. May 2011.

Summary (excerpted from text): "A series of comparative laboratory-scale experiments were carried out in the Lhasa plateau and the Hefei plain respectively to investigate the characteristics of flame spread over the extruded polystyrene (XPS) foam, a typical thermal insulation material. Flame shape and the temperature profile in solid phase were monitored, and the effects of altitude on the heat transfer process were analyzed. Comparing of the temperature change rate curve on plateau with that in plain, it is found that the peak characteristics of the curves in the pyrolysis stage changed from single peak to multi-peaks, which suggests that the altitude difference might change the pyrolysis mechanisms of XPS material. Moreover, the sample scale effects on flame spread are also explored. Two different regimes are found in flame spread behavior with sample scale at the both altitudes. The spread rate drops with sample scale in convection regime and rises in radiation regime."

28. Zhang, Jianping, Dembele, Siaka, Karwatzki, John, and Wen, Jennifer X. "Effect of Radiation Models on CFD Simulations of Upward Flame Spread". Fire Safety Science – Proceedings of the Eighth International Symposium, pp 421-432. 2005.

Summary (excerpted from text): "The objective of this study is to examine the effect of radiation models on CFD predictions of flame spread. To this end, a statistical narrow band (SNB) model and the WSGG model are employed for the simulation of two upward flame spread scenarios, one being a large scale flame spread over a vertical PMMA wall while the other representing flame spread along vertical corner walls. Quantitative comparison is made between the prediction results obtained with the SNB model and the WSGG model as well as the experimental data. Results clearly show that the SNB model yields more accurate results than the WSGG approach. However, the SNB model is about four to five times more time consuming than the WSGG model. Therefore, for simulations of complex engineering applications a compromise between accuracy and numerical efficiency should be taken into account."

URL: http://www.iafss.org/publications/fss/8/421/view

29. Collier, PCF. "Fire Properties of Floor Coverings: New Fire Test Methods and Acceptable Solutions". BRANZ Study Report 181. BRANZ Ltd, Judgeford, New Zealand. 2007.

Summary (excerpted from text): "This project trailed the current reaction to fire test requirements for flooring and compared this with two alternative test methods on a range of flooring products. The findings indicated that the current test method of the Hot Metal Nut (HMN) required by the NZBC Compliance Documents does not adequately identify the flooring products that present a hazard. Alternative test methods – the Flooring Radiant Panel Test (FRPT) and the cone calorimeter (CC) – were shown to identify flooring products that do present a hazard when the HMN had indicate the same products to be in the low hazard category."

URL:
http://www.branz.co.nz/cms_show_download.php?id=0d2ebab737a645d7f1f5608789b3ed16705815d4

30. Collier, PCR, Whiting, PN, and Wade, CA. "Fire Properties of Wall and Ceiling Linings: Investigation of Fire Test Methods for Use in NZBC Compliance Documents". BRANZ Study Report 160. BRANZ Ltd, Judgeford, New Zealand. 2006.

Summary (excerpted from text): "This project has demonstrated the effectiveness of the ISO 9705 room corner test method and the AS/NZS 3837/ISO 5660 Cone Calorimeter in evaluating the reaction-to-fire performance of a selection of surface lining materials as applied to walls and ceilings. The measurement of heat release rate (HRR) and smoke production rate (SPR) are direct indicators of the hazard. The growth of the HRR enables a lining material to be classified with respect to time based on if or when flashover occurs. The measurements of gas species, percentage of flame spread area over the lining surface, and compartment temperatures and smoke layer height, are compared to confirm that the conditions generated are consistent with the primary parameters of HRR and SPR and accurately reflect the fire hazard. Recommendations are made for changes to the fire test methods in NZBC Compliance Documents."

URL:
http://www.branz.co.nz/cms_show_download.php?id=7652db415e65acf4391dcaffb8edb87fac3784ff

31. Robbins, AP. "Simplified Reaction to Fire for Interior Wall, Ceiling and Floor Linings". BRANZ Study Report 301. BRANZ Ltd, Judgeford, New Zealand. 2014.

Summary (excerpted from text): "The focus for the overall project was to investigate the possibility of providing simplified 'deemed to comply' solutions to demonstrate code compliance for fire properties of surface coatings and other interior finishes in the New Zealand regulatory context. The approach used for this literature review has been to collect together published test results that may be (directly or indirectly) relevant to the fire testing procedures required for compliance with the New Zealand Building Code, and to provide guidance for designing a test program."

URL:
http://www.branz.co.nz/cms_show_download.php?id=5b356fa1555e3f55b844b0a4f17a51e9d589bc21

32. California State Fire Marshal. "Flammability Standards for Building Insulation Materials". Draft Edition, April 2014.

Summary: This is the report of a working group from the Office of the California State Fire Marshal, which reviews flammability standards for building insulation materials. The purpose of the working group is to review the published information and determine recommendations to the SFM on conditions where flame retardant chemicals may be omitted from building insulation without reducing the fire safety level. This research uses information from the NIST NCST investigation and thus cites the report. However, it was not done in response to the NIST research recommendation and has a lower relevance rating.

Table 8 - Literature Summary for Recommendation 9a

Source	Data Source	Peer reviewed?	References NIST report?	Relevancy Score
1	Original Data	Yes	No	3
2	Existing Data	Yes	No	3
3	Original Data	Yes	No	3
4	Original Data	Yes (conference)	No	3
5	Existing Data	Yes	No	3
6	Original Data	Yes	No	3
7	Original Data	Yes (conference)	No	3
8	Existing Data	Yes (conference)	No	3
9	Original Data	Yes (conference)	No	3
10	Original Data	Yes (conference)	No	3
11	Existing Data	Yes (conference)	Yes	2
12	Original Data	Yes	No	2
13	Original Data	Yes	No	2
14	Original Data	Yes	No	2
15	Existing Data	Yes	No	2
16	Original Data	Yes	No	2
17	Original Data	Yes	No	2
18	Original Data	Yes	No	2
19	Original Data	Yes	No	2
20	Existing Data	Yes	No	2
21	Original Data	Yes	No	2
22	Existing Data	Yes	No	2
23	Existing Data	Yes	No	2
24	Original Data	Yes	No	2

Source	Data Source	Peer reviewed?	References NIST report?	Relevancy Score
25	Original Data	Ph.D. Thesis	No	2
26	Original Data	Yes (conference)	No	2
27	Original Data	Yes	No	1
28	Existing Data	Yes (conference)	No	1
29	Existing Data (literature review)	No (BRANZ report)	No	1
30	Existing Data (literature review)	No (BRANZ report)	No	1
31	Existing Data (literature review)	No (BRANZ report)	No	1
32	Existing Data	No	Yes	1

For recommendation 9b related to quantification of smoke and toxic gas production, the following relevant literature was identified, using these search terms:

- "smoke production room fire",
- "room fire smoke",
- "toxic gas room fire",
- "room fire toxicity",
- "room fire smoke quantification",
- "room fire toxicity quantification".

1. Stec, Anna A., Hull, T. Richard. "Assessment of the fire toxicity of building insulation materials". *Energy and Buildings*, Volume 43, pp 498–506. February-March 2011.

Summary (excerpted from text): "A significant element in the cost of a new building is devoted to fire safety. Energy efficiency drives the replacement of traditional building materials with lightweight insulation materials, which, if flammable can contribute to the fire load. Most fire deaths arise from inhalation of toxic gases. The fire toxicity of six insulation materials (glass wool, stone wool, expanded polystyrene foam, phenolic foam, polyurethane foam and polyisocyanurate foam) was investigated under a range of fire conditions. Two of the materials, stone wool and glass wool failed to ignite and gave consistently low yields of all of the toxic products. The toxicities of the effluents, showing the contribution of individual toxic components, are compared using the fractional effective dose (FED) model and LC50 (the mass required per unit volume to generate a lethal atmosphere under specified conditions). For polyisocyanurate and polyurethane foam this shows a significant contribution from hydrogen cyanide resulting in doubling of the overall toxicity, as the fire condition changes from well-ventilated to under-ventilated. These materials showed an order of increasing fire toxicity, from stone wool (least toxic), glass wool, polystyrene, phenolic, polyurethane to polyisocyanurate foam (most toxic).”

2. Zhang, Jiaqing, Lu, Shouxiang, Li, Qiang, Yuen, Ricahrd Kwok Kit, Chen, Bing, Yuan, Man, and Li, Changhai. “Smoke filling in closed compartments with elevated fire sources”. *Fire Safety Journal*, Volume 54, pp 14–23. November 2012.

Summary (excerpted from text): “An experimental study on smoke filling in closed compartments with elevated fire sources is presented. Experiments were conducted with elevated fires in a closed compartment with interior dimensions of 3.000 m (L)×3.000 m (W)×1.950 m (H). Various parameters, such as the light extinction coefficient, the oxygen concentration and the gas temperature, showed distinct stratification phenomena, and the interface of the stratification was the fuel surface level. The results indicated that the smoke layer descended to the fuel surface level but did not descend directly to the floor at the center of the compartment; rather, it continued the filling process by wall jets. A similar stratification was observed in a closed burning compartment with interior dimensions of 1.000 m (L)×1.000 m (W)×0.750 m (H) through tracking the smoke by a laser sheet. A visualization showed that the wall jets penetrated the interface, traveled along the wall, concentrated at the floor and then rose from the center of the floor. With continuous burning, the smoke filled the lower layer.”

3. Hull, T. Richard and Paul, Keith T. “Bench-scale assessment of combustion toxicity—A critical analysis of current protocols”. *Fire Safety Journal*, Volume 42, pp 340–365. July 2007.

Summary (excerpted from text): “This paper reviews current fire effluent toxicity tests, their relevance to fire, and the ways of assessing and applying their results to reduce fire hazards. There are a large number of different methods for determination of the toxic potency of fire effluents from materials or products. These different methods yield apparently inconsistent data because they represent different fire scenarios; measure product yields either as a function of material flammability or independent of it; base the toxicity assessment on the concentrations of different species; or use animal exposure to generate an overall estimate of toxic potency without knowledge of the relative contributions of the chemical species.”

4. Pierce, J.B.M. and Moss, J.B. “Smoke production, radiation heat transfer and fire growth in a liquid-fuelled compartment fire”. *Fire Safety Journal*, Volume 42, pp 310–332. June 2007.

Summary (excerpted from text): “A detailed investigation is described of the interaction between fire development, smoke production and radiative exchange in a half-scale ASTM compartment in which the source is a heptane pool fire. Measurements of heat flux, fuel mass loss rate, ventilation flow rates, and temperature and soot volume fraction are reported for the compartment for varying door widths. Data from the compartment are compared with open pool fire measurements using the same equipment. The confined geometry is shown to exert a strong influence on pool fire development and suggests that considerable caution is needed in employing open pool fire data as boundary conditions for CFD simulation. Numerical simulations based on the direct calculation of radiative exchange between the liquid fuel surface, the smoke-laden environment and bounding walls do reproduce the behavior observed when combustion, soot production and radiation are modelled in detail and finely resolved spatially."

5. Wang, Z., Jia, F., and Galea, E. R. "Predicting toxic gas concentrations resulting from enclosure fires using local equivalence ratio concept linked to fire field models". *Fire and Materials*, Volume 31, Issue 1 pp 27–51. January/February 2007.

Summary (excerpted from text): "A practical CFD method is presented in this study to predict the generation of toxic gases in enclosure fires. The model makes use of local combustion conditions to determine the yield of carbon monoxide, carbon dioxide, hydrocarbon, soot and oxygen. The local conditions used in the determination of these species are the local equivalence ratio (LER) and the local temperature. The heat released from combustion is calculated using the volumetric heat source model or the eddy dissipation model (EDM). The model is then used to simulate a range of reduced-scale and full-scale fire experiments. The model predictions for most of the predicted species are then shown to be in good agreement with the test results."

6. Lassus J., Courty L., Studer E., Garo, J.P. and Aine P., "*Experimental approach to estimate species concentrations in a compartment fire*". Draft Proceedings of the 11th International Symposium for Fire Safety Science. 2014.

Summary (excerpted from text): "An approach for estimating species concentration during a fire in a well-stirred compartment is investigated. A semi-empirical model based on oxygen concentration is used. It gives an estimate of the concentrations of carbon monoxide, carbon dioxide, hydrogen and hydrocarbons with a carbon chain length lower than five. Three intervals of oxygen concentration are noticed, they correspond to sufficiently ventilated, underventilated and very underventilated fires."

URL: http://www.iafss.org/publications/fss/11/69/view

7. Stec, A.A. and Rhodes J., "*Bench Scale Generation of Smoke Particulates and Hydrocarbons from Burning Polymers*". Proceedings of the 10th International Symposium for Fire Safety Science, pp. 629-639. 2011.

Summary (excerpted from text): "The soot and hydrocarbon generation behaviour from four common polymers has been investigated under different fire conditions using different bench scale apparatuses. Hydrocarbon and soot production from polyethylene, polystyrene, polyamide and polyvinyl chloride were investigated using the steady state tube furnace (ISO TS 19700) under well-ventilated, small under-ventilated and large under-ventilated fire conditions; and in the smoke density chamber (ISO 5659-2) under the three standard test conditions; and the results have been compared to published data from the fire propagation apparatus (ASTM E 2058). To investigate the soot generation further, the particle size distribution was determined using a cascade."

URL: http://www.iafss.org/publications/fss/10/629/view

8. Stec, A. A., Hull, T. R., Purser, J. A., and Purser, D. A. "Comparison of toxic product yields from bench-scale to ISO room". *Fire Safety Journal*, Volume 44, pp 62–70. January 2009.

