

## ***“It just hit right then, and everything started flying”*: Lessons learned from the May 22, 2011 Joplin, MO tornado**

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Even with 17 minutes of warning lead time – 3 minutes longer than the national average tornado warning time (14 minutes)<sup>1</sup> – 161 lives were lost and over 1000 people were injured as a result of the powerful tornado that struck the City of Joplin, Missouri on the evening of Sunday, May 22, 2011. Days after the tornado struck, the National Institute of Standards and Technology (NIST), in cooperation with the National Oceanic and Atmospheric Administration (NOAA), dispatched a team of researchers with expertise in structural, fire, and wind engineering, disaster sociology (human behavior and emergency communication and response), meteorology, and severe storm predictions and warnings to conduct a technical investigation of the event under the National Construction Safety Team (NCST) Act (P.L. 107-231) (see Kuligowski et al. 2014).

One of the objectives of the NIST investigation was to understand how the public responded to the National Weather Service’s (NWS) and the City of Joplin’s emergency warnings and communications during that fateful event, and in turn, identify the patterns, locations, and causes of deaths and injuries due to the tornado. In order to achieve this objective, data were collected and analyzed on the following: (1) the damage to the built-environment and vegetation (trees); (2) building design and construction; (3) the emergency communication protocol and procedures in place before the storm hit; and (4) the response of the public to the emergency communications and the storm itself. This study provided an approximation of the environmental condition that existed during the storm (via wind speed estimates), an evaluation of the performance of buildings in the affected area, and an understanding of the consequences of the tornado for the people who were in its path. As with any NCST investigation, the ultimate goal was the develop findings and recommendations that would serve as the basis for potential improvements to codes, standards, and practices for buildings and emergency communication procedures that will lead to improved life safety in tornadoes.

### ***Failure of Buildings to Provide Life-Safety Protection for Occupants***

One unique aspect of the May 22, 2011 Joplin tornado was the broad range of building systems that it affected. While most buildings damaged by tornadoes are typically low-rise, non- or marginally-engineered buildings (e.g., manufactured homes), the Joplin, MO tornado damaged both non-engineered and engineered buildings alike. Most notable were the East and West towers of the St. John’s Regional Medical Center that were both a critical facility and the tallest buildings in the immediate region. While these towers did not collapse, they sustained significant damage to their envelopes due to the combination of high wind pressure and wind-borne debris impact. Regardless of construction type, neither these towers, nor other affected residential and non-residential buildings, were able to provide life-safety protection for their occupants, as evidenced by the high death toll of occupants in the buildings (135 of the 161 deaths, or 83.8 percent of all fatalities). Details of the 135 fatalities that occurred within buildings, and the circumstances surrounding these deaths, are shown in Table 1.

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<sup>1</sup> Source: National Weather Service

Virtually all of the buildings in which there were fatalities experienced maximum wind speeds (i.e., 136 mph and above) in excess of the code-level design wind speed for these building types. In fact, these buildings were subjected to wind speeds close to or above the speeds that would be expected to cause collapse of or major damage to structures designed to the non-tornadic wind design building code requirements. While it is recognized that conventional buildings in the United States are not required to be designed for tornado hazards and there are no building code requirements for tornado-resistant design currently, the high death and injury toll, in a city with long history of timely code adoption, points to serious failure of buildings to provide life-safety and gives rise to an important question: Can building safety in tornadoes be enhanced?

<b>Building</b>	<b>Estimated wind speed (mph)<sup>a</sup></b>	<b>Structural System</b>	<b>Degree of Damage</b>	<b>Basement (Y/N)</b>	<b>No. of Deaths</b>	<b>Circumstances of the Deceased</b>
AT&T store	160	Metal frame walls with brick facade	Unrated	No	1	Crushed in back office (refuge)
Elks Lodge	170	Wood frame	Demolished	No	4	Attempting to run to cooler (refuge)
Full Gospel Church	150	Wood frame	Demolished	No	4	Located in nursery (refuge)
Harmony Heights Baptist Church	160	Concrete masonry unit/wood frame walls with wood roof trusses	Demolished	No	3	Located in nursery and library (refuge)
Meadows Healthcare facility	100	Wood frame connecting structure; rest of building unknown	Heavy/ Totaled	No	2	(Not known)
Pizza Hut	170	Wood frame	Demolished	No	5	Thrown from cooler (refuge)
Stained Glass Theater	170	Unreinforced masonry walls with brick facade	Demolished	Yes	3	Above-ground theater area (survivors in basement)
Walmart	165 (southern half of building)	Box-type system with concrete masonry perimeter walls and metal roof diaphragm	Demolished (southern half)	No	3	(Not known)
Home Depot	170	Box-type system with tilt-up reinforced concrete perimeter walls and metal roof diaphragm	Demolished	No	8	Structural collapse toward front of the store (lumber area)

