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Public alert and warning system literature review in the USA: identifying research gaps and lessons for practice

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Abstract

As emergencies continue to impact communities in the USA on an unprecedented scale, it is imperative for communities to look for effective ways to keep people safe and reduce future impacts. Public alert and warning systems are an effective means of accomplishing these goals. As such, researchers have studied public alert and warning systems extensively in the USA. Due to the plethora of studies on public alert and warning systems, a systematic and comprehensive synthesize is needed to understand what has been studied and their major findings and identify practical lessons that can be used to further improve public alert and warning systems. Hence, the goal of this study is to answer the following two questions: (1) What are the major findings from public alert and warning system research? (2) What policy and practical lessons can be gleaned from public alert and warning system research to improve public alert and warning system research and practice? We answer these questions by conducting a systematic and comprehensive review of the public alert and warning system literature, starting with a keyword search. The search produced 1737 studies, and we applied six criteria (e.g., the study has to be a peer-reviewed article, dissertation, or conference paper), which narrowed the number of studies to 100. After a reverse citation search, that number increased to 156 studies. Analysis of the 156 studies, the results reveal 12 emergent themes regarding the major findings from public alert and warning system research. The results also reveal eight emergent themes related to the policy and practical lessons. We then offer recommended topics for future research as well as outline some policy and practical recommendations. We conclude by summarizing the findings and discussing the limitations of the study.

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1 Introduction

Emergencies are events that cause huge losses to persons and/or property and require communities to respond with routine procedures and resources (Kapucu et al. 2022). An effective way to ameliorate the impact of emergencies on communities is for governments to issue alert and warning to the public before, during, and after emergencies. Public alert and warning involves providing "the necessary information to warn the public and effect the necessary actions that will lead to their safety and to deliver the messages to populations at risk of imminent hazards with the goal of maximizing the probability that people take protective actions and minimize the delay in taking those actions" (National Academies of Sciences, Engineering, and Medicine [NAS] 2018, p. 2). Alerts and warnings[1] can be issued by various entities, such as local, state, and federal governments, schools, and media stations for different types of emergencies, including but not limited to, tornadoes, floods, earthquakes, terrorist attacks, tsunamis, wildfires, and school shootings (NAS 2018). In recognition of the benefits of alerting and warning the public before, during, and after emergencies, in 2006, President George W. Bush signed into law the Public Alert and Warning System through Executive Order 13407 and Congress passed the Warning, Alert, and Response Network (WARN) Act (Bean et al. 2015). According to Bean et al. (2015) the goal of both legislations is "to create a more effective and reliable system to notify the American people in the event of war, terrorist attack, natural disaster, or other hazards" (p. 61).

One public alert and warning system used in the USA by the Federal Emergency Management Agency (FEMA) is called Integrated Public Alert & Warning System (IPAWS). IPAWS is a national system for notifying local communities about emergencies by sending important and life-saving information to mobile phones, TVs, radios, and National Oceanic and Atmospheric Administration's Weather Radios (FEMA 2022). There is significant evidence suggesting that public alert and warning systems can be effective in saving lives and reducing community losses from emergencies. For example, on July 26, 2012, a tornado ripped through Elmira, New York, damaging about 2000 buildings but with few injuries thanks to the wireless emergency alert (WEA) from the National Weather Service (NWS) that notified residents and enabled them to seek shelter in their basements before the tornado touched down (NWS, n.d.). Similarly, WEA was also credited to saving the lives of 34 people who were in the Sport World Complex Soccer dome in East Windsor, Connecticut. After receiving the WEA on her phone from the NWS, the manager of the complex evacuated everyone to a safer nearby building, thus preventing loss of lives (NWS, n.d.).

In recognition of the importance of public alert and warning systems in keeping society safe and reducing the impacts of emergencies, researchers have studied public alert and warning system extensively in the USA. Public alert and warning systems exist to "detect impending disaster, give that information to people at risk, and enable those in danger to make decisions and take action" (Sorensen 2000, p. 119). As a result of these numerous studies, there is a compelling need to synthesize this large body of knowledge

[1] "Alerts" indicate "something significant has happened or may happen; "Warnings" "typically follow alerts and provide more detail information indicating what protective action should be taken" ([NAS] 2018, p. 2).

to understand what has been studied, what the major findings are, and what practical lessons can be gleaned to further improve public alert and warning systems and protect communities. Past studies have reviewed public alert and warning systems, but updated studies are needed. Beginning in 1975, Mileti examined literature on the effectiveness of warning systems. Then, in 1990, Mileti and Sorenson examined approximately 200 publications on warning system. They found that (1) the warning impacts the extent to which the public responds to the warning, (2) the population being warned impacts the extent to which the public responds to the warning, (3) myths commonly accepted about emergency warnings are inconsistent with research findings, and (4) the alert method used to warn the public can impact its effectiveness. Finally, in 2000, Sorensen reviwed advances in public alert and warning systems over the past 20 years and found that while alert systems have improved, the extent to which communities are prepared varies significantly throughout the USA and across hazard type (ex. hurricanes v. floods v. tornadoes).

