Impact of Elevated Walkways in Storage on Sprinkler Protection: Phase 1

Final Report by:

Noah L. Ryder, PhD, P.E. & Stephen J. Jordan
Fire & Risk Alliance
Rockville, MD, USA

March 2020
Solid and open metal grate walkways are often installed in aisles as part of rack storage. Further, open metal grates are also used as mezzanine levels above storage. There is little information on how these walkway and mezzanine installations impact current storage protection requirements. When is this type of installation considered a problem from a sprinkler protection standpoint? At what point do walkways interfere with pre-wetting of adjacent arrays? There is a need to compile available information and develop a research plan on this topic.

Therefore, the Fire Protection Research Foundation initiated this project with a goal to develop guidance on protection of storage when solid or open metal grate walkways are present. The objective of this Phase 1 project was to document knowledge gaps related to this topic and develop a research plan.

The Fire Protection Research Foundation expresses gratitude to the report authors Noah L. Ryder, PhD, P.E., and Stephen J. Jordan, who are with Fire & Risk Alliance located in Rockville, MD, USA. The Research Foundation appreciates the guidance provided by the Project Technical Panelists, the funding provided by the project sponsors, and all others that contributed to this research effort.

The content, opinions and conclusions contained in this report are solely those of the authors and do not necessarily represent the views of the Fire Protection Research Foundation, NFPA, Technical Panel or Sponsors. The Foundation makes no guaranty or warranty as to the accuracy or completeness of any information published herein.

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)

Founded in 1896, NFPA is a global, nonprofit organization devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards. The association delivers information and knowledge through more than 300 consensus codes and standards, research, training, education, outreach and advocacy; and by partnering with others who share an interest in furthering the NFPA mission.

All NFPA codes and standards can be viewed online for free.

NFPA’s membership totals more than 65,000 individuals around the world.

Keywords: sprinkler protection, warehouse, storage protection, walkways in storage, mezzanines in storage

Report number: FPRF-2020-03
Project Technical Panel

Chase Browning, Medford Fire Rescue
Christina Francis, P&G
Ray Grill, Arup
Mark Hopkins, National Fire Sprinkler Association (NFSA)
Roland Huggins, American Fire Sprinkler Association (AFSA)
Sultan Javeri
Tom Pedersen, IKEA
Leonard Ramos, Telgian
Dave Hague, NFPA staff liaison
Chad Duffy, NFPA staff liaison

Project Sponsors

Property Insurance Research Group (PIRG):
AIG
CNA Insurance
FM Global
Liberty Mutual Insurance
Tokio Marine America
Travelers Insurance
Verisk
Zurich Insurance Group
Phase I – Impact of Elevated Walkways in Storage on Sprinkler Protection

Prepared for:

Fire Protection Research Foundation
One Batterymarch Park
Quincy, MA 02169

Prepared by:

Noah L. Ryder, PhD, P.E.
Stephen J. Jordan
Fire & Risk Alliance
7640 Standish Place
Rockville, MD 20855

January 31, 2020
## TABLE OF CONTENTS

**List Of Figures** ........................................................................................................................................ iii

**List Of Tables** ........................................................................................................................................ iii

1.0  **Introduction** ........................................................................................................................................ 4

2.0  **Background** .......................................................................................................................................... 4

3.0  **Literature Review** ............................................................................................................................... 5

  3.1  Codes and Standards .......................................................................................................................... 5
  3.1.1  NFPA .................................................................................................................................................. 6
  3.1.2  FM Global .......................................................................................................................................... 9

  3.2  Technical Basis ...................................................................................................................................... 10

  3.3  Critical Variables and Impact ........................................................................................................... 12
  3.3.1  Pertinent variables of the wetting problem ..................................................................................... 13
  3.3.2  Pertinent variables of the activation problem .................................................................................. 13
  3.3.3  Impact of blockage on sprinkler spray ............................................................................................ 16
  3.3.4  Sprinkler Layout and Spacing .......................................................................................................... 17
  3.3.5  Sprinkler location relative to walkways .......................................................................................... 17
  3.3.6  Impact of floor coverings on open grates ........................................................................................ 18

4.0  **Gap Analysis** ..................................................................................................................................... 20

5.0  **Research Plan and Next Steps** ......................................................................................................... 20

  5.1  Survey .................................................................................................................................................. 22

  5.2  Spray Characterization ....................................................................................................................... 22

  5.3  Modeling .............................................................................................................................................. 24

  5.4  Cold Flow Testing ............................................................................................................................... 24

  5.5  Fire Testing .......................................................................................................................................... 24

  5.6  Schedule .............................................................................................................................................. 25

6.0  **References** ........................................................................................................................................ 26
LIST OF FIGURES