Summary (excerpted from text): "The steady-state tube furnace (ISO TS 19700) allows individual fire stages to be replicated and shows a good general agreement with product yield data (measured for CO2, CO, HCN, NOx, total hydrocarbons and smoke particulates) obtained from large-scale ISO room tests for the five materials considered here and expressed as functions of equivalence ratio and CO2/CO ratio. The closest direct agreement between the large- and small-scale data were obtained for pool fires involving PP and nylon 6.6 product yield. For materials burned as wall linings, with varying decomposition conditions at different room locations, and/or when a propane flame is also present, direct comparison with tube-furnace data is more problematic. Nevertheless MDF, MDF-FR and PS show reasonable agreement for CO, CO2, HCN and hydrocarbon yields between the scales. Smoke yields tended to be more variable and may be influenced by the presence of different areas of flaming and non-flaming decomposition."

9. Chow, W. K. and Yin, R. "Smoke Movement in a Compartmental Fire". *Journal of Fire Sciences*, Volume 24, Number 6 pp 445-463. November 2006.

Summary (excerpted from text): "Transport of larger smoke particles generated by a fire in a compartment is studied. An atrium fire with three different heat release rates is taken as an example. The air flow pattern and temperature contours are predicted by a fire field (or application of computational fluid dynamics (CFD) model. The paths of smoke particles are modeled by the Lagrangian method coupled with the air movement induced by hot smoke. Distribution of smoke particles and their trajectories are then calculated. By superimposing the trajectories of particles of different sizes, the shape of the smoke plume is observed."

10. Lizhong, Yang, Wenxing, Feng, and Junqi, Ye. "Experimental Research on the Spatial Distribution of Toxic Gases in the Transport of Fire Smoke". *Journal of Fire Sciences*, Volume 26, Number 1, pp 45-62. January 2008.

Summary (excerpted from text): "This study, through experiments conducted in a reduced-scale compartment—corridor model, examines the assumption and explores the characteristics of spatial distribution of toxic gases in smoke transport from a fire hazard. The results suggest that the toxic gases in the upper layer in the corridor are characterized by uniform expansion, while those in the lower layer are not. It has also been found that evolutions of the gases in different layers are not synchronous, while they are identical at the same height where the densities are close. Further analyses indicate that the formation of CO from the deoxidization of O_2, CO_2, and the unburned hydrocarbon in the smoke movement delays the time of the maximum concentration."

11. Remesh, K. and Tan, K. H. "Field Model Analysis and Experimental Assessment of Fire Severity and Smoke Movement in a Partitioned and a Non-partitioned Dwelling Unit". *Journal of Fire Sciences*, Volume 24, Number 5, pp 365-391. September 2006.

Summary (excerpted from text): "To study the smoke movement and gas temperature evolution, computational fluid dynamics (CFD) analysis is carried out for a partitioned and a non-partitioned dwelling unit for the same fire load. The model predictions in terms of gas temperatures are then compared with the experimental measurements for both units. The gas temperatures inside the units are measured using K-type mineral insulated thermocouples, positioned at various elevations in the room of fire origin, and at other locations that were in the path of anticipated smoke movement. Also, to study the effectiveness of fire suppression methods, water spray and water mist methods are employed in the partitioned and non-partitioned units, respectively, when the fire reached decay stage."

12. Crewe, Robert J., Stec, Anna A., Walker, Richard G., Shaw, John E. A., Hull, T. Richard. "Experimental Results of a Residential House Fire Test on Tenability: Temperature, Smoke, and Gas Analyses". *Journal of Forensic Science*, Volume 59, Number 1. January 2014.

Summary (excerpted from text): "A fire experiment conducted in a British 1950s-style house is described. Measurements of temperature, smoke, CO, CO2, and O2 were taken in the Lounge, stairwell, and front and back bedrooms. The front bedroom door was wedged open, while the door to the back bedroom was wedged closed. Contrary to expectations and despite the relatively small fire load, analysis and hazard calculations show permeation of toxic fire gases throughout the property with lethal concentrations of effluent being measured at each sampling point. A generally poor state of repair and missing carpets in the upper story contributed to a high degree of gas and smoke permeation. The available egress time was calculated as the time before the main escape route became impassable. Given known human responses to fire, such an incident could have caused fatalities to sleeping or otherwise immobile occupants."

13. Chow, W. K., Chow, C. L., and Li, S. S. "Simulating Smoke Filling in Big Halls by Computational Fluid Dynamics". *Modelling and Simulation in Engineering*, Volume 2011, Article ID 781252. 2011.

Summary (excerpted from text): "An update on applying Computational Fluid Dynamics (CFD) in smoke exhaust design will be presented in this paper. Key points to note in CFD simulations on smoke filling due to a fire in a big hall will be discussed. Mathematical aspects concerning of discretization of partial differential equations and algorithms for solving the velocity-pressure linked equations are briefly outlined. Results predicted by CFD with different free boundary conditions are compared with those on room fire tests. Standards on grid size, relaxation factors, convergence criteria, and false diffusion should be set up for numerical experiments with CFD."

URL: http://www.hindawi.com/journals/mse/2011/781252/

14. Wang, Z., Jia, F., Galea, E. R., and Patel, M. K. "Predicting toxic gas concentrations at locations remote from the fire source". *Fire and Materials*, Volume 35, Issue 7, pp 505–526. November 2011.

Summary (excerpted from text): "A toxicity model capable of predicting toxic gas concentrations within fire enclosures utilizing the concept of the local equivalence ratio (LER) was recently developed. This paper describes an enhancement of the original model that improves its accuracy in predicting species concentrations at remote locations from the room of fire origin. The enhanced technique involves dividing the CFD computational domain into two regions for species calculation, a control region (CR) and a transport region. Toxic gas concentrations in the CR are calculated using the formulation developed in the earlier study whereas in the transport region, gas concentrations are determined as a result of the mixing of hot combustion gases with fresh air. The concept of a critical equivalence ratio, which is derived from the effective heat release rate (or combustion efficiency) of the fire scenario being simulated, is introduced to perform the domain division. Predictions of temperatures and species concentrations at various locations made by the new model are compared with the results from two experiments. Compared with the earlier model, the modified model provides considerable improvements in the predictions of toxic species levels."

15. Riahi S. and Beyler, C.L. "*Measurement and Prediction of Smoke Deposition from a Fire Against a Wall*". Proceedings of the 10th International Symposium for Fire Safety Science, pp. 641-654. 2011.

Summary (excerpted from text): "Smoke deposition from different fuels and fire sizes to a vertical gypsum wall were studied using gravimetric and a newly developed optical method. Optical properties of the deposited smoke were deduced from the gravimetric and optical measurements. Based on the new optical method, a photographic method was developed and used to quantify the smoke patterns on a wall adjacent to the fire source. The method is suitable for use in fire research and fire scene documentation. A thermophoretic smoke deposition model was extended and validated, using the experimental results from this work. The model can be used to predict smoke deposition rates and patterns due to thermophoresis."

URL: http://www.iafss.org/publications/fss/10/641/view

16. Babrauskas, V., Blum, A., Daley R. and Birnbaum L., "*Flame Retardants in Furniture Foam: Benefits and Risks*". Proceedings of the 10th International Symposium for Fire Safety Science, pp. 265-278. 2011.

Summary (excerpted from text): "The extensive use of chemical flame retardants to meet the California Furniture Flammability Standard Technical Bulletin 117 (TB117) provides an example of the need for consideration of environmental impacts of fire safety interventions before they are widely implemented. Flame retardants are currently being used in products with high levels of human exposure without adequate toxicological testing. For example, flame retardants commercially used to meet TB117 have been found to have negative consequences in the environment. And notably, the TB117 standard has not been shown to have a measurable fire safety benefit. Both the unintended adverse environmental and health impacts and the lack of fire safety benefits of California TB117 are discussed in detail."

URL: http://www.iafss.org/publications/fss/10/265/view

17. Kaczorek K., Stec, A.A. and Hull, T.R. "*Carbon Monoxide Generation in Fires: Effect of Temperature on Halogenated and Aromatic Fuels*". Proceedings of the 10th International Symposium for Fire Safety Science, pp. 253-263. 2011.

Summary (excerpted from text): "Carbon monoxide is widely regarded as the major toxicant in fire effluents. It is produced as a result of incomplete combustion, by low temperatures, flame quenching, or under-ventilation. Polymers containing halogens and aromatic rings give higher carbon monoxide yields in well-ventilated conditions, when burnt in the steady state tube furnace (ISO 19700) at a furnace temperature of 650 °C. This is believed to result from flame quenching by hydrogen halides or the enhanced stability of aromatic rings in flames, respectively. This work investigates the effect of ventilation condition and furnace temperature on the yield of carbon monoxide from burning mixtures of polyvinyl chloride and polyethylene, polyamide 6 containing a brominated flame retardant and an antimony synergist, and polystyrene. In each case, the high carbon monoxide yields in well-ventilated burning reduced at higher furnace temperatures, showing a diminution of fire toxicity above 850 °C."

URL: http://www.iafss.org/publications/fss/10/253/view

18. Hull, T.R., Stec, A.A. and Paul, K.T. "*Hydrogen Chloride in Fires*". Proceedings of the 9th International Symposium for Fire Safety Science, pp. 665-676. 2008.

Summary (excerpted from text): "Experimental data is presented from burning unplasticised PVC, plasticized PVC cable, and LDPE to show that HCl interferes with the flame chemistry, particularly the conversion of CO to CO2, further increasing the hazard from the fire effluent. The product yields are used to estimate the fire effluent toxicity, comparing the standard based on rat lethality, ISO 13344 with the newer standard, which also takes the effect of incapacitating irritants into account, showing the large contribution of HCl to the fire hazard. Finally, the relationship between the toxicity and a simple analysis of effluent acidity (EN 50297-2-3) is discussed."

URL: http://www.iafss.org/publications/fss/9/665/view

19. Stec, A.A., Hull, T.R., Purser, J.A., Blomqvist, P. and Lebek, K., "*A Comparison of Toxic Product Yields Obtained From Five Laboratories Using the Steady State Tube Furnace (ISO TS 19700)*". Proceedings of the 9th International Symposium for Fire Safety Science, pp. 653-664. 2008.

Summary (excerpted from text): "The steady state tube furnace has been developed from BS 7990 into the first internationally recognized standard for assessment of fire gas toxicity, ISO TS 19700. The apparatus has been shown to reliably replicate different fire stages, and is capable of generating toxic product yields as a function of the equivalence ratio. Work is reported from 5 laboratories currently using the steady state tube furnace where it has been used to assess the toxic product yields from a range of generic polymer materials, as a function of equivalence ratio."

URL: http://www.iafss.org/publications/fss/9/653/view

20. Beyler, C.L., "*Toxicity Assessment Of Products Of Combustion Of Flexible Polyurethane Foam*". Proceedings of the 9th International Symposium for Fire Safety Science, pp. 1047-1058. 2005.

Summary (excerpted from text): "The scientific literature on the toxicity of products of combustion of flexible polyurethane foam is reviewed to assess its potential for use in toxic hazard analysis. Combustion modes examined include pyrolysis/thermal decomposition, smoldering, and open flaming, and under ventilated flaming combustion."

URL: http://www.iafss.org/publications/fss/8/1047/view

21. Lai, Chi-ming, Chen, Chien-Jung, Tsai, Ming-Ju, Tsai, Meng-Han, and Lin, Ta-Hui. "Determinations of the fire smoke layer height in a naturally ventilated room". *Fire Safety Journal*, Volume 58, pp 1–14. May 2013.

Summary (excerpted from text): "According to the case-based reasoning of natural ventilation designs in recommended Green Buildings, an investigated model space was proposed in this study. FDS simulations and full-scale experiments were carried out to measure the impact of natural ventilation conditions and the installation of a natural ventilation shaft on smoke layer descent during different fire scenarios. The feasibility of using the N-percentage rule to determine the fire smoke layer height in a naturally ventilated space was also investigated."

22. Xie, Qiyuan, Yuan, Hongyong, Song, Liwei, and Zhang, Yongming. "Experimental studies on time-dependent size distributions of smoke particles of standard test fires". *Building and Environment*, Volume 42, Issue 2, pp 640–646. February 2007.

Summary (excerpted from text): "In this paper, the time-dependent size distributions of smoke particles are measured using the SMPS spectrometers for four typical standard test fires in the field of fire detection. The changing trend of the normalized number distributions of smoke aerosol as experiments go on is analyzed for each fire."

23. Kang, Kai. "Verification of CFD Modeling for Smoke Control Using Two Compartment Fire Experiments". *ASHRAE Transactions*, Volume 115, Issue 1, p 254. 2009.

Summary (excerpted from text): "This paper compares the numerical predictions from computational fluid dynamics (CFD) to two sets of selected compartment fire experimental data. Using a Reynolds-averaged approach for turbulence in the first compartment fire comparison, it is shown that the numerical results of the heat and mass exchange through the compartment opening are in good agreement with the experimental measurements. Overall, a difference within approximately 10% is observed for the centerline flow velocity and temperature, as well as the upper layer height and the temperature at one corner of the compartment. In addition, the results suggest that far-field predictions would not be sensitive to the modeling approach of the fire inside the compartment when the fire-associated transport phenomena are taken into account. The second comparison verified the prediction of the compartment interior wall surface temperature using large eddy simulation. The discrepancy in the numerical results is between 10% to 25% for a pool fire from 170 to 390 kW. From these results, the practical implications of CFD modeling for smoke control are discussed."

24. Staubli, O., Sigg, C., Peikert, R., Gubler, D., and Gross, Markus. "Volume rendering of smoke propagation CFD data". *Proceedings IEEE Visualization*. October 2005.

Summary (excerpted from text): "This paper presents real-time volume rendering of transient smoke propagation conforming to standardized visibility distances. It visualized time dependent smoke particle concentration on unstructured tetrahedral meshes using a direct volume rendering approach. A simple absorption-based lighting model is evaluated in a preprocessing step using the same rendering approach. Back-illuminated exit signs are commonly used to indicate the escape route. As light emitting objects are visible further than reflective objects, the transfer function in front of illuminated exit signs must be adjusted with a deferred rendering pass."