The goal of this study is to build off existing research and answer the following two questions: (1) What are the major findings from public alert and warning system research? (2) What practical lessons can be gleaned from public alert and warning system research to improve public alert and warning system research and practice? Answering these questions will identify knowledge gaps in public alert and warning systems literature and outline a future research agenda on public alert and warning systems. In addition, the review will recommend practical ways to improve how communities' alert and warn their residents before, during, and after emergencies.

The rest of the paper is organized as follows. Next, we discuss our methodology for identifying the public alert and warning system studies included in the review, then we present the results. The discussion of the results follows, including a discussion of research gaps and policy and practical lessons. We also presented some recommended topics for future research as well as outlined some policy and practical recommendations. Finally, we conclude by summarizing the findings and discussing the limitations of the study.

2 Methods

2.1 Selection criteria

Prior to conducting the keyword searches, the authors identified a set of criteria articles must meet to be selected for inclusion. The authors employed an iterative process for identifying the selection criteria. Originally, the authors determined that studies must meet the following four criteria:

(1) written in English;
(2) examine a community in the USA;
(3) peer-reviewed article, or proceeding paper; and
(4) focus primarily on public alert and warning systems in the context of social sciences. The fourth criteria's subject area specification was key to the selection process, because comprehension of risk and decision-making rests on public response (MacPherson-Krutsky et al. 2020; Mileti and Sorensen 1990). As the technology and data science of public alert and warning systems grow, understanding the *how* and *why* of the human element of response to these warnings requires the social science perspective (Sorensen 2000). Relevant social science disciplines include sociology, psychology, and politi-

cal science. Two additional criteria were added to narrow the scope of the systematic review and to ensure that the studies included in this review were evidence-informed (i.e., relying on data) and focused on public alert and warning systems and their use in the social science realm. These two criteria are:

(5) studies had to be empirical (i.e., use quantitative or qualitative data) and
(6) articles could not solely focus primarily on the technological applications of specific public alert and warning systems.

2.2 Search strategy

After weighing the pros and cons of various academic literary databases, such as Web of Science, Google Scholar, and Scopus, the authors elected to use Web of Science. This was mainly due to two reasons. First, Web of Science has a strong reputation of being one of the premier databases for conducting systematic reviews (Adriaanse and Rensleigh 2013; Norris and Oppenheim 2007). Second, Web of Science has advanced filtering capabilities, allowing researchers to easily narrow their search to only identify articles that are, for the purposes of this study, written in English and published in the USA. These filters help make the review process more efficient by reducing the number of articles to review for selection criteria determination.

The authors employed a seven-phase approach to determining the keyword search and conducting the search. Phase 1 consisted of the authors determining the keyword search. To do so, the authors tested a variety of word combinations that appeared in the abstract or title of the article until the first few pages of results generally met the selection criteria. The final keyword search was ("disaster" OR "emergency manage*" OR "crisis") AND ("alert" OR "warning" OR "notification" OR "notice" or "alarm"). This keyword search produced a total of 1737 articles.

Phase 2 and Phase 3 involved the authors measuring their inter-rater agreement of determining whether or not an article met the first four selection criteria. Specifically, in Phase 2, each author reviewed the title and abstracts of the first 50 articles individually to determine if each study met the selection criteria. This initial review produced an inter-rater agreement score of 58%. Given that this score does not meet the 70% threshold common in social science research (Multon and Coleman 2018), the authors met to discuss the discrepancies and repeated the process for articles 51–100 (Phase 3). This second time produced an inter-rater agreement score of 74%. Any disagreements among the authors were resolved through discussion and a majority vote amongst the four authors.