Figure 1 - Reported warehouse fires in the US, 1980-2013 [3] .......................................................... 5
Figure 2 - Mezzanine Storage Area in a Warehouse, Exhibit 4.7 extracted from NFPA 13 Handbook (2019) (© National Fire Protection Association) [5] ................................................................. 6
Figure 3 - Figures 9.3.7(a) and 9.3.7(b) extracted from NFPA 13 (2019) (© National Fire Protection Association) [5] ............................................................................................................. 7
Figure 4 - Figure A.9.5.5.1 extracted from NFPA 13 (2019) Obstructions to Sprinkler Discharge Pattern Development for Standard Upright or Pendent Spray Sprinklers (© National Fire Protection Association) [5] ............................................................................................................. 7
Figure 5 - Zurich loss experience by walkway, mezzanine, and rack configuration, Courtesy Zurich Services Corporation [10] ........................................................................................................... 11
Figure 6 - Impact of grate opening fraction on temperatures at the ceiling, Tan et al. [11] .......... 12
Figure 7 - Impact of mezzanine/walkway on sprinkler spray and activation. (a) Standard solid mezzanine/walkway; (b) No mezzanine/walkway or meets FM Global criteria for no walkway sprinkler requirement; (c) Sprinkler underneath grated walkway causing delayed activation of ceiling level sprinkler; and (d) Fire spreading up commodity and activating ceiling level sprinkler, cold soldering of under walkway sprinkler ........................................................................... 12
Figure 8 - 5 tier pick module configuration, Courtesy of Zurich Services Corporation [10] ......... 14
Figure 9 – Gaps between mezzanine and rack supports, Courtesy of Zurich Services Corporation [10] ................................................................................................................................................. 14
Figure 10 – (a) Grated mezzanine and (b) area beneath mezzanine, Courtesy of Proctor & Gamble ............................................................................................................................................. 15
Figure 11 - Example grates and view factor. (a) high W/L/Ws ratio, (b) low W/L/Ws ratio .......... 16
Figure 12 - Temperature slice across three tiers, showing conditions at 50 s for solid pallets (right) and grated pallets (left) scenarios. ............................................................................................................. 18
Figure 13 – (a) Schematic of open grate; and (b) impact of grate on spray ................................... 19
Figure 14 – Example of impact of pressure on spray pattern. Sprayviz predictions from spray characterizations. (a) Sprinkler @ 35 psi, (b) Sprinkler @ 50 psi .................................................. 23
Figure 15 – Flowchart of Proposal Research Plan ........................................................................... 23

LIST OF TABLES

Table 1 Proposed CFD/Cold Flow Test Matrix Parameters .............................................................. 24
1.0 INTRODUCTION

The National Fire Protection Association (NFPA) Fire Protection Research Foundation (FPRF) “Impact of Elevated Walkways in Storage on Sprinkler Protection” project seeks to address knowledge gaps related to the impact of walkways and mezzanines on sprinkler performance.

The goal of this project was to conduct a literature review to document the current sprinkler criteria in NFPA 13: Standard for the Installation of Sprinkler Systems [1], previously available studies examining sprinkler performance in the presence of walkways and mezzanines, and the technical substantiation for the currently provided guidance. Based on the review of this information a gap analysis was performed to help guide the research plan to fill the identified gaps in knowledge.

This research was necessary as sprinkler performance may be affected due to the presence of a mezzanine, walkway grating interfering with the spray, delayed activation of the sprinklers as a result of the grate’s influence on the plume, or the impact of pre-wetting of adjacent racks.

Ultimately the objective of this effort is to provide guidance to the NFPA 13 technical committee on walkways/sprinkler interface criteria that is well founded in sprinkler performance.

This report summarizes the literature review, gap analysis, and proposed research plan to examine the impact of walkways and mezzanines on sprinkler performance. For ease the term mezzanine will be applied throughout and will be generally reflective of mezzanines and walkways. Where sections are specific to either it will be clearly stated.

2.0 BACKGROUND

According to the US Department of Energy Information Administration (US DOE EIA) as of 2018 there were over 400,000 warehouses within the US, with nominally 10% of the warehouses exceeding 100,000 ft² in footprint. [2] Warehouse sizes vary significantly, however within the past decade the average size has increased significantly along with storage height. Warehouses vary based on the type of material stored, the age of the structure, the construction and storage method, and many other factors which despite their common purpose make protecting them challenging.

Based on data compiled from the National Fire Incident Reporting System (NFIRS), NFPA [3] indicates that property losses are higher than most other occupancies but that the average rate of injury is significantly lower. Additionally, the loss statistics only account for direct losses, but do not factor in indirect costs, such as business interruption or environmental remediation, which may outweigh direct losses.

The NFPA report [3] indicates that nominally 63 large loss events occur in storage facilities each year, though an additional 1,100 fires occur on average per year. Though not specific to storage fires the data indicates that the average large loss event exceeded $2.5M dollars, indicating that storage fires likely account for at least $160M in fire losses each year, though it is expected that the losses may be significantly higher due to the value of the commodities being stored.
While the average number of warehouse fires has been reduced drastically over the past 40 years, Figure 1, there has not been a corresponding decrease in property damage with property loss numbers fluctuating significantly but not apparently correlated directly to the number of fires. [3] This is partly due to the fact that a single fire event can drastically skew the loss totals in any given year. For example, in July 2019 Jim Beam suffered a warehouse fire that is estimated to have caused $45M in direct losses [4], thus 2019 total loss figures may be higher based on this.