25. Stec, A. A., Hull, T. R., Lebek, K., Purser, J. A., and Purser, D. A. "The effect of temperature and ventilation condition on the toxic product yields from burning polymers". *Fire and Materials*, Volume 32, Issue 1, pp 49-60. January/February 2008.

Summary (excerpted from text): "This work presents combustion product yields generated using a small-scale fire model. The Purser Furnace apparatus (BS7990 and ISO TS 19700) enables different fire stages to be created. Identification and quantification of combustion gases and particularly their toxic components from different fire scenarios were undertaken by continuous Fourier transform infrared spectroscopy. The relationship between type of the fire particularly the temperature and ventilation conditions and the toxic product yields for four bulk polymers, low-density polyethylene, polystyrene (PS), Nylon 6.6 and polyvinyl chloride (PVC) is reported."

26. Amundsen, D. E., Hadjisophocleous, G., Kashef, A., and Zhu, X. "Algorithm for smoke modeling in large, multi-compartmented buildings--implementation of the hybrid model". *ASHRAE Transactions*, Volume 117, Issue 1, p777. May 2011.

Summary (excerpted from text): "This paper presents the implementation of a hybrid model to simulate fires in different building geometries. The hybrid model combined two independent models: a zone model and a network model. The solution procedure consisted of two parts: simulation of two-zone model, which dealt with the room of fire-origin and neighboring rooms, and simulation of the network model, which included rooms far away from the fire. The two-zone and network models were first tested individually; then the performance of the integrated model was investigated in different types of applications. Finally, the models were integrated, where the solutions (temperature and mass flow rate) of the two-zone model become input source for the network model."

27. Vaux, S. and Pretrel, H. "Relative effects of inertia and buoyancy on smoke propagation in confined and forced ventilated enclosure fire scenarios". *Fire Safety Journal*, Volume 62, Part B, pp 206-220. November 2013.

Summary (excerpted from text): "This study focuses on smoke propagation in confined and forced ventilated enclosure fire scenarios as it is a source of possible hazardous situations. The objective of the present contribution is to investigate the effect of the three physical mechanisms (buoyancy, gas expansion and forced ventilation) on diverse examples of smoke flow through transfer elements. Three types of pool fire scenario have been considered with several transfer elements typical of nuclear industry. Each scenario and the smoke propagation are analyzed on the basis of large scale representative fire tests performed during the PRISME project and numerical simulations with a zone-modelling code, SYLVIA of

IRSN. The results show ventilation is the driving mechanism for smoke propagation in the one-room configuration whereas buoyancy plays the major role for the doorway flow. Finally, depending on the kind of leakages, mechanical ventilation can act on the buoyancy-induced smoke propagation."

28. Kaye, N. B. and Hunt, G. R. "Smoke filling time for a room due to a small fire: The effect of ceiling height to floor width aspect ratio". *Fire Safety Journal*, Volume 42, Issue 5, pp 329–339. July 2007.

Summary (excerpted from text): "The research considered the filling of a room with smoke from a small, centrally located floor fire. It presented theoretical arguments for the behavior of the filling time relative to the idealized 'filling box time' as a function of the room height to width aspect ratio. Initially, the rate at which the smoke layer deepens is shown to be more rapid for relatively wide rooms (large aspect ratio). However, at larger times, relatively tall rooms (small aspect ratio) fill more rapidly due to large scale overturning and engulfing of ambient fluid. A series of experiments were performed to verify these results and showed good qualitative agreement with our theoretical predictions. The experiments were also used to evaluate the extent of deviation of the actual smoke front position from the idealized filling box model as a function of the aspect ratio."

29. Johansson, Nils and van Hees, Patrick. "A correlation for predicting smoke layer temperature in a room adjacent to a room involved in a pre-flashover fire". *Fire and Materials*, Volume 38, Issue 2 pp 182–193. March 2014.

Summary (excerpted from text): "In this paper, a correlation for predicting gas temperatures in a room adjacent to a room involved in a pre-flashover fire is developed. The correlation is derived from results from computer simulations and the external validity is studied by comparing results from the correlation with full-scale test data."

30. Klason, Lars-Gunnar, et. al. "Dimensionerande brand: anlagda skolbränder". SP Report 2010:15. SP Technical Research Institute of Sweden. 2010.

Summary: This report identifies typical arson fires to be used in the evaluation of different fire protection measures, based on previous work. The focus of the program is on arson in schools. The literature search includes fire data on ignition sources uses and suggestions for future work where the data is limited. Although this research uses information from the NIST NCST investigation and cites the report, it was not done in response to the NIST research recommendation and has a lower relevance rating.

URL: http://www.anlagdbrand.se/Documents/Publikationer/SP_Rapport_2010_15.pdf (in Swedish)

31. Williamson, J., Beyler, C.L. and Floyd, J. "*Validation of Numerical Simulations of Compartment Fires with Forced or Natural Ventilation Using the Fire and Smoke Simulator (FSSIM), CFAST and FDS*". Proceedings of the 10th International Symposium for Fire Safety Science, pp. 1277-1288. 2011.

Summary (excerpted from text): "The Fire and Smoke Simulator (FSSIM) Version 1.5 is a continuous time, physics-based simulation of the spread of fire and smoke inside a multi-level, multi-compartment geometry with complex ventilation. The performance of FSSIM will then be compared to other commonly used fire simulation tools, including the Consolidated Model of Fire and Smoke Transport (CFAST) [4], and the Fire Dynamics Simulator (FDS) [5]. This study is intended to demonstrate the relative level of accuracy that can be obtained from several fire models using simplistic methodologies such as those that may be employed in the design evaluation stage of fire hazard analysis."

URL: http://www.iafss.org/publications/fss/10/1277/view

32. Walsh, Donald W. "Cyanide: An Ubiquitous Product of Combustion in Modern Fires". *Cyanide and Modern Fires: Scientific and Practical Fundamentals for Fire Service Professionals*, p. 6. EMD Pharmaceuticals, 2010.

Summary: The paper discusses the topic of cyanide as a common product of combustion in fires to build awareness of the issue for first responders. The author uses data from the NIST report from The Station Nightclub as well as data from the Swedish National Testing and Research Institute, which are consistent with the NIST findings. Although this research uses information from the NIST NCST investigation and cites the report, it was not done in response to the NIST research recommendation and has a lower relevance rating.

URL: http://www.firesmoke.org/wp-content/uploads/2010/10/FireEMS_Supplement.pdf

Table 9 - Literature Summary for Recommendation 9b

Source	Data Source	Peer reviewed?	References NIST report?	Relevancy Score
1	Existing Data	Yes	No	3
2	Original Data	Yes	No	3
3	Existing Data	Yes	No	3
4	Original Data	Yes	No	3
5	Original Data	Yes	No	3
6	Original Data	Yes (conference)	No	3

Source	Data Source	Peer reviewed?	References NIST report?	Relevancy Score
7	Original Data	Yes (conference)	No	3
8	Original Data	Yes	No	2
9	Existing Data	Yes	No	2
10	Original Data	Yes	No	2
11	Original Data	Yes	No	2
12	Original Data	Yes	No	2
13	Original Data	Yes	No	2
14	Existing Data	Yes	No	2
15	Original Data	Yes (conference)	No	2
16	Existing Data	Yes (conference)	No	2
17	Original Data	Yes (conference)	No	2
18	Original Data	Yes (conference)	No	2
19	Original Data	Yes (conference)	No	2
20	Existing Data	Yes (conference)	No	2
21	Original Data	Yes	No	1
22	Original Data	Yes	No	1
23	Original Data	Yes	No	1
24	Existing Data	Yes	No	1
25	Original Data	Yes	No	1
26	Existing Data	Yes	No	1
27	Existing Data	Yes	No	1
28	Original Data	Yes	No	1
29	Existing Data	Yes	No	1
30	Existing Data	No	Yes	1
31	Existing Data	Yes (conference)	No	1
32	Existing Data	No	Yes	1

For recommendation 9c related to development of models for fire suppression with sprinklers and hose streams, the following relevant literature was identified. The following were the list of search terms:

- “fire suppression model”,
- “sprinkler suppression model”,
- “hose stream suppression model”,
- “fire suppression with sprinkler”, and
- “fire suppression with hose stream”.

1. Yoon, Sam S., Figueroa, Victor, Brown, Alexander L., and Blanchat, Thomas K. “Experiments and Modeling of Large-scale Benchmark Enclosure Fire Suppression”. *Journal of Fire Sciences*, Volume 28, Number 2, pp 109-139. March 2010.

   Summary (excerpted from text): “This article presents a series of experiments on benchmark fire suppression. The experiments were performed in a controlled environment, utilizing a cylindrical object or calorimeter centered above a 2 m diameter pan filled with kerosene-based hydrocarbon fuel, JP8. The experimental setup and procedure for gathering data on water suppression performance are presented. The characteristics of the nozzles used in the experiments are presented as well. The experimental results provide the boundary condition and temporal data necessary for validation of the fire suppression models used. The article also includes simulation results on the fire suppression experimental tests. The suppression simulations were carried out using a numerical model based on a Temporally Filtered Navier-Stokes (TFNS) formulation coupled with a Lagrangian model for droplets, which includes detailed descriptions of the interaction between the water droplets and the fire plume.”

2. Yang, Dong, Huo, Ran, Hu, Longhua, Li, Sicheng, and Li, Yuanzhou. “A Fire Zone Model Including the Cooling Effect of Sprinkler Spray on Smoke Layer”. Fire Safety Science – Proceedings of the Ninth International Symposium, pp. 919-930. 2008.

   Summary (excerpted from text): “A fire zone model which includes the cooling effect of sprinklers is developed. Heat transfer from the smoke layer to sprinkler water spray was considered as an additional heat loss term in energy balance equation. In the absence of a sprinkler, the predicted temperature of this model matched that of CFAST6.0, while when sprinkler effects were included, the model predicted the temperature profile of the smoke layer with good agreement with published experiments. This model was applied to a hypothetical compartment fire. Results showed that a higher heat release rate of fire led to a significant decrease in smoke temperature following sprinkler activation, while only a small decrease in smoke layer temperature is predicted when increasing sprinkler pressure from 0.05MPa to 0.1MPa.”

URL: http://www.iafss.org/publications/fss/9/919/view

3. de Vries, J., Meredith, K., and Xin, Y. "An Experimental Study of Fire Suppression Physics for Sprinkler Protection". Fire Safety Science – Proceedings of the Tenth International Symposium, pp. 429-442. 2011.

Summary (excerpted from text): "An experimental study was conducted to investigate the key physics of sprinkler-based fire suppression and associated water-film transport. The objective was to evaluate experimental methods for their appropriateness in studying the key physics, and provide validation data for numerical modeling. The numerical model is currently under development to simulate sprinkler-based suppression of large-scale, rack-storage fires. Individual experimental techniques were explored to study water absorption, surface flow, evaporation, and suppression on vertically arranged, corrugated cardboard surfaces. In addition, water transport was investigated in full-scale rack storage configurations. The experimental results show that the tested experimental techniques are appropriate to study the key phenomena related to sprinkler-based fire suppression."

URL: http://www.iafss.org/publications/fss/10/429/view

4. Li, S.C., Chen, Y., and Li, K.Y. "A mathematical model on adjacent smoke filling involved sprinkler cooling to a smoke layer". *Safety Science*, Volume 49, Issue 5, pp 670–678. June 2011.

Summary (excerpted from text): "Conventional two-zone model determines the smoke filling time in buildings without considering the cooling effect of sprinkler spray on the smoke layer. In order to improve the prediction, the current zone model is revised with a new mathematical model developed by taking the sprinkler cooling effect into account. The heat transfer between smoke layer and sprinklers spray was mathematically calculated. By using the mathematical model, the smoke filling time in an adjacent space under the sprinkler cooling effect are calculated. A set of experiments were carried out to validate the model. The smoke layer height was experimentally measured. Results show that the model predictions agree well with the experimental results. The smoke filling becomes slower due to the reduced volumetric smoke flow under sprinkler cooling. The variation of sprinkler operating pressure has little influence on the smoke filling since the cooling gets less effective as the operating pressure increases."

5. Hu, L. H. et al. "A mathematical model on interaction of smoke layer with sprinkler spray". *Fire Safety Journal*, Volume 44, Issue 1, pp 96– 105. January 2009.

Summary (excerpted from text): "A mathematical model was developed for predicting the downward descending behavior of the buoyant smoke layer under sprinkler spray. The behavior of the smoke layer was determined by considering the interaction between the drag force of the sprinkler spray and the buoyancy force of the hot smoke layer itself in the spray region. The smoke layer may be pulled down with its thickness increased at the center of the spray region due to the cooling and drag effects of the sprinkler spray, thus to form a downward "smoke logging" plume. In the mathematical model developed in this paper, the critical condition under which the smoke layer lost its stability, as a serious concern, was predicted. Additionally, the length of the downward plume, which was rarely investigated before, was also further calculated. Full-scale experiments were carried out to validate the model. Results showed that the predictions, including the critical condition and the length of the plume, by the mathematical model agreed well with that observed and measured in the experiments. The length of the downward plume was shown to increase with the sprinkler operating pressure by an approximately linear correlation."

6. Robbins, AP. "Automatic Water-Based Fire Suppression System Experiments-Literature Summary for Model Validation Purposes". BRANZ Study Report 257, BRANZ Ltd, Judgeford, New Zealand. 2011.

Summary (excerpted from text): "A BRANZ project was conducted that aimed to identify the current state of the data available for validation of fire models incorporating suppression algorithms for suppression and post-suppression conditions in buildings, which are largely ignored in current performance-based design practices. This report contains a summary of collated water-based fire suppression test data and guidance on the important parameters, and variables for consideration when performing validation evaluations of models incorporating suppression algorithms."