Phase 4 consisted of splitting up the remaining 1637 articles to individually review their abstracts and determine if the study met the selection criteria. After reviewing the remaining article abstracts, the authors determined 421 met the selection criteria. In Phase 5, the authors added the last two selection criteria to further narrow the scope of the review: (5) articles had to be empirical, meaning they relied on quantitative or qualitative data; and (6) articles that focused primarily on the technology of public alert and warning systems were excluded. Criteria 6 was added to remove any papers that were technical and reflected only specific warning systems and how they worked, the overall use and impact of public alert and warning systems in communities. The authors reviewed the abstracts of the 421 studies again to determine if they met the two additional selection criteria; the authors determined only 209 studies did. In phase 6, the authors reviewed the full-text versions of the 209 articles to confirm they met all the eligibility criteria. This confirmation process eliminated an additional

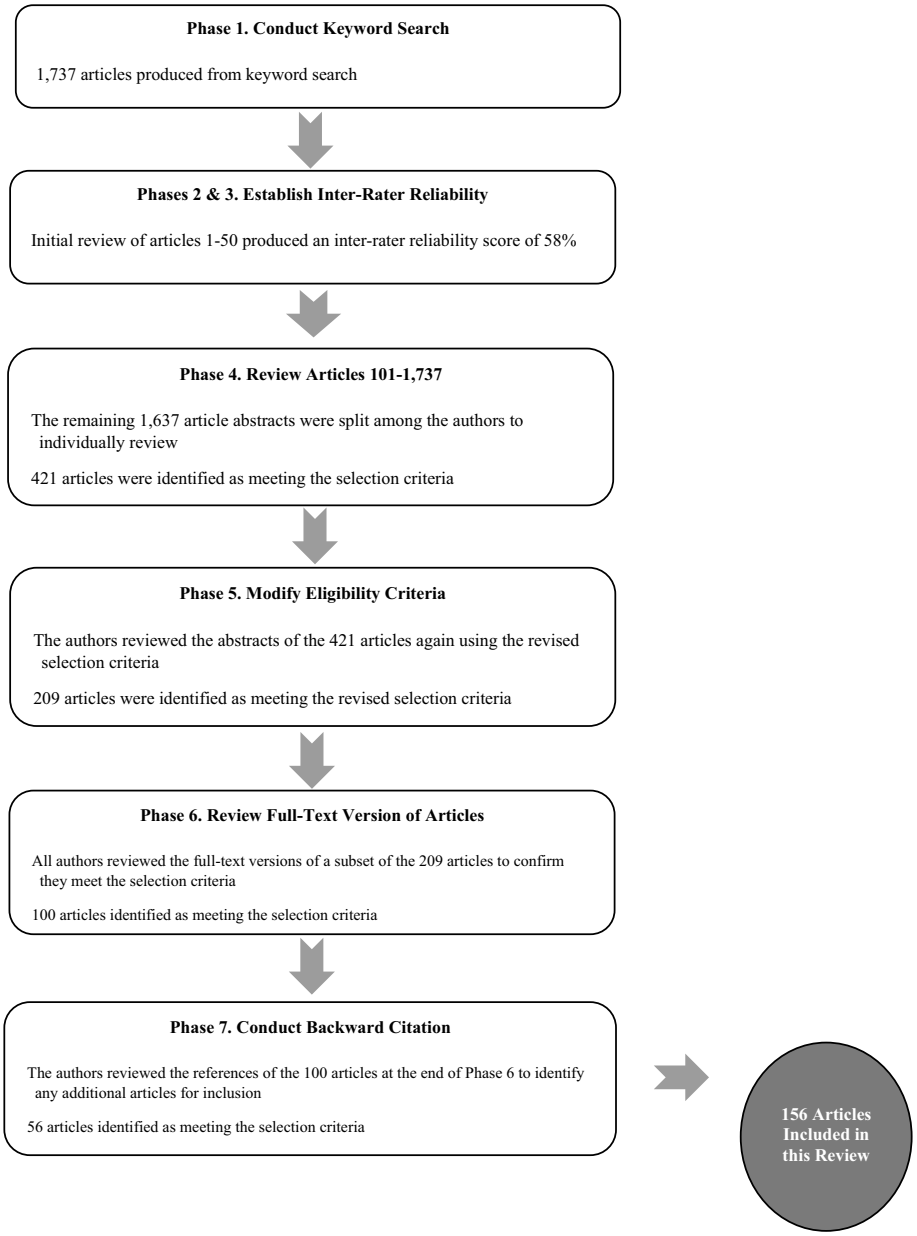

Fig. 1 Search strategy process

109 studies, resulting in 100 studies. Finally, in stage 7 the authors conducted a reverse citation search, where they reviewed the citations of each of the 100 studies for potential inclusion. Two researchers examined the title and abstracts of each study and phases 2–6 were repeated with studies that met inclusion criteria which were not previously included. A total of 56 additional studies were identified as meeting the selection