How to properly protect storage facilities is an evolving science and the standards have been updated throughout the years to reflect the latest knowledge. As indicated in the introduction, storage configuration, walkways, and mezzanines can impact sprinkler performance and may contribute to the size of a fire loss. The impacts of the variables have not been studied in depth and thus it is not known what the impacts are and which are critical to sprinkler performance.

3.0 LITERATURE REVIEW

The literature review is focused on identifying what guidance currently exists with regards to walkways and mezzanines, in particular in storage configurations. This review covers the present codes and standards, the technical justification and basis for the guidance, as well as loss history, fire testing, and modeling to the extent that information on these topics is available.

3.1 Codes and Standards

Guidance on sprinkler protection for mezzanines and walkways is provided in NFPA and through FM Global data sheets. An overview of the guidance is provided below.
3.1.1 NFPA

NFPA provides minimal guidance related specifically to mezzanines and walkways. However, it does provide several references to them as well as to catwalks and obstructions which are briefly discussed below.

3.1.1.1 Mezzanines

Within NFPA 13 mezzanines are primarily discussed from a system area perspective. The word “mezzanine” only appears in NFPA 13 (2019) twenty-three times, is not defined, and primarily addresses sprinkler system area limitations. The other section discussing mezzanines is contained in Annex D and discusses exclusions from the requirements of protection of vertical openings. NFPA does not provide any guidance on non-solid mezzanines with regards to sprinkler protection and effectively treats solid mezzanines as separate fire areas requiring appropriate protection above and below the mezzanine(s). While NFPA 13 does not provide a definition, per NFPA 1 (2018) §3.3.178 a mezzanine is defined as “An intermediate level between the floor and the ceiling of any room or space”.

![Figure 2 - Mezzanine Storage Area in a Warehouse, Exhibit 4.7](image)

3.1.1.2 Catwalks

Prior to the 2010 edition of NFPA 13, there was no guidance provided on walkways or mezzanines. While some language was added to include mezzanines, there is no guidance on non-solid mezzanines. In the 2010 edition criteria was added for cartoned record storage which included catwalk aisles as well as expanding the guidance on obstructions to include open grate flooring. Per NFPA 13 (2019) §3.3.23 a catwalk is defined as “For the purposes of carton records storage, a storage aid consisting of either open metal grating or solid horizontal barriers supported from
a rack storage system that is utilized as a walkway for access to storage at elevated levels. Catwalks are access using stairs and are not separate floors of a building.”

It should be noted that presently there is no definition of what constitutes “open grating” within NFPA 13, however based on limited testing conducted in 2007 of cartoned record storage NFPA 13 allows for metal catwalk aisles between racks that are at least 50% open. It should be noted that the guidance is limited to Class III commodities and CMDA sprinklers at the roof, rack and catwalk.

Detailed guidance is provided for sprinkler requirements for single level and multi-level catwalks with sprinklers required at each catwalk level, NFPA 13 (2019) §21.11.6.3.5.

The information provided on open-grated catwalks is the closest to guidance on walkways that exists.

3.1.1.3 Miscellaneous NFPA 13 Sections

3.1.1.3.1 NFPA 13 (2019) §9.3.7 Library Stack Areas and Record Storage

NFPA 13 (2019) §9.3.7 addresses Library Stack Areas and Record Storage and specifies that when solid vertical dividers are in place that sprinklers are required in each aisle and at every tier. When the vertical shelf dividers are incomplete, water is allowed to be distributed to adjacent aisles, and vertical ventilation openings are present an alternating scheme is acceptable, Figure 3. The commentary indicates that “To overcome the obstruction caused by the bookshelves, sprinklers are installed at every tier and aisle unless adequate clearance can be maintained.” While this guidance is provided it does not appear that any testing was done to inform the standard.

![Figure 3 - Figures 9.3.7(a) and 9.3.7(b)](Reproduced with permission of NFPA from NFPA 13, Standard for the Installation of Sprinkler Systems, 2019 edition. Copyright© 2018, National Fire Protection Association. For a full copy of NFPA 13, please go to www.nfpa.org) [5]
3.1.1.3.2 NFPA 13 (2019) §20.5.3.2 Aisles

A new section, §20.5.3.2.1, was added to the NFPA 13 (2019) regarding aisles stating that “Aisles...shall not be obstructed unless Chapters 21 through 25 include specific guidance allowing obstructions over the aisle”. An example of an exception to this requirement is the previously discussed cartoned storage/catwalk configuration.

3.1.1.3.3 NFPA 13 (2019) §21.2.4.1.1 Bin Box and Shelf Storage.

NFPA 13 (2019) §21.2.4.1.1 addresses specialized storage of Class I through Class IV commodities in Bin Box and Shelf Storage configurations. The standard allows for tall bin boxes and shelf arrays with catwalks which allows access to otherwise inaccessible areas from the floor. It is worth noting that the standard makes reference to walkways, while the commentary uses the term catwalk. Regardless, as the walkways/catwalks interfere with the spray, the code requires that sprinklers be installed below the catwalks even if they are of an open grate construction and that the maximum commodity storage height is not exceeded.