URL:
http://www.branz.co.nz/cms_show_download.php?id=bd2e89c5197dadfe117a7f94f395d5d4fedf49fe

7. Li, S.C., Yang, D., Huo, R., Hu, L.H., Li, Y.Z., Li, K.Y. and Wang, H.B. "Studies of Cooling Effects of Sprinkler Spray on Smoke Layer". Fire Safety Science – Proceedings of the Ninth International Symposium, pp. 861-872. 2008.

Summary (excerpted from text): "An experimental study was performed to measure the cooling of a smoke layer by water sprays. This was followed by the development of a mathematical model based on the theory of Chow and Tang. The predictions of the model agree well with the experimental measurements. Water sprays investigated in the present work provided significant cooling of the smoke layer. We observed little effect of increasing the water pressure from 50 to 100 kPa on the cooling of the smoke layer."

URL: http://www.iafss.org/publications/fss/9/861/view

8. Schwille, John A. and Lueptow, Richard M. "A Simplified Model of the Effect of a Fire Sprinkler Spray on a Buoyant Fire Plume". *Journal of Fire Protection Engineering*, Volume 16, Issue 2, pp 131-153. May 2006.

Summary (excerpted from text): "A simple modification of the theory by Morton et al. for buoyant plumes has been made to incorporate a fire sprinkler spray by adding a term in the momentum equation to reflect the momentum of a uniform disperse droplet field. Of course, actual fire sprinkler sprays do not have uniform droplet fields. The results of this model agree with previous complex CFD simulations even though thermal effects of the droplet phase are not included in the model. Thus, given the agreement of the momentum-based model with previous work, it appears that momentum plays a key role in the interaction between droplet sprays and buoyant plumes."

9. O'Grady, N. and Novozhilov, V. "Large Eddy Simulation Of Sprinkler Interaction With A Fire Ceiling Jet". *Combustion Science and Technology*, Volume 181, pp 984–1006. 2009.

Summary (excerpted from text): "A large eddy simulation (LES) CFD model is used to predict water sprinkler spray interaction with a fire environment. The emphasis is on computing gas temperatures and velocities induced by sprinkler discharge onto the ceiling jet flow. Results are presented for two different water discharge rates, in addition to simulation of free-burning fire. Extensive variation of physical and numerical parameters is performed to investigate the robustness of the predictions. The results of the computations compare favorably to measurements from full-scale fire tests reported in the literature, indicating good accuracy of LES approach in application to practical fire design problems. Results are also compared with the earlier treatment of the same problem using the Reynolds-averaged Navier–Stokes (RANS) approach."

10. Wang, Y., Meredith K., Zhou, X., Chatterjee, P., Xin, Y., Chaos M., Ren, N. and Dorofeev, S., "*Numerical Simulation of Sprinkler Suppression of Rack Storage Fires*". Draft Proceedings of the 11th International Symposium for Fire Safety Science. 2014.

Summary (excerpted from text): "Fire suppression tests with ceiling sprinkler protection in a rack storage fuel configuration are simulated using a Computational Fluid Dynamics tool. Two types of ceiling sprinklers are used in this study: a pendent quick response sprinkler designated as K14, and an upright standard response sprinkler designated as K11.2. The tests are simulated using FireFOAM, which couples necessary sub-models for fire growth, sprinkler response, and fire suppression. Numerical results are compared with experiments for both free burn tests under a 20-MW calorimeter and sprinkler suppression tests under a 7.6 m high ceiling."

URL: http://www.iafss.org/publications/fss/11/209/view

11. Meredith K., Xin, Y. and de Vries J., "*A Numerical Model for Simulation of Thin-Film Water Transport over Solid Fuel Surfaces*". Proceedings of the 10th International Symposium for Fire Safety Science, pp. 415-428. 2011.

Summary (excerpted from text): "A model for simulating water film transport over solid fuel surfaces has been developed. The fundamental film-transport equations for mass continuity, momentum, and energy were formulated. These equations have been implemented in OpenFOAM along with essential source terms for inter-phase transport. The model has been coupled to a gas-phase solver, solid boundary condition, and spray transport model. Initial validation of the model has been performed and good agreement is seen with the Nusselt solution for continuous film flows over inclined surfaces. Comparison of the film model was also made with experimental measurements for film thickness, velocity, and mass flow rate."

URL: http://www.iafss.org/publications/fss/10/415/view

12. Ren, N., Blum, A., Zheng, Y., Do, C. and Marshall, A. "Quantifying the Initial Spray from Fire Sprinklers". Fire Safety Science – Proceedings of the Ninth International Symposium, pp. 503-514. 2008.

Summary (excerpted from text): "A Sprinkler Atomization Model (SAM) has been developed based on these physics to predict the initial drop velocity, location, and size based on the nozzle geometry and injection conditions. The initial spray from a simplified yet realistic sprinkler geometry has been quantified through detailed measurements to provide insight into these atomization processes and to evaluate SAM performance. The measured and predicted breakup locations and drop sizes follow We-1/3 scaling laws, previously established by other researchers in similar canonical configurations. However, SAM over predicts the volume median drop diameter by as much as 40%, probably due to the absence of models to characterize the orthogonal stream underlying the radially expanding sheet. This orthogonal stream generated by the spaces was measured to consist of nearly 50% of the flow and produces smaller drops than the radially expanding sheet."

URL: http://www.iafss.org/publications/fss/9/503/view

13. Bryner, Nelson P., Madrzykowski, Daniel, and Grosshandler, William. "Reconstructing The Station Nightclub Fire – Computer Modeling Of The Fire Growth And Spread". 11th International Interflam Conference Proceedings, September 2007.

Summary: This report documents a study undertaken at NIST to simulate The Station fire using a computer model. The data input into the model was taken from investigation photographs, site visits, floor plans, small scale material testing, and real-scale mock up experiments. The model simulation is consistent with the video footage of the fire. A second simulation included automatic sprinklers to study the impact they could have had on the fire. Although this research uses information from the NIST NCST investigation and cites the report, it was not done in response to the NIST research recommendation and has a lower relevance rating.

URL: http://www.nist.gov/customcf/get_pdf.cfm?pub_id=900085

Table 10 - Literature Summary for Recommendation 9c

Source	Data Source	Peer reviewed?	References NIST report?	Relevancy Score
1	Original Data	Yes	No	3
2	Original Data	Yes (conference)	No	3
3	Original Data	Yes (conference)	No	3
4	Original Data	Yes	No	3
5	Original Data	Yes	No	3
6	Existing Data (literature review)	No (BRANZ report)	No	3
7	Original Data	Yes (conference)	No	2
8	Existing Data	Yes	No	2
9	Existing Data	Yes	No	2
10	Original Data	Yes (conference)	No	2
11	Existing Data	Yes (conference)	No	2
12	Original Data	Yes (conference)	No	1
13	Original Data	Yes (conference)	Yes	1

Recommendation 10: Computer Aided Decision Tools

Recommendation 10 relates to research on developing and refining computer models and tools to assist in determining the costs and benefits of code changes and fire safety and to aid communities in allocating resources for large emergencies:

Recommendation 10. Research on Computer-aided Decision Tools: *NIST recommends that research be conducted to:*

> *a) refine computer-aided decision tools for determining the costs and benefits of alternative code changes and fire safety technologies; and*
>
> *b) develop computer models to assist communities in allocating resources (money and staff) to ensure that their response to an emergency with a large number of casualties is effective.*

Literature was reviewed for each of the above sub-categories for this recommendation. There have been some significant developments in these research areas, but none that can be directly attributed to the NIST recommendations.

For recommendation 10a related to computer tools for determining the costs and benefits of alternative code changes and fire safety technologies, limited information was found, but there have been some developments. For example, the National Association of State Fire Marshals (NASFM) are nearing the completion of a one-year project with the purpose of developing a tool for inspectors in the field that evaluates the impact of alternative solutions and fire safety technologies. This project is focused on business occupancies, but if they receive funding, NASFM hopes to continue the project for other occupancies.

For recommendation 10b related to computer models to assist communities in allocating resources for a disaster, there are computer tools available that can aid with these decisions including Geographic Information Systems (GIS). Extensive work on improving GIS has occurred since the NIST NCST investigation report was issued. GIS is a system designed to capture, analyze, manage, and display geographic information to inform decision making. Two new proposed related standards are currently under development at NFPA: NFPA 950, *Standard for Data Development and Exchange for the Fire Service*, and NFPA 951, *Guide to Building and Utilizing Digital Information*. While developments of GIS will certainly assist communities in allocating resources for emergencies, they are not directly related to the NIST recommendation.

Other work on computer models to assist with allocating resources for disaster planning includes:

1. Blankinship, David, Grise, Steve, and Schottke, Jennifer. "Fire Service/HazMat GIS Data Model Implementation Guide". National Association of State Fire Marshals. March 2008.

Summary: This document gives information about the Fire Service GIS Data Model. The Fire Service GIS Data Model was developed with collaboration from several national organizations including NASFM, Metro Fire Chiefs Association, and International Association of Fire Chiefs. The purpose of the data model is to give a starting point for fire and emergency service organizations just getting started with ArcGIS as well as to address those departments that are further along the implementation timeline.

URL: https://www.firemarshals.org/pdf/FSGDM-Implementation-Guide-final.pdf

2. National Fallen Firefighters Foundation. "Report of the 2nd National Fire Service Research Agenda Symposium". National Fire Academy. May 2011.

Summary: The research agenda highlights the need for research to support community risk reduction. The specific research recommendations include the development of tools to quantify the impact of building and fire code adoption in the community, developing a scientifically-based tool for evaluating the effectiveness of fire prevention and risk reduction programs, and a need for tools to assist company officers and incident commanders with risk assessments.

URL: http://www.everyonegoeshome.com/symposium/report2.pdf

3. NASFM. "National Association of State Fire Marshals Newsletter". May 2014.

Summary: Insurance Services Office (ISO) formed ISO Community Analytic Services to meet the needs of the fire service. The evaluation includes an algorithm and a set of community-defining criteria so that the community being analyzed can be compared to a peer group of 10 fire departments across the country. The evaluation also includes comparison to jurisdictions across the state and around the nation. Each analysis includes specific recommendations to help fire departments improve.

URL: https://www.firemarshals.org/pdf/NASFM_News_May_2014.pdf

4. Diaz, Rafael, et. al. "Humanitarian/Emergency Logistics Models: A State of the Art Overview". Proceedings of the 2013 Summer Computer Simulation Conference (SCSC '13). Society for Modeling and Simulation International. 2013.

Summary: The paper provides a literature review of the relevant modeling efforts related to emergency management and humanitarian logistics tools. These tools can assist decision makers to plan for catastrophic events.

5. Mielczarek, Bozena. "Using Discrete-Event Simulation to Forecast the Volume of Hospital Emergency Services to be delivered at the Regional Level". Proceedings of the 3rd International Conference on Simulation and Modeling Methodologies, Technologies, and Applications (SIMULTECH). 2013.

Summary: The paper describes a simulation model to estimate the volume of services to be provided by emergency departments in a region of Poland. This analysis provides a forecast of services for the following year based on the simulated demand level.

6. Ghahfarokhi, B. S. “Evolving Fuzzy Neural Network Based Fire Planning in Rescue Firebrigade Agents”. Proceedings of the 2006 Summer Computer Simulation Conference. Society for Modeling and Simulation International. 2006.

Summary: The paper presents a method for choosing design fires based on Evolving Fuzzy Neural Networks (EFNN). This method is intended to be used in the simulation platform RoboCopRescue.

URL: http://www.appliedemotion.com/files/2006SCS02.pdf

Table 11: Literature Summary for Recommendation 10b

Source	**Data Source**	**Peer reviewed?**	**References NIST report?**	**Relevancy Score**
1	Existing Data	No	No	3
2	Existing Data	No (research agenda)	No	3
3	Existing Data	No	No	3
4	Existing Data	Yes (conference)	No	3
5	Existing Data	Yes (conference)	No	1
6	Existing Data	Yes (conference)	No	1

Summary Observations: Literature Review

General Protocol Observations

The best indicator of a link between the relevant literature and the NIST recommendations is a direct citation of the NIST NCST investigation report. However, this was only found in a handful of sources. Therefore, the next best indicator is the relevancy of a particular literature source to the NIST recommendations. Although this approach is subjective, it provides additional context and categorization to the literature around each of the research needs identified by the investigation report.

Observations Related to the Example

The literature review revealed limited impact from the recommendation on research around use of portable fire extinguishers in new and existing nightclubs. The only source found that focused on nightclubs was a workshop summary published by NIST. However, more general research has been done investigating how the general public uses extinguishers, which is helpful for all assembly type occupancies. However, it is difficult to link these studies back to the NIST recommendation.

There was a good amount of literature found related to most of the human behavior research recommendations. In particular, there were many references found related to the theoretical models of group behavior. Overall, there were fewer references found related to crowd crush and crowd managers. One of the reasons for this, noted by the Technical Panel, is that most of the research and practices are coming out of the security world, which is not linked to the NIST recommendations specifically. It was also noted by the Panel that an important issue related to crowd behavior is how messages/announcements are made to the crowd, which was not addressed by the recommendations specifically. For recommendation 8e on the level of safety that model codes provide, the search was broadened a bit to include the effectiveness of building code requirements as well as fire prevention activities in general as they both relate to the overall effectiveness of building codes.

Some literature was found that cited the NIST NCST report, but it was limited. However, there were many that directly relate to one of the sub-topics of recommendation 8 and were given a relevancy score of 3. Although it cannot be said that the most relevant documents definitely relate back to the NIST recommendations, there is a chance that the recommendations had an impact on at least some of this research being done. For recommendation 8a related to the impact of fire products on egress, there were seven with a relevancy level of 3. For recommendation 8b related to number and placement of exits and recommendation 8c on crowd crush, there were also seven most relevant documents. There were only two very relevant sources related to the impact of crowd mangers (recommendation 8d), but there were many relevant documents related to recommendation 8e on models of group behavior with twelve. For recommendation 8f related to the level of safety of codes and fire prevention, there were eight very relevant documents.