Table 1 Emergent themes and their frequencies

	Emergent themes	Frequency
1	Perceptions of alert and warning systems	20
2	The role of message characteristic in the decision to take protective action	18
3	Barriers and strategies for forecasting and communicating risk	10
4	Response to hazards, threats, false alarms	10
5	Influence of warning information on behavior	7
6	Predictors, preferences, and characteristics of warning information sources	7
7	Tornado warning reception, comprehension, and response	7
8	Channel preference for information	6
9	Evacuation information, awareness, preparedness, and departure	6
10	Predictors of alert and warning systems use	5
11	Warning and alert at night versus during the day	2
12	Hazard risk, exposure, and vulnerability	2
	Total	100

criteria. As a result, 156 studies are included in this systematic review (see Fig. 1). The 156 studies are listed in "Appendix 1".

We analyzed each of the 156 studies by examining their research question(s) and/or purpose(s) and major findings. Next, we grouped studies together based on their research question(s) and/or purpose(s) and major findings (Sadiq et al. 2019), and took a careful look at each group to determine a common theme. For example, studies that focused on how individuals perceive public alert and warning systems were group together under perceptions of alert and warning systems.

3 Results

3.1 Major findings from the public alert and warning system literature

The analysis revealed 12 themes. See Table 1 for the emergent themes and their frequencies. Below, we discuss the major findings under each theme. It is important to note that some studies had more findings than what is reported here. We focused on what we consider as the major findings (i.e., the findings that relate directly to public alert and warning systems in each of the 100 studies reviewed).

3.1.1 Theme 1: perceptions of alert and warning systems

The first theme, perceptions of alert and warning systems, has the highest number of studies with 20. We begin the discussion of studies included in this theme by looking at the study by Dunn et al. (2016). These researchers examined West Coast residents' perceptions of earthquake early warning (EEW) systems and found that individuals prefer that the federal and state governments pay for EEW systems, although a good number of the respondents said they do not mind paying for EEW systems. In general, there is a strong support for and interest in EEW systems among West Coast residents. Elsass et al. (2016) investigated the perceptions of staff and faculty about emergency notification systems and

found that a majority of the respondents wanted to be notified about emergencies on campus, preferred to be notified via email and texts, favored a tiered notification system, and requested more information about how to respond to campus emergencies.

Johnston (2014) investigated international students' understanding and response to warnings. The author found, among other results, that international students were neither aware of nor registered for the university's emergency notification system (ENS), and international students did not understand what shelter-in-place meant. Jauernic and Van den Broeke (2017) studied how undergraduates at a university in Nebraska, U.S. responded to and perceived tornado warnings. Their findings indicated, among others, that myths about tornadoes negatively influenced students perceptions of tornado risk, it was common among students to seek confirmatory information about tornado risk before seeking shelter, and some students said they would not seek shelter after receiving a warning. Their results also showed that students do not know precisely how to interpret tornado warning polygons and that sources of tornado knowledge for domestic students were parents/guardians and the school. For international students, sources of tornado knowledge were friends and self-education. Lastly, students were interested in learning more about tornadoes, but noted a lack of tornado resources on campus. Schildkraut et al. (2017) also studied students' perceptions of campus notification systems and found, among other results, that a majority of the students said the notification system was useful, received notifications via e-mail, and preferred not to receive an alert unless there was an actual emergency.

Jung et al. (2015) studied the comprehension levels of emergency notifications of Korean Americans living in New York City, U.S., and found that language is still a major barrier to the comprehension of emergency notifications among individuals with limited English proficiency. Madden (2015) studied how university publics perceived and responded to alert systems and found that university publics see information dissemination as the primary purpose of its alert systems and that crime, weather, and traffic were the hazards with the most alerts. In addition, the author found, among other results, that response to alert depended on an individual's perception of how the hazard might affect them, which is influenced by location and time. Ahn et al. (2021) explored individual perceptions of earthquake risks and the awareness of disaster prevention strategies in Sendai, Japan and Seattle, U.S. The results indicated that in both cities, the willingness to pay for an improved EEW was influenced by individuals' perceived effectiveness of the EEW in protecting the individual as well as their risk perceptions. Pelfrey (2021) studied the perceptions of emergency managers regarding the effectiveness and use of mass notification systems (MNS). The results indicated, among others, that jurisdictions vary in their usage of MNS, a weak relationship existed between population size and economic variables and enrollment in MNS, and MNS were perceived as an important communication modality.