3.1.1.4 Obstructions to Sprinkler Discharge

While NFPA doesn’t provide much guidance on mezzanines/walkways, it does provide guidance on obstructions and sprinkler performance. NFPA 13 handbook (2019) indicates that a sprinkler discharge pattern is fully developed within about 48 inches of the deflector, with the greatest impact to sprinkler discharge occurring within 18-36 inches, Figure 4. Specifically, NFPA 13 (2019) § A.9.5.5.3.1 states: When obstructions are located more than 18 in. (450 mm) below the sprinkler deflector, an adequate spray pattern develops and obstructions up to and including 4 ft (1.2 m) wide do not require additional protection underneath. Examples are ducts, decks, open grate flooring, catwalks, cutting tables, overhead doors, soffits, ceiling panels, and other similar obstructions.

Of note here is that grate flooring and catwalks are included as potential obstructions, however per §9.5.5.3.1 they are only considered an obstruction if they are wider than 4 feet, in which case a sprinkler is required to be installed under the obstruction.

The NFPA 13 (2019) handbook commentary poses the question:

Where open grating is utilized, are additional sprinklers required below the open grating?

and provides the following justification for the need for sprinklers under open grating:

Although open grating allows heat from a fire to pass through it and reach a sprinkler, the openings are not adequate to compensate for obstructions to the sprinkler spray pattern. Thus, supplemental sprinklers under the open grating deck are necessary. Gratings or slatted decks and walkways are frequently covered with goods in storage or by a light surface dust stop. Sprinklers are required under such gratings and walkways. Sprinklers located below the open grating must be provided with a water shield or be of the intermediate level/rack storage type to prevent water
from sprinklers that are operating above from wetting the thermal element and delaying sprinkler operation.

It should be noted that code requires sprinkler protection only in the event that grated openings are greater than 4 feet wide, even though the explanation provided clearly indicates that the reason sprinklers should be installed underneath is due to the grating interference with the spray pattern.

Thus, within the confines of NFPA today, there is minimal guidance for mezzanines or walkways and the guidance that is provided is primarily limited to cartoned records storage which has been established based on large scale testing or existing generalized obstruction criteria requirements.

Several recent FPRF projects focused on ESFR’s [6, 7] have provided additional guidance on spray obstructions and a recent FPRF project focused on spray sprinklers has highlighted current gaps in understanding of spray obstruction interactions [8]. The conclusions from these studies have not been fully implemented into NFPA 13 as of the date of this study.

3.1.2 FM Global

Factory Mutual provides guidance for sprinkler protection of mezzanines and walkways in storage environments in FM Global Property Loss Prevention Data Sheet 2-0 [9]. In general FM Global recommends that solid mezzanines and walkways be installed, and that sprinkler protection be provided beneath them. However, grated walkways and mezzanines are generally permitted if sprinklers are installed underneath of the grating and have the same specifications as the ceiling level sprinklers.

Sprinklers may only be omitted from under the grid if the following conditions are met:
• The open grid is a minimum of 70% open, and
• The open grid is a maximum of ¼ in. (6 mm) deep, and
• The open grid is at least 3 ft (0.9 m) vertically below the deflector of the ceiling-level sprinklers, and
• It is not possible for materials to fall onto the top of the open grid and obstruct sprinkler discharge during a fire, and
• There is only one open grid ceiling between the solid ceiling and the floor, and
• The ceiling sprinkler system can protect the occupancy in the absence of the open grid.

The FM Global guidance clearly indicates a preference for solid surfaces as this provides the best protection however, they do permit open grated mezzanines to be used if appropriate protection is provided.

### 3.2 Technical Basis

The technical substantiation for the evolution and currently provided guidance on mezzanines can broadly be categorized into three possible categories: (1) Historical Events, (2) Fire Testing, and (3) Modeling. Currently NFPA 13 provides limited prescriptive requirements for open-grate mezzanines (i.e. an obstruction greater than 4 feet), specific guidance for catwalks in cartoned record storage, and no broad guidelines for open-grate walkways in other storage applications.

The guidance itself is very limited within NFPA, though FM Global provides additional guidance, and what little guidance is provided appears to be based on very limited publicly available data.

These requirements are based largely on engineering judgment and limited fire test data or modeling studies.

There is minimal published data on historical events. NFPA 13 handbook (2019) §21.2.3.1.1 commentary states, Experience with fires in storage warehouses with walkways has shown that, even with open grate walkways, burning materials sometimes collapse and fall on the walkway, blocking the sprinkler discharge, however neither the standard nor the TC documents indicate specifically what events or testing this conclusion was derived from, though it intuitively is logical.

The other notable exception is a brief summary provided by Zurich from a 2018 SUPDET [10] presentation indicating the extent of internal losses by storage configuration, Figure 5.

Five basic cases were identified by Zurich that provide a good general representation of the conditions that may be observed in the field. These cases are shown in Figure 5 and listed below.

1. Case 1: Solid Mezzanine/Walkway and Solid Shelving;
2. Case 2: Solid Mezzanine/Walkway and Solid Shelving with gaps along mezzanine;
3. Case 3: Solid Mezzanine/Walkway and Solid Shelving with gaps at upright supports;
4. Case 4: Solid Mezzanine/Walkway and Open Shelving; and
5. Case 5: Open Mezzanine/Walkway and Open Shelving.