St. John's Regional Medical Center	170	West tower: 7-story cast-in-place reinforced concrete frame; East tower: 9-story steel moment frame	Significant damage to envelope	No	12	Four patients in ICU, one additional on 3 <sup>rd</sup> floor; others (unknown locations)
Greenbriar Nursing home	170	Unreinforced masonry with wood roof trusses	Demolished	No	19	Located in hallway (refuge)
Single-family homes	>136	Wood frame	Heavy/ totaled to demolished	56 none, 3 partial	59	All above ground when storm hit; 20 known to take internal refuge (all others unknown)
Apartments	>136	Wood frame	Demolished	None	12	All above ground when storm hit; 2 known to take internal refuge (all others unknown)

a. Estimated wind speeds with uncertainties +/- 20-30 %

To begin to answer this question, we first looked at the fatalities that occurred within designated tornado refuge areas. Many non-residential facilities, including high-occupancy commercial and critical facilities surveyed by NIST, did not have tornado-resistant community shelters or safe rooms. Instead, they had designated refuge areas. For the Pizza Hut restaurant, for example, shown in Table 1, the cooler was specified as the refuge area for shelter from tornadoes. However, these areas are typically best-available refuge areas within the facilities and are not specifically designed for tornado-resistance. During the Joplin tornado, NIST found that several of these designated refuge areas suffered severe structural damage and there was no evidence that these areas yielded positive outcomes with respect to loss of life.

Also contributing to the death and injury toll was the fact that the City of Joplin had limited access to underground or tornado-resistant community shelters or safe rooms. At the time of the May 22, 2011, Joplin tornado, the City of Joplin or Jasper County did not have or operate community shelters or safe rooms. Thus, with 82 percent of the homes in Joplin lacking basements, only a few residential buildings with some type of above-ground storm shelters, and a few non-residential buildings with underground locations (e.g., basements, like in the Stained Glass Theater), the option for safe sheltering for many in the affected area was limited.

### ***The Impact of Emergency Communication and Public Perception on Response Delay***

The next step in the process was to study the Joplin tornado fatalities that were located outside of designated refuge areas when the storm hit. In some cases, people were attempting to reach a designated refuge area within a building (e.g., the deaths that occurred in the Elks Lodge or those attempting to reach the basement level in the Stained Glass theater; See Table 1). In other cases, deaths occurred while people were located outdoors or in vehicles. Therefore, it was important to understand, given the relatively generous tornado warning lead time, the reasons why people did not seek some form of shelter before the tornado hit.

NIST was unable to ascertain what emergency information the deceased had received and the subsequent motives or perspectives that guided their actions. However, it was possible to determine the factors that influenced survivors (those injured or not injured) to decide against protective action; especially since many decided against protective action at some point in their decision-making process. Therefore, qualitative interview data from 140 survivors<sup>2</sup> from the Joplin, MO tornado (particularly those who were responsible for their own protective decision-making [e.g., head of household or alone in his/her car]) were analyzed to develop a conceptual model of decision-making in the Joplin tornado (Kuligowski et al. 2014). This model was developed to identify the reasons why protective actions were or were not taken; and in turn, identify necessary improvements to the emergency communication system and/or protocols, if warranted.

Qualitative analysis determined that responses to the approaching tornado among members of the public, in many cases (and even among those who survived the incident without injury), were delayed or incomplete. Two factors were found to have contributed to the delayed or incomplete public response to the Joplin tornado. The first was a lack of awareness of the approaching tornado. The second factor was an inability to perceive personal risk due to one or more of the following: receipt of conflicting or uncertain information about the tornado; pre-existing beliefs about Joplin's immunity to direct tornado strikes; and distrust of or confusion about Joplin's emergency communications system.

#### *Lack of Awareness*

In the first case, individuals who did not receive tornado alert- or warning- related cues on May 22, 2011, i.e., who were unaware that a tornado event was taking place, did not formulate any general risk associated with the event and thus, did not act to protect themselves. Of the 140 survivors included in this analysis, 16 percent were unaware that a tornado event was taking place until a family member or friend called and/or the tornado was upon them. The 16 percent of decision-makers who fell into this category were distributed among three different awareness states that made the receipt of warning information difficult: asleep, awake with impaired hearing, and awake but disconnected from tornado-related emergency communications.