A significant amount of literature was found related to the research recommendations on fire spread and suppression (recommendation 9). Although not many cite the NIST NCST report, there are several that are given a relevancy score of 3, which means that they directly relate to one of the specific sub-bullets for recommendation 9. It could be postulated that the NIST recommendations may have had some impact on this research being completed. For the literature with the highest relevance to the recommendations, the project team followed up with the authors to inquire if the NIST investigation report had any impact on them performing the research, but it was largely unsuccessful. Another way to measure the level of impact of the research recommendations may be to complete a literature review of the literature published before the report was issued and compare the research level of interest in the topics both before and after the recommendations were issued.

For recommendation 9a, research on prediction of flame spread over actual wall, ceiling, and floor lining materials, and room furnishings, ten references were given the highest relevancy score. Seven sources were rated a 3 related to relevancy to recommendation 9b, research on the quantification of smoke and toxic gas production in realistic room fires. There were six references found that directly address recommendation 9c, research on the development of generalized models for fire suppression with fixed sprinklers and for firefighter hose streams.

There was significantly less literature related to recommendation 10, which states that research should be conducted to develop tools to compare code changes and alternative fire protection measures (10a) and tools to plan for large emergency situations (10b). There was not any specific literature found relating back to recommendation 10a, but there are now more sophisticated tools to aid in planning for large emergencies. However, it cannot be said that these developments relate in any way to the NIST recommendation.

Section 4: Synergistic Review of Primary Evaluations

Comparison of Model Code Changes and Local Practice

General Protocol

As part of the review of the outcomes from each of the tasks, a comparison should be made between the changes in model codes and standards and the local analysis. Changes to the model codes typically need to take place before changes are made on the local level due to the model code adoption process used by most jurisdictions. If there are no changes in the model code, there is no expected change on the local level. This is why it is recommended that for future evaluations, the model codes are analyzed ahead of the local study.

Applying to the Example

The following discussion is a comparison of the results from the analysis of changes to model codes and standards (in Section 2) and the analysis of local practices (in Section 1) related to recommendations 2, 3, 4, and 5 of the NIST NCST investigation report.

Recommendation 2: Sprinklers

One of the major changes that were made in the model codes were related to the sprinkler protection of nightclubs. The 2006 editions of the IBC and IFC require sprinklers in all new nightclubs with an occupant load of 100 or more (previous edition was 300 or more). However, the requirement is not extended to existing nightclubs. The 2006 editions of the NFPA model codes require sprinklers for all new nightclub occupancies and for existing nightclubs where the occupant load is more than 100.

For the first recommendation, which relates generally to adopting updated national model codes and enforcing them regularly, it was found that up to 12% of departments in communities over 50,000 fall short of this recommendation for new construction as they are using an older version of the code. More notably, a large share of departments fall short for existing nightclubs because they have adopted the IFC, which has not incorporated changes for sprinkler protection of existing nightclubs. For this reason, one of the recommendations that may improve the adoption of NIST recommendations into model codes and other standards would be the direct involvement of NIST in the codes and standards processes.

For the second recommendation, which relates to sprinkler requirements in new and existing nightclubs, it was found that 80% of the communities surveyed have sprinkler requirements in place consistent with the NIST recommendations for existing nightclubs and 90% have requirements in place consistent with the NIST recommendations for new nightclubs. Notably, half of the communities with a population of at least 50,000 changed their sprinkler requirements after 2003. This appears to be a direct link to changes made in the model codes related to the NIST recommendations.

Recommendation 3: Interior Finish Materials

There were no specific changes in the model codes and standards related to the recommendations on interior finishes. The survey found that all communities over 50,000 have interior finish requirements in place, but more than half appear to have no requirements for existing buildings. Nearly all (93%) reference a standard test. It was reported that 29% of these communities made changes to interior finish requirements after The Station nightclub fire in 2003. Since there were no changes to interior finish requirements at the model code level, it is more difficult to say if the NIST recommendations played a role in the 29% of communities that made changes.

Recommendation 4: Indoor Use of Pyrotechnics

There were no specific changes in the model codes and standards related to the recommendations on the use of indoor pyrotechnics. From the survey, it was found that 98% of communities with a population over 50,000 have requirements related to indoor pyrotechnics with 66% of those communities referencing NFPA 1126. It was also found that 18% of communities changed their indoor pyrotechnics requirements after 2003. Again, since there were no changes to indoor pyrotechnic requirements at the model code level, it is more difficult to say if the NIST recommendations played a role in the 19% of communities that made changes.

Recommendation 5: Occupant Limits and Egress Requirements

Related to emergency egress, two changes were made to the 2006 and later editions of the NFPA model codes related to the occupancy limit and emergency egress recommendations made by NIST. Specifically, the capacity of the main exit/entrance was increased to accommodate two-thirds of the total occupant load. The second change was a requirement for crowd managers for all gatherings over 250, except religious services, at a ratio of 1:250 occupants. The 2009 and later editions of the IFC also require a crowd manager for all gatherings over 1000 at a ratio of 1:250 occupants.

Based on the survey, it was found that 100% of the communities of 50,000 or more have occupancy limits in place, with 95% citing a model code. However, it was assumed during the implementation of the survey that there had been more extensive changes to egress requirements in the current model codes related to The Station. It was also found that occupancy limits changed in 12% of the communities after 2003, but a direct link to NIST recommendations cannot be drawn.

In addition, a requirement for a crowd manager was not a specific recommendation from NIST, but it was something that all the model codes did implement based on the findings from The Station. However, a question related to the requirement of a crowd manager was not included specifically in the survey.

Further, it was noted by the Technical Panel that the 2015 editions of NFPA 101 and the IFC are both incorporating changes related to the training of crowd managers, which is a result of The Station nightclub fire. Because the code change process can sometimes take several cycles to incorporate major changes, it is generally recommended that this type of evaluation process may need to be completed more than once to capture the full impact of the recommendations.

Comparison of Research to Changes in Model Codes and Local Practices

General Protocol

Research on a topic can inform changes to model codes and standards as well as local practices. Therefore, the results from the literature review related to the research recommendations should be compared to the results of the analysis of changes to the codes and standards to gain an overall understanding of the impact of the recommendations. This type of comparison can also give an idea of what changes may be on the horizon associated with more recent completed research.

Applying to the Example

The deliverables from the literature review (Section 3) and the analysis of changes to model codes and local practices (Sections 2 and 3) were reviewed and analyzed for any links. At the start of the project, links between Group B recommendations and Group A recommendations were anticipated in these areas:

- Portable fire extinguisher (6) research because of its potential impact on recommendations for rules related to indoor pyrotechnic displays (4);
- Human egress behavior (8) research because of its potential impact on recommendations for rules on occupancy limits and emergency egress (5);
- Fire spread and suppression (9) research because of its potential impact on recommendations for rules on finish materials and building contents (3); and
- Computer-aided decision tools (10) research because of its potential application to decisions on the ability of all relevant rules (1-5 and 7), in combination, to efficiently and effectively deliver the level of risk that society, acting through the technical committees who write the model codes and standards, deems appropriate.

During the literature review, only limited literature was found on the use of portable fire extinguishers in public buildings; therefore, the research has not had an impact on rules for indoor pyrotechnic displays.

There was a good amount of literature found on the human behavior topics covered in the NIST recommendations. While there have not been many changes to rules related to occupancy limits and emergency egress, there have been some changes to crowd manager requirements. Specifically, the upcoming changes in the 2015 editions of the model codes related to training requirements of crowd managers is likely based on the research completed after The Station on this issue.

There was an array of research related to the fire spread and suppression topics covered by the NIST recommendations. However, there have not been any rule changes for the use of interior finishes and building contents at this point, as a result of this research. This is a topic that should be explored further in any future evaluations of The Station recommendations as the research on this topic is on-going and could result in rule changes in the future.

There was little specific research found on the computer tools noted in the NIST recommendations, but due to many advancements in technology generally, there are related tools to aid in planning for major emergencies. This is another topic that would benefit from further exploration in future evaluations. Technology is constantly evolving and the tools that are available now may pale in comparison to tools that may be available even five years from now.

Summary Observations

General Protocol

This pilot study was undertaken to develop a general model impact evaluation protocol to be adapted to the recommendations from the other NIST NCST report and similar report. As with any pilot study, lessons were learned along the way that should apply to the model for these types of evaluations going forward. This section contains the recommended protocol for an impact evaluation that can be applied to other sets of NIST recommendations.

A general recommendation for this type of evaluation is that this analysis should be completed more than once. The reason for this is two-fold. First, it takes time for major changes to be implemented in the model codes and standards. This can sometimes take several cycles. Secondly, research takes time to conduct and consequently it takes even more time for that research to have an impact on rules in the model documents. Further, sometimes changes made to local rules and practices are rescinded due to local political environments, etc. An example of this is the Chattanooga, Tennessee City Council rescinding a prior ordinance requiring sprinklers at bars and clubs in 2013.

Another general recommendation to NIST is related to wording of the recommendations. In order to evaluate the impact of the recommendation, it is best that the recommendations made are clear and measureable. Specifically, it may be helpful to have separate recommendations relating to education and training as a bump in training may occur after an event.

Step 1: Analysis of Changes to Model Codes

The pilot study documented in this report performed the analysis of changes to model codes and standards as a second task, but ideally, this should be undertaken as a first step in the evaluation. This is because changes are usually made in the model codes as a first step and then the local jurisdictions adopt the model codes.

The general approach of this step is to analyze the requirements related to the NIST recommendations before the recommendations were issued, and compare them to later editions of the codes and standards. This should be done for all editions issued after the event because, as noted above, it sometimes takes several cycles for changes to be implemented.

Step 2: Analysis of Changes to Local Practices

The goal of this type of exercise is to provide an evaluation of the degree of implementation of features and practices that were recommended – usually in the form of a new code or standard or changes to an existing code or standard. What is sought is information on:

- *adoption* of requirements (for those features and practices), which connects the gap between impact of recommendations at the national level (on model codes and standards) and impact at the local level (on local requirements and practices);

- *compliance* with requirements (for features of properties but not for fire department practices; if fire departments report adoption of requirements for fire department practices, then there is no point in asking fire departments about inspection and enforcement activities to check compliance); and
- *timing of changes* in requirements, as this is the most accessible information indicating a role on NIST recommendations and other national changes or guidance following a major incident in changing local practices (e.g., some localities may already have local practices that match the recommendations)

An evaluation exercise can be conducted using a number of different types of information:

- The exercise can be conducted using only local *information that is already routinely collected*, recorded and transmitted to a national body. Such an exercise will be very inexpensive, but it is very unlikely that such existing, nationally compiled data sources will be able to provide enough details for any significant evaluation.
- The exercise can be conducted using *site visits and/or special data collection protocols* that are set up to run for at least a year. Such an exercise will likely require a six-figure budget and still provide data on only a dozen or so communities. The detail obtained will be the most possible and will address the recommendations and their impacts in the greatest detail possible, but the lack of breadth of coverage will severely limit any conclusions that can be reached. Previous such studies have rarely incorporated smaller communities. Including these communities will add to the costs of the study, but not including these communities may limit the generalizability of any conclusions.
- The best balance of affordability and useful detail will likely be achieved through a *survey*. However, it is important to check costs, response rates, design bias, and resulting statistical significance of a particular survey proposal. It is also important to check whether the level and type of detail obtainable from a survey will provide sufficient evaluative depth to be worth the cost. For this prototype application of an evaluation protocol, NFPA was able to use data collected in the earlier, independent NFPA survey as the issues addressed match well with the NIST recommendations on similar topics. In a normal application of the generic protocol, those conducting the evaluation would have to review the considerations listed here for and against a survey as a source of evaluative information. They would also have to design a survey, if they chose to conduct one. Appendix A contains the survey used by NFPA, which is offered here for its illustrative value to anyone seeking to develop a survey with the same structure for evaluation of any set of recommendations arising from investigation of a major incident.

Determining the target. Since a survey provides the best balance of affordability and useful detail, it is recommended that it be used as a tool for further evaluations. The first step in implementing a survey is to determine the target for the survey. For recommendations defined by a class of properties, the first step starts with identifying the number of such establishments in the country, followed by looking for any clustering of establishments that would permit a narrower focus in the evaluation (e.g., most properties located in certain states or in communities of a certain size).

For this pilot study, this involved estimating the number of nightclubs. The NFPA survey asked about the number of nightclubs in the community but only surveyed fire departments protecting communities with at least 50,000 population. This provided a manageable test of the survey protocols, while also offering the possibility of capturing a large share of the nightclubs or drinking establishments in the country. Success in implementation of recommendations will often be dependent on success in smaller communities. **Ideally, an evaluative survey should cover all sizes of communities.**

The fact that an all-community survey would be best for evaluation and may even be necessary for evaluation does not mean that such a survey will be practical or affordable. The first concern is that response rates will drop with smaller communities. Analysis on the expected response rates would need to be made in order to determine the cost of a survey with sufficient statistical power to provide credible results for all sizes of communities.

General protocol to evaluate targeted conditions. An evaluation is built around best estimates of answers to three questions, for a particular recommended feature or practice that was called for in a recommendation.

Question 1. To what extent do communities have *requirements* related to the feature or practice?

Typically, a requirement will be set forth in an adopted code provision, standard, or other legislative authorization. The "condition" could be a characteristic (e.g., system, feature) of the property that enhances safety, a practice of the fire department that reinforces the property characteristics (e.g., enforcement), or one that improves the ability to mitigate incidents when they occur. This question should also include any specific local law that may not be based on a model code or, alternatively, if the changes are being removed at the local level due to the level of resources available.