These cases highlight the various configurations that may be encountered and while not directly stated also indicate that multiple tiers may exist and potentially each tier may not be identical with regards to construction.

![Diagram of Cases 1 to 5](image)

<table>
<thead>
<tr>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid mezzanine</td>
<td>Small gaps along walkway</td>
<td>Gaps between uprights</td>
<td>Open racks, solid walkways</td>
<td>Open racks, open walkways</td>
</tr>
<tr>
<td>3 losses</td>
<td>1 loss</td>
<td>No losses yet</td>
<td>No losses yet</td>
<td>No losses yet</td>
</tr>
<tr>
<td>Fire 1 level</td>
<td>Fire 2 levels</td>
<td>Fire 4 level</td>
<td>Aware of multiple sites with total values &gt; $100M</td>
<td></td>
</tr>
<tr>
<td>$0.2M USD</td>
<td>No loss estimates</td>
<td>$25M USD</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5 - Zurich loss experience by walkway, mezzanine, and rack configuration, Courtesy Zurich Services Corporation [10]**

Results from publicly available fire testing is similarly limited and the authors could only find information on a single test series that was conducted by Southwest Research Institute (SWRI) in 2007 and is referenced in the NFPA 13 Handbook. [5] The research served as the technical basis for the introduction of specific guidance for cartoned record storage in NFPA 13. A summary of this research is available in the NFPA 13 Handbook (2019) [5] commentary in §C.25 and the three successful tests led to the development of the present guidance.

To date there is been minimal modeling work conducted examining the impact of grating on fire growth, plume development, and sprinkler activation. Tan et al. [11] used the Fire Dynamics Simulator (FDS) to examine the impact of opening percentage on ceiling temperature at several distances from the fire. They concluded that as the percentage increased that the observed temperature at the ceiling similarly increased. This was determined to be due to the increased ability for the plume to penetrate the grate as well as the reduced heat absorption of the grate material. FDS results for a sprinkler located immediately above the fire are shown in Figure 6.
Figure 6 - Impact of grate opening fraction on temperatures at the ceiling, Tan et al. [11]

Figure 7 - Impact of mezzanine/walkway on sprinkler spray and activation. (a) Standard solid mezzanine/walkway; (b) No mezzanine/walkway or meets FM Global criteria for no walkway sprinkler requirement; (c) Sprinkler underneath grated walkway causing delayed activation of ceiling level sprinkler; and (d) Fire spreading up commodity and activating ceiling level sprinkler, cold soldering of under walkway sprinkler

3.3 Critical Variables and Impact

As discussed above there is minimal published research that has focused on the impact of walkways and mezzanines on sprinkler performance, however there are variables that are believed to be impactful based on other existing information. In general variables may affect the activation of a sprinkler and/or the delivery of water. Any component of the system that impacts either of these may be relevant, though they may have different levels of importance. The most important parameters therefore are those that have the ability to significantly affect activation and the initial spray field itself once activation has occurred.

It is typically assumed that sprinklers form similar spray patterns and that the pattern is generally formed after about 4 feet (see Figure 4). However, while similar, not all sprinklers produce the
same spray pattern and the pattern itself is impacted by pressure and sprinkler type [12]. As a result, the initial spray development is a variable that requires examination to ensure that the same general guidance may be provided for all sprinklers at all pressures.

### 3.3.1 Pertinent variables of the wetting problem

Pre-wetting of adjacent fuel loads plays a critical role in limiting secondary ignition and flame spread. This requires the water to be able to be delivered to the adjacent combustibles, Figure 7. This pre-wetting may occur at the same level as the sprinkler or could occur at a lower tier as the water penetrates the grating. In this case activation and spray patterns both play a role on the pre-wetting performance. A delayed ceiling level activation, due to mezzanine effects, may delay prewetting of storage at that level and may encourage vertical flame spread from a lower tier. Additionally, the presence of a grated mezzanine may preclude pre-wetting of lower tier storage from a ceiling mounted or higher tiered sprinkler if the spray is blocked. It is important to note that oftentimes if the spray is partially blocked and the water still reaches the floor the overall impact on suppression performance may be minimal, however in this case if the spray hits the grate it will fall downwards and won’t have the ability to “drip” onto the target surfaces for pre-wetting purposes.

In addition, the aisle width, the physical layout of the mezzanine relative to the aisle/racks, the percent open, and how the percent open is determined (i.e. perpendicular to the grate will yield a higher percent open than if the “view” is tangential) will all impact the wetting performance.

### 3.3.2 Pertinent variables of the activation problem

A number of variables were identified in the RFP including the types of walkways (solid, grated, grated with floor coverings) and the installation methods of the walkways which may alter the activation of sprinklers both under walkways and at ceiling level. Further, the types of rack assemblies (open storage arrays, solid racks, etc.), installation methods of walkways (gaps parallel to walkways or between beams), and methods of construction further contribute to the overall activation challenge. Configurations of open racks with open walkways, seen in a number of existing, high value installations are anticipated to provide the highest challenge for sprinkler activation at all mezzanine levels and ceiling level sprinklers. Some examples of these configuration are shown in Figure 8 and Figure 9. A particular concern is that if the fire originates at a lower tier and there is a solid walkway but an open rack that the fire may spread vertically and the sprinkler under the walkway may be significantly delayed or may never activate.