Spence et al. (2022) explored the role of radios in crisis situations, and found among other results, that radio stations still engage in crisis training and preparedness and see the Emergency Alert System (EAS) as a relevant resource. Bostrom et al. (2018) investigated Florida coastal residents' perceptions of hurricane forecast and warning. Their results showed that prior hurricane experience among Florida coastal residents influenced the protective action taking to reduce the impact of hurricanes. Bui (2019) examined differences in the perceptions of social media use during Hurricane Maria between community members and emergency management officials. The author found that emergency management officials used social media to provide updates on Hurricane Maria prior to landfall, while community members used social media to share information after Hurricane Maria. DeYoung et al. (2019) studied individuals' perceptions of the Hawaii wireless emergency alert in 2018 and the protective action taken after receiving the warning. The results showed,

among others, that individuals believed the missile warning than they understood it, individuals also believed that others were more likely to die than themselves, and those that understood the warning decided quickly on the action to take.

Using experiments, Gutter et al. (2018) examined the relationship between severe weather watches and risk perceptions. Their results indicated that the decision by an individual to stop an ongoing activity during a severe weather watch is dependent on the length of the activity and the type of severe weather watch (i.e., thunderstorm watch, tornado watch, and a particularly dangerous situation (PDS) tornado watch). In addition, the authors found that individuals are more likely to stop an activity for a thunderstorm watch than for a tornado watch, and for a PDS tornado watch than for a tornado watch. They also found a negative and significant relationship between the severity of the watch and the continuation of an activity. Jon et al. (2018) studied how individuals perceive and respond to tornado warning polygons and found, among other results, that individuals made better judgments regarding polygon's numerical strike probability when polygons were presented in the context of radar images rather than when polygons were presented in isolation. Krocak et al. (2020) investigated individuals' perceptions of tornado warning outside of warning polygon bounds, and found among other results, that individuals' perceptions of a tornado warning outside of warning polygon bounds were influenced by proximity to the tornado warning, presence of other warning products, and the sources of information. Walters et al. (2020) studied NWS personnel's perceptions about how the public responds to tornado warnings, the factors impacting public response, and how NWS personnel's perceptions affect their communication, among other questions. The results indicated, among other findings, that NWS personnel were aware of the guidelines but still engaged in risky behaviors, and that public response was affected by proximity to the tornado, personal experience, and the influence of family and friends. The results also indicated that the NWS personnel were concerned about a lack of access to safe shelters by mobile home residents and the lack of specificity in tornado warning messages.

Ernst et al. (2021) studied public perceptions regarding the use and interpretation of the Storm Prediction Center (SPC) convective outlook. The results indicated that the public correctly identified the color codes, which are based on risk, and that the words used in the convective outlook confused the public. Johnston et al. (2005) examined individuals' perceptions regarding their understanding of tsunamis, the Washington State tsunami warning system, and their level of tsunami preparedness. The authors found that there was low to moderate levels of tsunami preparedness, the initiatives to increase public awareness of tsunamis were effective, the information about tsunami warning and preparedness was lacking, and the tsunami warning information was too generic. Edwards et al. (2011) analyzed feedback from participants regarding their use of ENS during a multi-agency functional exercise, and found that a little less than half of the participants picked up their devices to listen to messages in their entirety from all communication sources. Also, the authors found that the communication system used (Communicator! NXT system) was viewed favorably by participants, there were some communication issues with the ENS, and a quarter of the respondents said they received too few messages.

3.1.2 Theme 2: The role of message characteristic in the decision to take protective action

Eighteen studies belong to this theme. We start with the study by Casteel (2018) who used experiments to investigate the influence of impact-based tornado warning on individuals'

decision to shelter in place and found that individuals had higher sheltering intentions when the warning contained impact language that was stronger than a low intensity impact-based tornado warning. In investigating the influences of wireless emergency alert messages on protective action behavior, Kim et al. (2019) found that one in five experimental participants took protective action after receiving a text-based warning message. They also found that protective action taking is influenced by the language spoken at home, belief in the message, previous exposure and desensitization of emergency alert messages, and situational factors, such as looking for environmental and social cues about the hazard.