Question 2. What is the degree of *compliance* with those requirements in the communities?

For property characteristics, there may be no existing basis for direct measurement of compliance because many, possibly most, communities do not have annual fire code inspections of all properties or of a representative sample of properties. A special survey of properties could be used, but in most cases, the only practical measurement will be best estimates by community authorities.

For fire department practices to improve mitigation ability (such as communications at the fire scene, deployment and staffing, incident management), the fire department is involved directly in adoption, which means the entity that needs to implement the requirements and assure compliance is not a separate entity. As a result, they may require more persuasion or motivation to comply with a requirement in which they had nothing to do with creating.

In both cases, an audit involving direct observation of practices and conditions by an independent third party would provide more evidence of compliance, but at a considerably greater cost per community.

Question 3. Did the requirements *change after the major event* that led to the recommendations?

This is the best high-level indicator of the impact of the recommendations. It is not necessarily the case that improvements in safety introduced after a major event were made in response to that event, let alone that they were made in accordance with specific recommendations emerging from that event, but it is a reasonable premise for a first-order evaluation of the impact of recommendations. Additionally, a more detailed evaluation would be much more expensive.

These three questions are associated with more detailed follow-up questions:

a) For question 1, *are the requirements in place well-aligned with the requirements that were recommended*? Data on this point will allow the evaluation to estimate relative success in implementation instead of a more rigid and inflexible either/or assessment.
b) For question 2, *are communities using inspections, tests and other means to achieve and assure compliance*? If no, then the best estimates by community authorities may not be accurate. Also if no, this points to programs where more active enforcement programs would be an obvious path to higher levels of compliance.

   Going to a deeper level of detail, are community estimates of compliance higher in places that are using particular means to achieve and assure compliance?

   If estimates are higher in places that are using more effective means, like inspections and tests, then that is evidence of the potential value of such means in improving compliance and can be used in designing follow-up programs and related advocacy arguments.
c) If estimates are actually lower in places that are using more effective means, then that is evidence that community authorities may be overly optimistic about their levels of compliance, in the absence of any real data. That supports a different kind of follow-up and different kinds of related arguments.

For questions 1 and 3, *is adoption of requirements or full adoption of recommended requirements and practices associated more with one or another source of model codes and standards*? This can be useful in designing follow-up programs to improve adoption rates.

The description of the protocol is fairly basic and could be refined for increased ease of use. For example, there may be value in converting the evaluation scores to letter grades, which may convey the most important summary information more quickly than the current formats.

Further, if resources and time allow, a literature review could be undertaken to search for any enforcement/fire prevention studies that relate to the target of interest. For example, during the research literature search for the pilot study, a fire safety evaluation study of bars, nightclubs, and dance halls in the state of Texas was found (http://www.tdi.texas.gov/fire/documents/fmclubinspect.pdf). This was published in March 2005 by the State Fire Marshal's Office and directly references the draft NIST report. A focused literature review on the topic of local enforcement and fire prevention related to the target properties could be beneficial for a full evaluation.

Step 3: Literature Review Related to Research Recommendations

To evaluate the impact of recommendations relating to research, the recommended approach is to conduct a literature review, which should include the following types of materials:

- Published research (e.g., academia, government laboratories, private industry)
- Programs, plans, and agendas for research not yet completed;
- Research assembled or conducted as input to revisions of model codes, standards, and similar documents (e.g., ASTM, ICC, ISO, NFPA, SFPE)
- Research on the effectiveness of model codes, standards, and similar documents

The research recommendations are intended to lead to research that will in turn result in new rules and practices. To provide some assessment of the degree of progress toward this goal, the literature sources should be evaluated on the following:

- Quality (e.g., originality, peer-reviewed), including notes on availability as applicable (e.g., proprietary vs. non-proprietary)
- Relevance (e.g., relevance to topic, degree of progress toward eventual goal of recommendations on rules and practices) using a rating system

Step 4: Synergistic Review and Analysis

For the pilot study, a comparison was made between the changes in model codes and standards and the local analysis. However, as suggested above, the analysis of changes to model documents should be completed ahead of the survey used to evaluate the changes in local practice. Then, this analysis will feed into how the survey questions are formed.

Research on a topic can inform changes to model codes and standards as well as local practices. The deliverables from the literature review on any research related recommendations and the findings from the analysis of changes to model codes and local practices (Step 1 and Step 2 should be reviewed and analyzed for any links. However, this is often a long process, thus it is recommended above that this type of evaluation be completed more than once. This type of comparison can also give an idea of what changes may be on the horizon associated with more recent completed research.

The Station Nightclub Fire Example

Changes to Model Codes and Standards

The NIST recommendations had some impact on changes in the model codes and standards. This was especially true of automatic sprinkler requirements for assembly occupancies. The 2006 editions of the IBC and IFC require sprinklers in all new nightclubs with an occupant load of 100 or more (previous editions were 300 or more). The 2006 editions of the NFPA model codes require sprinklers for all new nightclub occupancies and for existing nightclubs where the occupant load is more than 100.

Specific changes related to interior finish requirements and indoor use of pyrotechnics related to the NIST recommendations were not found.

Two changes were made to the 2006 and later editions of the NFPA model codes related to the occupancy limit and emergency egress recommendations made by NIST. Specifically, the capacity of the main exit/entrance was increased to accommodate two-thirds of the total occupant load. The second change was a requirement for crowd managers for all gatherings over 250, except religious services, at a ratio of 1:250 occupants. The 2009 and later editions of the IFC also require a crowd manager for all gatherings over 1000 at a ratio of 1:250 occupants.

Changes to State and Local Practices

The first recommendation related generally to adopting updated national model codes and regular enforcement activities. At least 90% of departments protecting communities of 50,000 or more have local codes based on national model codes for both newly constructed and existing nightclubs. However, it was found that up to 12% of departments in communities over 50,000 fall short of this recommendation for new construction as they are using an older version of the code. More notably, a large share of departments fall short for existing nightclubs because they have adopted the IFC, which has not incorporated changes for sprinkler protection of existing nightclubs. For this reason, one of the recommendations that may improve the adoption of NIST recommendations into model codes and other standards would be the direct involvement of NIST in the codes and standards processes.

For the second recommendation, which relates to sprinkler requirements in new and existing nightclubs, it was found that 80% of the communities surveyed have sprinkler requirements in place consistent with the NIST recommendations for existing nightclubs and 90% have requirements in place consistent with the NIST recommendations for new nightclubs. Notably, half of the communities with a population of at least 50,000 changed their sprinkler requirements after 2003. This appears to be a direct link to changes made in the model codes related to the NIST recommendations.

The survey found that all communities over 50,000 have interior finish requirements in place, but more than half appear to have no requirements for existing buildings. Nearly all (93%) reference a standard test. It was reported that 29% of these communities made changes to interior finish requirements after The Station nightclub fire in 2003. Since there were no changes to interior finish requirements at the model code level, it is more difficult to say if the NIST recommendations played a role in the 29% of communities that made changes.

From the survey, it was found that 98% of communities with a population over 50,000 have requirements related to indoor pyrotechnics with 66% of those communities referencing NFPA 1126. It was also found that 18% of communities changed their indoor pyrotechnics requirements after 2003. Again, since there were no changes to indoor pyrotechnic requirements at the model code level, it is more difficult to say if the NIST recommendations played a role in the 19% of communities that made changes.

Based on the survey, it was found that 100% of the communities of 50,000 or more have occupancy limits in place, with 95% citing a model code. However, it was assumed during the implementation of the survey that there had been more extensive changes to egress requirements in the current model codes related to The Station. It was also found that occupancy limits changed in 12% of the communities after 2003, but a direct link to NIST recommendations cannot be drawn.

The NCST investigation report recommended state and local jurisdictions to adopt and follow existing model standards on communications, mutual aid, command structure, and staffing. Through the survey, it was found that 55% of communities with at least 50,000 population are using NFPA 1221, 94% of communities with at least 50,000 population are using NFPA 1561 or NIMS, and 80% of communities with at least 50,000 population are using NFPA 1710 or 1720. However, only 12-15% of communities with at least 50,000 population report that their use of these standards changed after 2003, the year of The Station Nightclub fire.

Research Relating to NIST Recommendations

The literature review revealed limited impact from the recommendation on research around use of portable fire extinguishers in new and existing nightclubs. The only source found that focused on nightclubs was a workshop summary published by NIST. However, more general research has been done investigating how the general public uses extinguishers, which is helpful for all assembly type occupancies. However, it is difficult to link these studies back to the NIST recommendation.

There was a good amount of literature found related to most of the human behavior research recommendations. In particular, there were many references found related to the theoretical models of group behavior. Overall, there were fewer references found related to crowd crush and crowd managers. One of the reasons for this, noted by the Technical Panel, is that most of the research and practices are coming out of the security world, which is not linked to the NIST recommendations specifically. It was also noted by the Panel that an important issue related to crowd behavior is how messages/announcements are made to the crowd, which was not addressed by the recommendations specifically. For recommendation 8e on the level of safety that model codes provide, the search was broadened a bit to include the effectiveness of building code requirements as well as fire prevention activities in general as they both relate to the overall effectiveness of building codes.

Some literature was found that cited the NIST NCST report, but it was limited. However, there were many that directly relate to one of the sub-topics of recommendation 8 and were given a relevancy score of 3. Although it cannot be said that the most relevant documents definitely relate back to the NIST recommendations, there is a chance that the recommendations had an impact on at least some of this research being done. For recommendation 8a related to the impact of fire products on egress, there were seven with a relevancy level of 3. For recommendation 8b related to number and placement of exits and recommendation 8c on crowd crush, there were also seven most relevant documents. There were only two very relevant sources related to the impact of crowd mangers (recommendation 8d), but there were many relevant documents related to recommendation 8e on models of group behavior with twelve. For recommendation 8f related to the level of safety of codes and fire prevention, there were eight very relevant documents.

A significant amount of literature was found related to the research recommendations on fire spread and suppression (recommendation 9). Although not many cite the NIST NCST report, there are several that are given a relevancy score of 3, which means that they directly relate to one of the specific sub-bullets for recommendation 9. It could be postulated that the NIST recommendations may have had some impact on this research being completed. For the literature with the highest relevance to the recommendations, the project team followed up with the authors to inquire if the NIST investigation report had any impact on them performing the research, but it was largely unsuccessful. Another way to measure the level of impact of the research recommendations may be to complete a literature review of the literature published before the report was issued and compare the research level of interest in the topics both before and after the recommendations were issued.

For recommendation 9a, research on prediction of flame spread over actual wall, ceiling, and floor lining materials, and room furnishings, ten references were given the highest relevancy score. Seven sources were rated a 3 related to relevancy to recommendation 9b, research on the quantification of smoke and toxic gas production in realistic room fires. There were six references found that directly address recommendation 9c, research on the development of generalized models for fire suppression with fixed sprinklers and for firefighter hose streams.

There was significantly less literature related to recommendation 10, which states that research should be conducted to develop tools to compare code changes and alternative fire protection measures (10a) and tools to plan for large emergency situations (10b). There was not any specific literature found relating back to recommendation 10a, but there are now more sophisticated tools to aid in planning for large emergencies. However, it cannot be said that these developments relate in any way to the NIST recommendation.

Appendix A: Tables of Results from NFPA Survey

Table 1
How many nightclubs are in your community? [Q.1]

	None		1		2 to 5		6 to 10		More than 10		Total	
Size of community	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent
500,000 or more	0	0.0	0	0.0	0	0.0	3	5.5	52	94.5	55	100.0
250,000 to 499,999	2	3.2	3	4.8	5	8.1	4	6.4	48	77.4	62	100.0
100,000 to 249,999	26	10.5	0	0.0	0	0.0	34	13.8	186	75.3	247	100.0
50,000 to 99,999	113	23.9	13	2.7	0	0.0	101	21.4	246	52.0	473	100.0
Total	141	16.8	16	1.9	5	0.6	142	17.0	532	63.6	837	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Note that the departments that reported no nightclubs were excluded from the remainder of the analyses in this report, and the analyses in the remainder of this report are based on an estimated 696 departments that protect 50,000 population or more and have at least one nightclub,

Table 2
What codes apply to newly constructed nightclubs in a community? [Q.2]

	NFPA 101 Life Safety Code		International Building Code		Local code not based on model code		Other model code*		None	
Size of community	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent
500,000 or more	18	32.7	47	85.5	8	14.5	18	32.7	0	0.0
250,000 to 499,999	12	20.0	46	76.7	0	0.0	22	36.7	0	0.0
100,000 to 249,999	74	33.3	176	79.7	16	7.2	80	36.2	0	0.0
50,000 to 99,999	142	39.4	292	81.1	28	7.9	85	23.6	0	0.0
Total	246	35.3	561	80.6	52	7.5	205	29.5	0	0.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Departments were asked to circle all that apply, so departments could select multiple responses, which means it is not appropriate to add percentages for a particular size community.

*This category is comprised almost entirely of state codes that were based on national model codes.

Table 3
What codes apply to existing nightclubs in the community? [Q.3]

	NFPA 1		NFPA 101 not as part of adoption of NFPA 1		International Fire Code		Local code not based on model code		Other model code*		No code	
Size of community	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**
500,000 or more	13	23.6	16	29.1	31	56.3	8	14.5	16	29.0	0	0.0
250,000 to 499,999	7	11.7	12	20.0	38	63.3	5	8.3	16	26.7	0	0.0
100,000 to 249,999	51	23.2	45	20.3	147	66.5	16	7.2	39	17.7	0	0.0
50,000 to 99,999	82	22.8	91	25.3	241	66.9	34	9.4	58	16.1	0	0.0
Total	154	22.1	163	23.4	458	65.8	63	9.1	128	18.4	0	0.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Departments were asked to circle all that apply, so departments could select multiple responses, which means it is not appropriate to add percentages for a particular size community.