In addition, due to the structural beams required to support the walkway and light fixtures the sprinklers are often installed some distance below the walkway. This distance may impact the activation time as a layer must develop unless the sprinkler is within the fire plume.
Phase I – Impact of Elevated Walkways in Storage on Sprinkler Protection

Figure 8 - 5 tier pick module configuration, Courtesy of Zurich Services Corporation [10]

Figure 9 – Gaps between mezzanine and rack supports, Courtesy of Zurich Services Corporation [10]
Figure 10 – (a) Grated mezzanine and (b) area beneath mezzanine, Courtesy of Proctor & Gamble
3.3.3 Impact of blockage on sprinkler spray

The impact that the walkway has on blocking of water will have a significant effect. The blockage ratio of the walkway will have a significant impact on the developed spray pattern and is critical to the performance of the sprinkler in a fire scenario. Typically, a walkway that is more than 50% blocked is treated as solid and while solid walkways and mezzanines are treated as separate fire areas, their presence may impact the wetting of adjacent racks. As Tan et al. [11] indicated in their study the percent open has a direct impact on the amount of heat that is transferred to a sprinkler. The impact of the percent open will affect the water that may pass through the walkway and also will impact the pre-wetting of adjacent racks.

Figure 11 shows an example of commercially available grates and Figure 13 shows a schematic of the sprinkler spray interaction with a grated walkway/mezzanine and also defines the critical measurements relative to the grating. Here H is the height from the sprinkler to the mezzanine, W_T is the total width of the walkway/mezzanine, W_i is the width of an individual grate, W_s is the narrow separation distance between grates, D is the depth of the grate, and W_L is the long separation distance between grates. Each of these variables play a role in the blockage of the spray. A brief survey of commercially available grates indicate that D normally is between 0.75-1.25 inches, and it should be noted that this is deeper than that allowed by FM Global Property Loss Prevention Data Sheet 2-0 [9] if a sprinkler under the grate is not provided. Also, of note is that a simple observation of the images in Figure 11 show that a droplet with a similar view factor as the image would be impacted by the grate.

As an example, if the typical W_s spacing is nominally 1 inch and D is assumed to be 1 inch then the approach angle of the droplet, \( \phi \), would have to be less than 45° off of vertical in order for the droplet not to strike the grate. Any portion of the spray that has an angle greater than 45° would strike the grate and its effectiveness may be reduced.
3.3.4 Sprinkler Layout and Spacing

Once the spray leaves the sprinkler the ability to deliver water is dependent not just on the spray pattern but the layout and spacing of the sprinklers relative to each and to the surroundings. Changes to spacing of sprinklers can drastically impact the quantity of water that is able to be delivered. Recent guidance on spacing indicates that 4-feet x 4-feet spacing may be beneficial and this will have a significant impact as fewer gaps in the spray may exist and additional overlap may be present thus making the spray less susceptible to the impact of obstructions. Additionally, the location of the sprinkler relative to the mezzanine may have a significant impact on activation and pattern development depending on whether the sprinkler is centered or at the face of the storage arrays.

3.3.5 Sprinkler location relative to walkways

Given that walkways and mezzanines can be solid or have some porosity, it is important to determine where sprinklers need to be installed in order to ensure timely and effective suppression. The lack of sprinklers beneath a walkway may lead to the development of larger HRR’s prior to activation, however locating a sprinkler beneath a walkway may also impact ceiling level activations and may push the fire out into a broader area. Thus, the specific interaction of the plume and spray dynamics in the context of a walkway is critical. There have not been any published experimental studies that examine this with the exception of the SWRI study referenced by NFPA [5], however the Tan et al. [11] study indicates that if sprinklers are not installed beneath open grated mezzanines that there will be the potential for significantly delayed ceiling sprinkler activation.

The authors conducted an unpublished study examining the impact of solid vs porous pallets/shelving on sprinkler activation using FDS. As can be observed in Figure 12 the solid surface pushes the smoke and heat out to the sides or the storage array while the open grated pallets allow for heat and smoke to rise through it. While this is not an identical scenario as the mezzanine challenge it clearly shows the impact of solid vs open surfaces for multiple tiers and depending on where sprinklers were located their activation time may be significantly impacted.
3.3.6 Impact of floor coverings on open grates

While an open grate walkway/mezzanine may initially be installed in a storage facility and the initial fire protection designed based on this, it is possible that floor coverings may be installed or placed on top of the open grating. The floor coverings may be “temporary” in nature such as during work or maintenance to protect against drop hazards or may be more permanent in nature, however the addition of these surfaces will most certainly impact the spray performance and thus need to be explored. Again, there is little published information on the impact of floor coverings on sprinkler performance, however it is clearly seen as a possibility that needs to be addressed in particular as the lifecycle of the storage facility may change.
It is generally understood that a sprinkler can only be effective if it activates and that its level of effectiveness is time-dependent, as a delayed activation may result in a larger than intended HRR at the time of activation. Similarly, a sprinkler will only suppress/control a fire if water reaches the surface of the burning fuel source, and its level of effectiveness is density dependent.