For example, a couple in their late 80s was watching television before the storm hit, and do not recall receiving any information on the impending tornado. They were both hard of hearing, potentially making it difficult for them to hear outdoor sirens (which others claimed they could hear from indoors) as well as audio information provided via the television programming that they were already watching. Additionally, extended family members who would normally call and alert them of bad weather were out of town on the evening of May 22. That evening, the wife had noticed that it was getting dark outside. So she went to light candles near the front of the house when the following happened, according to the couple's daughter:

It just hit right then, and everything started flying, and [the husband] threw her [his wife] down in the hallway and just jumped on top of her and held onto the carpet as best he could, and the floorboards. He said when it was over this whole part of the roof was off.  
(NIST Interview 20)

This couple was caught completely off-guard by this storm, and suffered only minor injuries from being thrown around the house.

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<sup>2</sup> 140 out of 168 survivors interviewed by NIST (Kuligowski et al. 2014)

For those disconnected from tornado-related emergency communications, individuals were out-of-range from the city-wide tornado siren system, and/or simply did not hear the sirens from inside their homes. Even though the siren system was meant to alert individuals located outside of structures only, there was a general sense among the interviewees that Joplin-area residents located indoors (especially at home) relied on this technology to alert them as well. These decision-makers were also disconnected from other forms of tornado-related emergency communication, such as NOAA Weather Radios or opt-in subscription services that provide messages to mobile phones in the Joplin area.

### *No Personal Risk Perceived*

In the second case, individuals who were unable to confirm the existence of a tornado, either due to the receipt of conflicting or uncertain information and/or their pre-existing perspectives on tornadoes in general (formed prior to May 22), did not perceive any personal risk as a result of the weather that day. Of the 140 survivors, a majority of the sample (61 percent) were unable to confirm the existence of a tornadic event until they encountered direct visual or audible evidence of a tornado.

When initial information was given to decision-makers on May 22, 2011, around 5:09 p.m., including the sirens that sounded at 5:11 p.m., there was little information available that would help confirm the risk of a tornado threatening Joplin. The tornado touched down around 5:38 p.m. Any warning information provided to individuals around 5:09 p.m. (until 5:17 p.m.) related to a storm that the NWS weather forecasters were tracking to the north of Joplin. A Joplin native remembered that

the announcer and the weatherman that came on the TV seemed to say the track was, you know, mainly north of town. It wasn't going to be a bother for where I was at towards the south part of town. So, I continued to sit there on the front porch and enjoy the cool air that was, you know, for the day. (NIST Interview 58)

After hearing this information and based upon the perceived tendency for storms to track toward the northeast only, interviewees assumed that they were not at risk.

Around this same time (5:09 PM), individuals were offered very little in the way of environmental cues of an impending storm, also making it difficult to confirm the tornado risk. People looked outside, to the sky, for clues that a tornado was coming and saw only clouds that did not look as menacing as what would normally accompany a tornado. An interviewee recalled his actions at home that evening:

The tornado sirens went off once, we walked outside and you couldn't really, didn't really see nothing then, and we went back in and finished eating. (NIST Interview 108)

The decision had become as simple as that—if there was nothing in the sky to worry about, then it was appropriate to return to your previous pursuits until something else caught your attention. Some people continued to monitor the weather reports, while others resumed activities unrelated to the weather.

Even after the first set of sirens stopped and time progressed, interviewees who continued to monitor the weather via television or radio (or Internet sources) still did not perceive firm confirmation of an impending storm likely to affect them. First, the NWS issued a tornado warning at 5:17 p.m. for the storm that eventually hit Joplin; however, the outdoor siren system was not reactivated at 5:17 p.m.

Additionally, interviewees who had been tuned into the news outlets at 5:17 p.m. primarily reported that the media continued to discuss a storm that was to the north of Joplin.

During this time, the inability to confirm personal risk in a timely manner on May 22, 2011, was exacerbated by Joplin– area residents’ perspectives on tornadoes in general. When asked about their views on the possibility of severe storms in Joplin, decision–makers in the 140–person sample (and even other NIST interviewees) generally did not believe that tornadoes in Joplin were something that they would witness during their lifetimes.