*This category is comprised almost entirely of state codes that were based on national model codes.

Table 4
(For departments that use the International Building Code, for newly constructed nightclubs in their community)
What edition of the code is used? [Q.2b]

	Prior to 2003		2003		2006		2009		2012		Total	
Size of community	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**
500,000 or more	0	0.0	3	6.4	16	34.0	19	40.4	9	19.1	47	100.0
250,000 to 499,999	0	0.0	0	0.0	10	21.7	29	63.0	7	15.2	46	100.0
100,000 to 249,999	4	2.3	0	0.0	35	19.9	74	42.0	63	35.8	176	100.0
50,000 to 99,999	3	0.9	6	2.1	68	23.2	158	54.1	56	19.2	292	100.0
Total	7	1.2	9	1.6	129	23.0	280	50.0	136	24.2	561	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 5
(For departments that use the NFPA 101, Life Safety Code for newly constructed nightclubs in their community) What edition of the code is used? [Q.2a]

	Prior to 2003		2003		2006		2009		2012		Total	
Size of community	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent
500,000 or more	7	38.9	0	0.0	0	0.0	7	38.9	4	22.2	18	100.0
250,000 to 499,999	12	100.0	0	0.0	0	0.0	0	0.0	0	0.0	12	100.0
100,000 to 249,999	7	9.5	0	0.0	7	9.5	45	60.8	15	20.3	74	100.0
50,000 to 99,999	36	25.3	7	4.9	0	0.0	74	52.1	26	18.3	142	100.0
Total	62	25.2	7	2.8	7	2.8	126	51.2	44	17.9	246	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 6
(For departments that use the International Fire Code for existing nightclubs in their community)
What edition of the code is used? [Q.3c]

	Prior to 2003		2003		2006		2009		2012		Total	
Size of community	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**
500,000 or more	0	0.0	3	9.7	8	25.8	18	58.1	2	6.5	31	100.0
250,000 to 499,999	2	5.3	0	0.0	8	21.1	23	60.5	5	13.2	38	100.0
100,000 to 249,999	0	0.0	0	0.0	22	15.0	70	47.6	55	37.4	147	100.0
50,000 to 99,999	6	2.5	0	0.0	63	26.1	125	51.9	47	19.5	241	100.0
Total	8	1.8	3	0.6	100	21.9	236	51.6	110	24.1	458	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 7
(For departments that use NFPA 1 for existing nightclubs in their community)
What edition of the code is used? [Q.3a]

	Prior to 2003		2003		2006		2009		2012		Total	
Size of community	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**
500,000 or more	0	0.0	0	0.0	3	23.1	6	53.8	4	23.1	13	100.0
250,000 to 499,999	3	42.9	0	0.0	0	0.0	4	57.1	0	0.0	7	100.0
100,000 to 249,999	0	0.0	0	0.0	5	9.8	31	60.8	15	29.4	51	100.0
50,000 to 99,999	8	9.8	4	4.8	4	4.8	55	67.1	12	13.4	82	100.0
Total	11	7.2	4	2.6	12	7.9	96	62.5	31	19.7	154	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 8
Are there any local amendments or other requirements applicable to nightclubs? [Q.4]

	Yes, changed after 2003		Yes, not changed after 2003		No		Total	
Size of community	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent
500,000 or more	19	34.5	8	14.5	28	50.9	55	100.0
250,000 to 499,999	14	23.3	5	8.3	41	68.3	60	100.0
100,000 to 249,999	46	20.8	11	5.0	164	74.2	221	100.0
50,000 to 99,999	80	22.2	42	11.7	238	66.1	360	100.0
Total	160	23.0	65	9.3	471	67.7	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 9
How are inspections used for enforcement? [Q5]

Size of community	No inspections conducted Number Depts	Percent	Building code inspections for new buildings Number Depts	Percent	Fire code inspections at least annually Number Depts	Percent	Fire code inspections less often than annually Number Depts	Percent	Inspections in response to complaints Number Depts	Percent
500,000 or more	0	0.0	50	90.9	52	94.5	13	23.6	3	6.0
250,000 to 499,999	0	0.0	36	60.0	41	68.3	22	36.7	38	63.3
100,000 to 249,999	0	0.0	128	57.9	170	76.9	64	29.0	157	76.0
50,000 to 99,999	0	0.0	230	63.9	275	76.4	62	17.2	258	71.7
Total	0	0.0	443	63.6	538	77.3	161	23.1	456	65.5

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Departments were asked to circle all that apply, so departments could select multiple responses, which means it is not appropriate to add percentages for a particular size community.

Table 10
Are sprinklers required in nightclubs in the community? [Q.6]

	Yes, Regardless Of Occupancy		Yes, Occupancy of 50 or More		Yes, Occupancy of 100 or More		Yes, Occupancy of 200 or More		No		Total	
Size of community	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent
500,000 or more	3	5.5	5	9.1	26	47.3	16	29.1	5	9.1	55	100.0
250,000 to 499,999	10	16.7	2	3.3	41	68.3	5	8.3	2	3.3	60	100.0
100,000 to 249,999	17	7.7	7	3.2	160	72.4	17	7.7	20	9.0	221	100.0
50,000 to 99,999	46	12.7	31	8.6	209	58.0	40	11.1	34	9.4	360	100.0
Total	76	10.9	45	6.5	437	62.8	77	11.1	61	8.9	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 11
How many nightclubs are in compliance with sprinkler requirements in the community? [Q.8]

	All		Most		Half		Some		None		Don't Know		Total	
Size of community	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent
500,000 or more	18	32.7	25	45.5	0	0.0	12	21.8	0	0.0	0	0.0	55	100.0
250,000 to 499,999	19	31.7	17	28.3	10	16.7	9	15.0	0	0.0	5	8.3	60	100.0
100,000 to 249,999	88	39.8	66	29.9	15	6.8	30	13.6	0	0.0	22	10.0	221	100.0
50,000 to 99,999	208	57.8	88	24.4	16	4.4	36	10.0	0	0.0	13	3.6	360	100.0
Total	334	48.0	195	28.0	40	5.7	87	12.5	0	0.0	40	5.7	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 12

(For communities with sprinkler requirements)
Are inspections conducted just to check compliance with these requirements? [Q.7]

	Yes		No		Total	
Size of community	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent
500,000 or more	17	30.9	38	69.1	55	100.0
250,000 to 499,999	24	40.0	36	60.0	60	100.0
100,000 to 249,999	101	45.7	120	54.3	221	100.0
50,000 to 99,999	104	28.9	256	71.1	360	100.0
Total	246	35.3	450	64.7	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 13
(For communities with sprinkler requirements)
Did requirements change after 2003 (year of The Station nightclub fire)? [Q.6a]

	Yes Requirements Changed		No Requirements Did Not Change		Total	
Size of community	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**
500,000 or more	26	47.3	29	52.7	55	100.0
250,000 to 499,999	32	55.2	26	44.8	58	100.0
100,000 to 249,999	125	62.2	76	37.8	201	100.0
50,000 to 99,999	135	41.4	191	58.6	326	100.0
Total	317	49.5	323	50.5	640	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 14

Are there interior finish requirements for nightclubs in the community? [Q.9]

	Yes, from International Building Code		Yes, from NFPA 101, Life Safety Code		Yes, from NFPA 1		Yes, from International Fire Code		Yes, from other model code		Yes, local requirements not based on model code		No requirements	
Size of community	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**
500,000 or more	39	70.9	21	38.2	8	14.5	26	47.3	8	14.5	8	14.5	0	0.0
250,000 to 499,999	36	60.0	14	23.3	5	8.3	38	63.3	10	16.7	0	0.0	0	0.0
100,000 to 249,999	119	53.8	64	29.0	35	15.8	128	58.0	29	13.1	3	1.4	0	0.0
50,000 to 99,999	235	65.3	122	33.9	71	19.7	218	60.6	26	6.9	10	2.8	0	0.0
Total	429	61.6	221	31.8	119	17.1	411	59.1	72	10.3	21	3.0	0	0.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Departments were asked to circle all that apply, so departments could select multiple responses, which means it is not appropriate to add percentages for a particular size community.

Table 15
(For communities with interior finish requirements for nightclubs)
Do the requirements reference a standard test for product and material performance?
[Q.10]

	Yes		No		Total	
Size of community	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent
500,000 or more	49	89.1	6	10.9	50	100.0
250,000 to 499,999	60	100.0	0	0.0	60	100.0
100,000 to 249,999	207	93.7	14	6.3	221	100.0
50,000 to 99,999	333	92.5	27	7.5	360	100.0
Total	648	93.1	48	6.9	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 16
How many nightclubs (do you think) are in compliance with interior finish requirements? [Q.13]

	All		Most		Half		Some		None		Don't Know		Total	
Size of community	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**
500,000 or more	8	14.5	39	70.9	0	0.0	5	9.0	0	0.0	3	5.5	55	100.0
250,000 to 499,999	14	23.3	36	60.0	2	3.3	3	5.0	0	0.0	5	8.3	60	100.0
100,000 to 249,999	52	23.5	107	48.4	7	3.2	17	7.7	0	0.0	38	17.2	221	100.0
50,000 to 99,999	138	38.3	146	40.6	20	5.5	18	5.0	3	0.8	35	9.7	360	100.0
Total	212	30.4	329	47.3	29	4.2	43	6.2	3	0.4	81	11.6	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 17
(For communities with interior finish requirements)
Are some inspections conducted where the sole purpose is to check compliance with these requirements? [Q.12]

	Yes		No		Total	
Size of community	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent
500,000 or more	5	9.1	50	90.9	55	100.0
250,000 to 499,999	5	8.3	55	91.7	60	100.0
100,000 to 249,999	33	14.9	188	85.1	221	100.0
50,000 to 99,999	86	23.9	274	76.1	360	100.0
Total	129	18.5	567	81.5	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 18
How do inspectors check for nightclub compliance with interior finish requirements? [Q.11]

Size of community	Visual Inspection Only Number Depts	 Percent	Routine Testing of Materials Number Depts	 Percent	Testing Based on Visual Screening Number Depts	 Percent	Review of Specification Sheets and Technical Data for Materials Number Depts	 Percent
500,000 or more	32	58.2	16	29.1	16	29.1	47	85.5
250,000 to 499,999	38	63.3	14	23.3	5	8.3	55	91.7
100,000 to 249,999	87	39.4	35	15.8	19	8.6	176	79.6
50,000 to 99,999	201	55.8	37	10.3	45	12.5	269	74.7
Total	358	51.4	102	14.7	85	12.2	548	78.7

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Departments were asked to circle all that apply, so departments could select multiple responses, which means it is not appropriate to add percentages for a particular size community.

Table 19
(For communities with interior finish requirements)
Did requirements change after 2003 (year of The Station nightclub fire)? [Q.9h]

Size of community	Yes Requirements Changed Number Depts	Percent	No Requirements Did Not Change Number Depts	Percent	Total Number Depts	Percent
500,000 or more	11	20.0	44	80.0	55	100.0
250,000 to 499,999	32	53.3	28	46.7	60	100.0
100,000 to 249,999	60	27.1	161	72.9	221	100.0
50,000 to 99,999	98	27.2	262	72.8	360	100.0
Total	201	28.9	495	71.1	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 20
Does the community have restrictions on indoor use of pyrotechnics by nightclubs? [Q.14]

Size of community	Yes, from NFPA 1126 Number Depts	Yes, from NFPA 1126 Percent	Yes, from other model code Number Depts	Yes, from other model code Percent	Yes, local restrictions not based on model code Number Depts	Yes, local restrictions not based on model code Percent	No restrictions Number Depts	No restrictions Percent
500,000 or more	39	70.9	18	32.7	21	38.2	0	0.0
250,000 to 499,999	46	76.7	17	28.3	14	23.3	0	0.0
100,000 to 249,999	151	68.3	80	36.2	58	26.2	3	1.4
50,000 to 99,999	221	61.4	74	20.6	139	38.6	9	2.5
Total	457	65.7	189	27.2	232	33.3	12	1.7

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Departments were asked to circle all that apply, so departments could select multiple responses, which means it is not appropriate to add percentages for a particular size community.

Table 21
How many nightclubs are in compliance with restrictions on indoor use of pyrotechnics at nightclubs? [Q.16]

	All		Most		Half		Some		None		Don't Know		Total	
Size of community	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent
500,000 or more	30	54.5	25	45.4	0	0.0	0	0.0	0	0.0	0	0.0	55	100.0
250,000 to 499,999	36	60.0	19	31.7	5	8.3	0	0.0	0	0.0	0	0.0	60	100.0
100,000 to 249,999	162	73.3	31	14.0	0	0.0	4	1.8	4	1.8	21	9.5	221	100.0
50,000 to 99,999	283	78.6	45	12.5	0	0.0	0	0.0	6	1.7	27	7.5	360	100.0
Total	511	73.4	120	17.2	5	0.7	4	0.6	10	1.4	48	6.9	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 22
Does the community conduct inspections that just check compliance with the restrictions on indoor use of pyrotechnics by nightclubs? [Q.15]

	Yes, at events		Yes, with managers in advance of event		Yes, based on complaints, concerns or requests received before or during event		No	
Size of community	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent
500,000 or more	45	81.8	37	67.3	34	61.8	3	5.4
250,000 to 499,999	50	83.3	29	48.3	31	51.6	5	8.3
100,000 to 249,999	138	62.4	106	48.0	112	50.6	32	14.5
50,000 to 99,999	210	58.3	176	48.9	176	48.9	62	17.2
Total	443	63.6	348	50.0	353	50.7	102	14.7

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Departments were asked to circle all that apply, so departments could select multiple responses, which means it is not appropriate to add percentages for a particular size community.