The primary heat transfer mechanisms for sprinkler activation are convective and radiative heat transfer, Figure 7. In the unobstructed case, convective and radiative heat exposure to the sprinkler is transparent and therefore its response (activation time) can be relatively well predicted. Similarly, in the unobstructed case the characteristics of the spray pattern are well known (as illustrated in Figure 7, and therefore the water delivered to the commodity is generally predictable.
4.0 GAP ANALYSIS

Broadly speaking there is minimal published information related to mezzanines and walkways and little published technical substantiation for the current guidance that exists. Therefore, unfortunately, there are extensive gaps in the generally available knowledge that exist related to almost all aspects of the topic.

However, knowledge gaps pertaining to the impact of mezzanines on spray sprinkler performance can be largely broken down into two key areas, (1) Fundamentals of sprinkler-mezzanine interactions, and (2) Sprinkler installation guidance.

Based on the literature review Fire & Risk Alliance (FRA) identified the following knowledge gaps that presently exist in the understanding of the interactions of sprinkler activations and spray patterns when walkways of various porosity are present. Knowledge is lacking in several key areas, specifically:

1. Fundamental understanding of sprinkler/walkway interactions
   a. Differences in spray patterns of sprinklers based on type, K-factor, and operating pressure;
   b. Impact of walkway porosity and grate geometry on plume development and subsequent sprinkler activation;
   c. Impact of walkway porosity on sprinkler spray development and pre-wetting of adjacent combustibles;
   d. Impact of sprinkler location and layout with respect to the mezzanine;
   e. Impact of aisle width on propensity for fire to jump the aisle;
   f. Impact of grate geometry on spray development and water delivery (i.e. 75% open with a 1 inch deep grate vs. 2 inch deep grate); and
   g. Impact of floor coverings (i.e. zero porosity) on sprinkler activation times, spray coverage, and pre-wetting.

2. NFPA 13 guidance on sprinkler protection when walkways/mezzanines are present
   a. Actual field conditions observed in warehouses;
   b. Linkage between guidance and actual sprinkler performance; and
   c. Consistent and expanded guidance on how to protect areas with solid/porous walkways/mezzanines in place.

5.0 RESEARCH PLAN AND NEXT STEPS

Based on FRA’s prior research experience involving sprays [7, 12, 13] the research plan includes the following components:
1. Survey of existing conditions. FRA will develop a survey and collect information on current warehouse configurations to gain insight into the status quo and to attempt to ascertain how storage protection may be changing;

2. Sprinkler characterization and modeling of spray/walkways/rack interactions. This will include baseline scenarios for comparison of the spray pattern development and water delivery and will help determine the range of scenarios to be examined experimentally;

3. Cold flow experiments to examine the sprinkler spray characteristics and determination of delivered density to fuel surfaces and storage array faces in a mock storage rack/walkway environment;

4. High resolution CFD modeling of anticipated fire test scenarios to examine activation and spray distribution; and

5. Fire tests to explore the scenarios identified during the literature review and identification of the knowledge gaps to develop technical guidance.

The research plan is designed to yield as comprehensive a set of guidance as possible recognizing that field variations and design scenarios are always changing. Thus, the intent is to create a plan that provides for simple guidance to address the most commonly encountered scenarios but also provides a framework for addressing scenarios that may fall outside of the norm. Ideally a combination of prescriptive solutions and a framework for a performance-based approach will be derived. In addition, the research plan is designed to maximize the information that is able to be obtained given a finite set of resources.

One of the primary goals of the research plan will be to identify the role that each of the parameters play and to divide them into three categories:

1. **Negligible** – a mezzanine/spray configuration that has negligible impact on sprinkler activation times and water delivery.

2. **Impactful** – a mezzanine/spray configuration that has a clear impact on either sprinkler activation or water delivery (Actual Delivery Density). Example – significant fraction of water is blocked preventing pre-wetting of surfaces.

3. **Questionable** – a mezzanine/spray configuration that is neither “Negligible” or “Impactful” and the impact of which needs to be determined through an engineering analysis.

As stated above the proposed research plan is comprised of three main components, (1) Sprinkler Spray Characterization, (2) CFD Modeling, and (3) Testing (cold and hot). These components will be supplemented with a survey that will be distributed to collect information on the status quo of storage configurations and protection. Ideally details about the rack construction, shelving gaps, mezzanine/walkway configuration, and storage commodity will be obtained.
The intent of the plan after the completion of the survey is to examine typical configurations representative of real-world scenarios via modeling and cold flow testing to establish acceptability thresholds and to use these to inform and fire testing that may take place. The modeling and cold flow testing will allow for enhanced scenario evaluation and ensure that the broadest set of conditions are able to be analyzed.

Figure 15 provides an overview of the proposed research plan highlighting the interdependencies of each step of the plan.