One factor behind these views was a public perception, which was pervasive among the decision–makers, that severe storm false alarms were common in Joplin. This false perception was also exacerbated by the tendency of NWS forecasters to over-warn tornado hazards. Indeed, official NWS verification statistics showed a 78% false alarm rate for the southern Missouri area (i.e., over three-quarters of all official tornado warnings did not have a verified tornado report). One individual described his perspective on storm warnings as follows:

I grew up in Arkansas and spent a lot of time in Oklahoma, and then Missouri in this area. So, tornado watches are common. But, tornadoes don’t always strike, and they’re usually small. So, the chances of it truthfully hitting are pretty slim. (NIST Interview 10)

Decision–makers seemed to blame the outdoor siren system for over-warning as well, even though the sirens sounded only once per year, on average, for wind–related events.

Even if a tornado did materialize, most interviewees erroneously believed that they would be safe inside the city limits of Joplin. Residents were confident that they would be protected from severe storms and tornado damage, and believed that “it cannot happen to us” based upon tornado tracking beliefs or myths. For example, interviewees believed that severe storms always went around Joplin to the north or the south, creating a mythical “bubble” around their city that protected them from harm.

Finally, some interviewees expressed their confusion regarding the tornado siren protocol. On May 22, 2011, some interviewees were confused about how long the sirens should sound and the reasons why the sirens stopped after 3 minutes, even though this was Joplin’s emergency communication protocol. However, contrary to protocol, Joplin survivors were unsure why the second siren had been initiated, since this had not happened in the past.

### *Protection is Deemed Necessary*

The majority of decision–makers, who eventually decided that protection was necessary, did so only after receiving intense cues from the environment. Intense cues were those visibly or audibly disseminated by the tornado. Actually seeing the massive debris wall heading straight for them or hearing the sound of a freight train caused Joplin survivors to perceive risk and that they were potentially in trouble. High–intensity cues also included seeing large trees swirling or laying down on the ground, seeing cars or other heavy objects lift or fly off of the ground, and hearing information about the tornado in an urgent tone (i.e., the newscaster who urgently prompted people to “Take cover now!”). It was at this point when they realized that protection was necessary if they wanted to escape this tornado unharmed. Seeing or hearing these cues prompted individuals to take shelter in various locations in buildings, in vehicles, or outdoors. Among these individuals, the intense cues triggered cognitions about risk and danger to themselves, their friends, and family members. In some cases, the cues were so severe that individuals who were already located in their basements (e.g., “early actors”) moved to an internal refuge area (closet or bathroom) within their basement.

### ***Next Steps in Tornado Safety Protocols and Design***

As a result of the Joplin tornado technical investigation, NIST made 16 recommendations for improving how buildings and shelters are designed, constructed, and maintained in tornado-prone regions and for improving emergency communications

(see <http://nvlpubs.nist.gov/nistpubs/NCSTAR/NIST.NCSTAR.3.pdf>). The following are three key recommendations where implementation is likely to have the greatest impact on life safety in future disasters:

- 1) Develop nationally accepted performance-based standards for tornado-resistant design of buildings and infrastructure, as well as design methods to achieve those standards. Under these standards, specific types of buildings, for example, hospitals, will be designed and constructed to meet specific performance objectives, depending upon the types of tornado intensities expected in certain events.
- 2) Install tornado shelters in new and existing multi-family residential buildings, mercantile buildings, schools and buildings with assembly occupancies located in tornado hazard areas. As part of this effort, develop and implement uniform national guidelines that enable communities to create safe and effective public sheltering strategies. The guidelines should address planning for siting, designing, installing, and operating public tornado shelters within the community.
- 3) Create national codes and standards and uniform guidance for clear, consistent, recognizable, and accurate emergency communications, encompassing alerts and warnings, to enable safe, effective, and timely responses among individuals, organizations, and communities in the path of storms having the potential to create tornadoes. Additionally, NIST recommends that emergency managers, the NWS, and the media develop a joint plan and take steps to make sure that accurate and consistent emergency alert and warning information is communicated in a timely manner to enhance the situational awareness of community residents, visitors, and emergency responders affected by an event. This involves improving the NWS information to include forecast uncertainty information in the form of probabilities to reduce over warning as well as utilizing modern “push” communications to personal cell phones and smart phones.

NIST is assigning top priority to work vigorously with key stakeholders, including the building, codes, standards, and other relevant communities, as well as other federal agencies, to assure that there is a complete understanding of the NIST recommendations and to provide technical assistance for implementing these recommendations into standards and codes.