Table 23
(For communities with restrictions on indoor use of pyrotechnics in nightclubs) Did requirements change after 2003 (year of The Station nightclub fire)? [Q.14e]

	Yes Requirements Changed		No Requirements Did Not Change		Total	
Size of community	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent
500,000 or more	5	9.1	50	90.9	55	100.0
250,000 to 499,999	27	45.0	33	55.0	60	100.0
100,000 to 249,999	23	10.4	198	89.6	221	100.0
50,000 to 99,999	69	19.2	291	80.8	360	100.0
Total	122	17.5	574	82.5	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 24
Does the community have egress requirements and/or occupancy limits for nightclubs? [Q.17]

Size of community	Yes, from International Building Code		Yes, from NFPA 101, Life Safety Code		Yes, from other model code		Yes, local requirements not based on model code		No requirements	
	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent	Number Depts	Percent
500,000 or more	37	67.3	21	38.2	24	43.6	8	14.5	0	0.0
250,000 to 499,999	43	71.7	12	20.0	19	31.7	0	0.0	0	0.0
100,000 to 249,999	163	73.8	61	27.6	67	30.0	10	4.5	0	0.0
50,000 to 99,999	283	78.7	142	39.4	96	26.7	20	5.5	0	0.0
Total	527	75.7	236	33.9	206	29.5	37	5.3	0	0.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Departments were asked to circle all that apply, so departments could select multiple responses, which means it is not appropriate to add percentages for a particular size community.

Table 25
How many nightclubs are in compliance with occupancy and egress requirements? [Q.19]

	All		Most		Half		Some		None		Don't Know		Total	
Size of community	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**
500,000 or more	8	14.5	45	81.8	0	0.0	0	0.0	0	0.0	2	3.6	55	100.0
250,000 to 499,999	20	33.3	40	66.7	0	0.0	0	0.0	0	0.0	0	0.0	60	100.0
100,000 to 249,999	75	33.9	116	52.5	3	1.4	13	5.9	0	0.0	14	6.3	221	100.0
50,000 to 99,999	171	47.5	156	43.3	3	0.8	6	1.6	0	0.0	24	6.7	360	100.0
Total	274	39.4	357	51.2	6	0.9	19	2.7	0	0.0	40	5.7	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013

Numbers may not add to totals due to rounding.

Table 26
Does a department conduct special inspections more frequent than fire code inspections just to check compliance with egress requirements and/or occupancy limits? [Q.18]

	Yes, Roughly Every Evening Nightclubs Are Open		Yes, At Least Weekly		Yes, But Not Weekly		No		Total	
Size of community	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**
500,000 or more	0	0.0	5	9.1	33	60.0	17	30.9	55	100.0
250,000 to 499,999	2	3.3	5	8.3	34	56.7	19	31.7	60	100.0
100,000 to 249,999	3	1.4	21	9.5	107	48.4	90	40.7	221	100.0
50,000 to 99,999	3	0.8	9	2.5	170	47.2	179	49.7	360	100.0
Total	8	1.1	40	5.5	206	49.1	306	44.0	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 27
(For communities with egress requirements and/or occupancy limits for nightclubs)
Did requirements change after 2003 (year of The Station nightclub fire)? [Q.17f]

Size of community	Yes Requirements Changed Number Depts	Yes Requirements Changed Percent	No Requirements Did Not Change Number Depts	No Requirements Did Not Change Percent	Total Number Depts	Total Percent
500,000 or more	0	0.0	55	100.0	55	100.0
250,000 to 499,999	25	41.7	35	58.3	60	100.0
100,000 to 249,999	27	12.2	194	87.8	221	100.0
50,000 to 99,999	35	9.7	325	90.3	360	100.0
Total	86	12.3	610	87.7	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 28
Does the community use NFPA 1221 in the operation, installation, and maintenance of public emergency services communication systems? [Q.20]

	Yes		No		Total	
Size of community	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**
500,000 or more	39	70.9	16	29.1	55	100.0
250,000 to 499,999	31	51.7	29	48.3	60	100.0
100,000 to 249,999	114	51.6	107	48.4	221	100.0
50,000 to 99,999	199	55.3	161	44.7	360	100.0
Total	383	55.0	313	45.0	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 29
Did the department's use of NFPA 1221 change after 2003 (the year of The Station nightclub fire)? [Q.20a]

	Yes Requirements Changed		No Requirements Did Not Change		Total	
Size of community	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**
500,000 or more	8	14.5	47	85.5	55	100.0
250,000 to 499,999	19	34.5	41	74.5	60	100.0
100,000 to 249,999	30	13.6	191	86.4	221	100.0
50,000 to 99,999	42	11.7	318	88.3	360	100.0
Total	99	14.2	597	85.8	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 30
Does the community use an emergency services incident system that complies with the National Incident Emergency System (NIMS) or NFPA 1561? [Q.21]

	Yes		No		Total	
Size of community	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**
500,000 or more	50	90.9	5	9.1	55	100.0
250,000 to 499,999	57	95.0	3	5.0	60	100.0
100,000 to 249,999	201	90.9	20	9.1	221	100.0
50,000 to 99,999	345	95.8	15	4.2	360	100.0
Total	653	93.8	43	6.2	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013

Numbers may not add to totals due to rounding.

Table 31
Did the department's use of an emergency services incident system change after 2003 (the year of The Station nightclub fire)? [Q.21a]

	Yes Requirements Changed		No Requirements Did Not Change		Total	
Size of community	**Number Depts**	**Percent**	**Number Depts**	**Percent**	**Number Depts**	**Percent**
500,000 or more	12	21.8	43	78.2	55	100.0
250,000 to 499,999	12	20.0	48	80.0	60	100.0
100,000 to 249,999	40	18.1	181	81.9	221	100.0
50,000 to 99,999	42	11.7	318	88.3	360	100.0
Total	106	15.2	590	84.8	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 32
Does the community use NFPA 1710 (for career departments) or 1720 (for volunteer departments) in establishing organizational and deployment procedures? [Q.22]

Size of community	Yes Number Depts	Yes Percent	No Number Depts	No Percent	Total Number Depts	Total Percent
500,000 or more	43	78.2	12	21.8	55	100.0
250,000 to 499,999	48	80.0	12	20.0	60	100.0
100,000 to 249,999	173	78.3	48	21.7	221	100.0
50,000 to 99,999	294	81.7	66	18.3	360	100.0
Total	558	80.2	138	19.8	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

Table 33
Did the department's use of NFPA 1710 or NFPA 1720 change after 2003 (the year of The Station nightclub fire)? [Q.22a]

Size of community	Yes Requirements Changed Number Depts	Yes Requirements Changed Percent	No Requirements Did Not Change Number Depts	No Requirements Did Not Change Percent	Total Number Depts	Total Percent
500,000 or more	0	0.0	55	100.0	55	100.0
250,000 to 499,999	12	20.0	48	80.0	60	100.0
100,000 to 249,999	34	15.4	187	84.6	221	100.0
50,000 to 99,999	41	11.4	319	88.6	360	100.0
Total	87	12.4	609	87.6	696	100.0

Source: NFPA Survey of Fire Department Practices Related to Nightclub Fire Safety, 2013.

Numbers may not add to totals due to rounding.

APPENDIX B

NATIONAL FIRE PROTECTION ASSOCIATION
SURVEY OF FIRE DEPARTMENT PRACTICES
RELATED TO NIGHTCLUB FIRE SAFETY

☐

☐

PART I. IDENTIFYING INFORMATION

Name of person completing form:___________________________________ Date:_______________

Title of person completing form:____

Non-emergency phone number: (   ) _____________________ Fax: (   ) _____________________

e-mail address: ________________________________

Population (Number of permanent residents your department has primary responsibility to protect, excluding mutual aid areas) __________________

Please use enclosed postpaid envelope to return form to:
Fire Analysis & Research, NFPA, 1 Batterymarch Park, Quincy, MA 02269-9101
OR reduce form to 8½" x 11" and fax us the form at (617) 984-7478
OR e-mail us at fcsurvey@nfpa.org that you would like to respond electronically. We will send you an electronic form, which you can complete, save and submit to fcsurvey@nfpa.org.
Thank you for your participation!

PART II. NIGHTCLUBS IN YOUR COMMUNITY

1. How many nightclubs are in your community? ☐ None [*No need to go further; please return form*]
☐ 1 ☐ 2-5 ☐ 6-10 ☐ More than 10

PART III. BUILDING AND FIRE CODES APPLIED TO NIGHTCLUBS

2. What code applies to newly constructed nightclubs in your community? (check all that apply)
☐a. NFPA 101, *Life Safety Code* (which edition (year)? _________)
☐b. International Building Code (which edition (year)? _________)
☐c. Local code not based on model ☐d. Other model code (please specify _______________) ☐e. No code

3. What code applies to existing nightclubs in your community? (check all that apply)
☐a. NFPA 1 (which edition (year)? _________) ☐b. NFPA 101 not as part of adoption of NFPA 1
☐c. International Fire Code (which edition (year)? _________) ☐d. Local code not based on model
☐e. Other model code (please specify _______________________________) ☐f. No code

4. Are there any local amendments or other requirements applicable to nightclubs? (check one)
☐Yes, changed after 2003 ☐Yes, not changed after 2003 ☐No

5. How are inspections used for enforcement? (check all that apply) ☐a. No inspections conducted
☐b. Building code inspections for new buildings ☐c. Fire code inspections at least annually
☐d. Regular fire code inspections less often than annual ☐e. Inspections in response to complaints

PART IV. SPRINKLERS IN NIGHTCLUBS

6. Are sprinklers required in nightclubs in your community? (check one) ☐Yes, regardless of occupancy
☐Yes, occupancy 50 or more ☐Yes, occupancy 100 or more ☐Yes, occupancy 200 or more
☐No (*Go to Q.9.*)

   a. If you said yes, did your sprinkler requirements change after the Station nightclub fire in 2003? ☐Yes ☐No

7. Do you conduct inspections just to check compliance with sprinkler requirements? ☐Yes ☐No

8. How many nightclubs do you think are in compliance with your sprinkler requirements? (check one)
☐All ☐Most ☐Half ☐Some ☐None ☐Don't know

PLEASE CONTINUE SURVEY ON OTHER SIDE

PART V. INTERIOR FINISH IN NIGHTCLUBS

9. Do you have interior finish requirements for nightclubs? (check all that apply)
☐a. Yes, from International Building Code ☐b. Yes, from NFPA 101, *Life Safety Code*
☐c. Yes, from NFPA 1 ☐d. Yes, from International Fire Code
☐e. Yes, from other model code (please specify ________________)
☐f. Yes, local requirements not based on model ☐g. No requirements (*Go to Q.14.*)
h. If you have requirements, did they change after The Station nightclub fire in 2003? ☐Yes ☐No

10. Do these requirements reference a standard test for product and material fire performance (e.g., NFPA 286, NFPA 255, ASTM E84)? ☐Yes ☐No

11. How do inspectors check for compliance? (check all that apply)
☐a. Visual inspection only ☐b. Routine testing of materials ☐c. Testing based on visual screening
☐d. Review of specification sheets and technical data for materials

12. Do you conduct some inspections where the only purpose is to check compliance with these requirements?
☐Yes ☐No

13. How many nightclubs do you think are in compliance with your interior finish requirements?
(check one) ☐All ☐Most ☐Half ☐Some ☐None ☐Don't know

PART VI. INDOOR USE OF PYROTECHNICS IN NIGHTCLUBS

14. Do you have restrictions on indoor use of pyrotechnics by nightclubs? (check all that apply)
☐a. Yes, from NFPA 1126 ☐b. Yes, from other model code (please specify __________________)
☐c. Yes, local restrictions not based on model ☐d. No restrictions (*Go to Q.17.*)
e. If you have restrictions, did they change after The Station nightclub fire in 2003? ☐Yes ☐No

15. Do you conduct inspections just to check compliance with these restrictions? (check all that apply)
☐a. Yes, at events (including inspections only for specific events or types of acts)
☐b. Yes, with managers in advance of event
☐c. Yes, based on complaints, concerns or requests received before or during event ☐d. No

16. How many nightclubs do you think are in compliance with your indoor use of pyrotechnics restrictions? (check one) ☐All ☐Most ☐Half ☐Some ☐None ☐Don't know

PART VII. OCCUPANCY LIMITS AND EMERGENCY EGRESS

17. Do you have egress requirements and/or occupancy limits for nightclubs? (check all that apply)
☐a. Yes, from International Building Code ☐b. Yes, from NFPA 101, *Life Safety Code*
☐c. Yes, from other model code (please specify ________________)
☐d. Yes, local requirements not based on model ☐e. No requirements (*Go to Q.20.*)
f. If you have requirements, did they change after The Station nightclub fire in 2003? ☐Yes ☐No

18. Do you conduct special inspections, more frequent than your fire code inspections, just to check compliance with these requirements? (check one)
☐Yes, roughly every evening clubs are open ☐Yes, at least weekly ☐Yes, but not weekly ☐No

19. How many nightclubs do you think are in compliance with your occupancy and egress requirements? (check one) ☐All ☐Most ☐Half ☐Some ☐None ☐Don't know

PART VIII. EMERGENCY RESPONSE STANDARDS

20. Do you use NFPA 1221 in the operation, installation, and maintenance of public emergency services communications systems within your jurisdiction? ☐Yes ☐No

    a. Did your use of this Standard change after The Station nightclub fire in 2003? ☐Yes ☐No

21. Do you use an emergency services incident management system that complies with the National Incident Emergency System (NIMS) or NFPA 1561? ☐Yes ☐No

    a. Did your use of an emergency services incident management system change after The Station nightclub fire in 2003? ☐Yes ☐No

22. Do you use NFPA 1710 (for career departments) or 1720 (for volunteer departments) in establishing organizational, operational and deployment procedures? ☐Yes ☐No

    a. Did your use of these documents change after The Station nightclub fire in 2003?
    ☐Yes ☐No