5.1 Survey
FRA previously conducted a broadly circulated survey to capture information about sloped ceilings that helped to guide three phases of a FPRF project focused on sloped ceilings in storage occupancies [14]. Based on the success of the survey and the lack of knowledge surrounding real world existing conditions, FRA proposes to develop a survey to be distributed to the fire protection and insurance community. While a detailed survey has not been developed to date, the desired information to collect would mirror the items identified in the gap analysis namely: storage configuration, stored commodity, details of mezzanine/walkway, sprinkler system details, loss history (if any), and photographs. This information can help to highlight the most commonly observed conditions within storage occupancies and thus focus the remainder of the effort.

5.2 Spray Characterization
FRA proposes to characterize three sprinklers at two pressures each using the Spatially Resolved Spray Scanning System (4S). This method has been successfully used to characterize sprays in other research efforts in which sprinkler spray modeling has been required [7, 12, 13]. The 4S will be used to provide spray characterization data (droplet size, velocity, volume flux, and delivered density) for the selected sprinklers. In addition, FRA will use existing data from prior characterizations of sprinklers to supplement the sprinklers evaluated.

It is proposed to choose three different K-factor sprinklers and to characterize them at three pressures, one pressure towards the lower limit of the operating range, the other at the midpoint of the operating range, and the third at the higher end of expected pressures. As systems are typically designed based on the minimum operating pressure at the most remote location, the proposed pressures (7, 20, and 50 psi) are intended to cover the widest range of expected normal operating pressures. Thus, the impact of the pressure effects on distribution and obstruction impacts will be addressed. The results of the spray characterization will show the impact of K-factor and pressure on spray characterization and water distribution and plots showing baseline performance will be provided. The data collected from the 4S effort will be used as input into the CFD modeling effort.
Figure 14 – Example of impact of pressure on spray pattern. Sprayviz predictions from spray characterizations. (a) Sprinkler @ 35 psi, (b) Sprinkler @ 50 psi

Figure 15 – Flowchart of Proposal Research Plan
5.3 Modeling

FRA proposes to perform up to 50 simulations using the computational fluid dynamics tool FireFOAM and the reduced order model Sprayviz [13] with varying walkway/storage configurations. Using the schematic shown in Figure 13 FRA will alter the variables to change the opening percentage, the spacing between openings, the depth of the grate, the number of levels, and the gaps around the commodity. Bounding conditions will be used to establish a baseline with a single solid mezzanine and will gradually change the other parameters according to Table 1 to attempt to identify trends in activation and blockage. Model configurations will also address a solid mezzanine open rack configuration.

While not specifically shown in Table 1 it would also be recommended to try and capture the impact of gaps around storage arrays, though this would be informed based on the survey results. The proposed values for the CFD modeling and cold flow experiments were selected largely based on a survey of the range of commercially available mezzanines over typical mezzanine widths and the types and K-factor sprinklers most commonly seen in these types of installations.

Table 1 Proposed CFD/Cold Flow Test Matrix Parameters

<table>
<thead>
<tr>
<th>Modeling Parameters</th>
<th>K-Factor</th>
<th>Sprinkler</th>
<th>Pressure (psi)</th>
<th>( W_T )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline No Mezzanine</td>
<td>11.2, 17, 22</td>
<td>1, 2, 3</td>
<td>7, 20, 50</td>
<td>NA</td>
</tr>
<tr>
<td>( D ) (in) = 1/4, 3/8, 1/2, 3/4, 1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( L ) (in) = 1, 1.5, 2, 3, 4, 5, 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( W_i ) (in) = 1/8, 1/4, 3/8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( W_s ) (in) = 1/2, 3/4, 1, 1.25, 1.5</td>
<td></td>
<td></td>
<td>( W_T = 36, 44, 52, 60 )</td>
<td></td>
</tr>
</tbody>
</table>

5.4 Cold Flow Testing

FRA proposes to conduct a reduced set of cold flow testing that will be based on the cold flow modeling results. The cold flow testing would involve testing various walkway/mezzanine configurations to determine the impact on the spray to the intended surface. Commercially available grates that are typical of those installed will be used to establish the impact on pre-wetting and delivered density.

5.5 Fire Testing

Finally, fire testing is proposed to be conducted in a third phase as necessary based on the results of the CFD and cold flow testing. The results from the proposed phase two work will ideally limit the number of tests that may be required such that the primary focus will be on “grey” areas in which guidance isn’t clear or the bounds may be pushed. At this stage sufficient research gaps still exist such that a fire test plan would be premature.
5.6 Schedule

The schedule for the proposed work is provided in the table below and assumes a 10-month completion for tasks 5.1-5.4. The fire testing schedule will be further defined in Phase III of the project.

<table>
<thead>
<tr>
<th>Task</th>
<th>Months</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1 Survey</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
</tr>
<tr>
<td>5.2 Spray Characterization</td>
<td></td>
</tr>
<tr>
<td>5.3 CFD Modeling</td>
<td></td>
</tr>
<tr>
<td>5.4 Cold Flow Testing</td>
<td></td>
</tr>
</tbody>
</table>
6.0 REFERENCES