Furthermore, Rehman et al. (2020) examined the impact of text message alerts on miners' evacuation decisions and found that the alert message content, such as more detail about how urgent the situation was, increased the likelihood of miners evacuating. Casteel and Downing (2016) examined how individuals perceived the risk and severity of tornado warning messages from WEAs. Their results showed no significant differences in individuals' risk perceptions and severity for different warning message types. Sutton et al. (2018) studied how to improve the design of tsunami warning messages issued by public alert agencies by focusing on the message style and content. The authors found, among other results, that shorter messages did not provide enough information about the imminent hazard and the protective action needed to be taken in comparison to longer messages. Sutton and Wood (2016) used a focus group to understand how individuals interpreted and made sense of tsunami warning messages. Their results indicated that individuals knew the message was about an impending hazard, thought the message source was credible, knew what protective actions to take, and believed they would be safe it they took the recommended action.

Wood et al. (2018) studied the relationship between milling and public warning messages. Milling involves searching for information and confirming information about a hazard before taking protective action (Sutton and Wood 2016). Their findings indicated that although high information messages (longer messages) did not completely eliminate milling, they provided better outcomes than low information messages (shorter messages). Bonaretti and Fischer-Pressler (2021) investigated the problems associated with short message service (SMS) in a campus warning system. They found SMS warnings do not provide enough spatial awareness to user, such as the particular area where the hazard is taking place. Sutton et al. (2015a) studied the impacts of message content, network properties, and message style on the retransmission of terse messages across five different hazards—hurricanes, terrorist attacks, wildfire, flood, and blizzards. The results indicated that messages that contained information on protective action to be taken and hazard impact were more likely to be retransmitted. In addition, messages in all caps and those that encourage personal and societal resilience were more likely to be retransmitted.

Ripberger et al. (2015b) studied the impact of consequence-based messages on public responsiveness to tornado warnings. The authors found that high risk perceptions, knowledge about tornadoes, availability of a response plan, being female, and high fatalism led to protective action taking. Sutton et al. (2021) explored the relationship between message interpretation and sense making, and individual risk information processing in the context of tsunamis. Their results indicated that individuals engaged in interpretive sense making by relying on media accounts of tsunamis, and using personal experiences with waves and warnings from other hazards like tornadoes. Whitmer and Sims (2016) used a series of experiments to understand the relationship between fear language and protective action taking. Their results showed that fear language positively influenced risk perceptions of individuals as well as their behaviors, especially in a case where a hurricane's intensity is reducing. Eachus and Keim (2020) sought to understand trends in receiver preferences

for warning format of tweets. By comparing warning format of tweets from the weather accounts of two television stations, they found that individuals preferred messages that contained photographs and are geo specific. In addition, they found that individuals were more attentive to warning tweets that provided hazard and efficacy information.

Sutton et al. (2020) investigated whether visual attention, behavioral responses, and individual perceptions of EEW messages are influenced by video type and message content. Using a series of simulated EEW messages in a laboratory environment, the authors found that the strongest predictor of message perceptions and behavioral responses is prior exposure of individuals to protective actions. They also found that including informational icons in messages had limited impact on behavioral responses, visual attention, and individuals' perceptions of messages. In analyzing the tweets sent during Hurricane Irma to ascertain if they contained the five elements of warning systems outlined by Mileti and Sorensen (1990),[2] Wang et al. (2020) found that tweets can contain the five elements and the tweets that do tend to be retweeted more. In addition, their results show that not all five warning elements had a significant effect on retweet count. Perreault et al. (2014) investigated the effectiveness of the National Weather Service's new (scary) tornado warning messages by comparing it to the traditional tornado warning messages. The results indicated that individuals said they would follow the protective actions outlined in both types of messages, and that they perceived the traditional messages to be more credible than the scary messages.

Sattler et al. (2011) evaluated the effectiveness of text and e-mail warning messages in active shooter situations in a campus setting. Their results showed that warning messages sent through both media are effective in providing a coherent information during emergencies. Sutton et al. (2015b) investigated how public agencies use terse health-based warning text messages to communicate during floods. Their results show that the public health messages tweeted during the floods were retweeted by other organizations, the messages were mostly about drinking water, and that terse public health messages used instructional and explanatory style to convey information.

3.1.3 Theme 3: Barriers and strategies for forecasting and communicating risk

Ten studies are featured under this theme. Childs and Schumacher (2018) investigated the barriers encountered when forecasting and communicating cold-season tornado risk by professionals. Their results showed that the barriers encountered by professionals during cold-season tornadoes were similar to those encountered during regular tornadoes. In general, the barriers encountered by professionals included inconsistent messages, uncertainties surrounding the time when tornadoes occurred, and uncertainties about meteorology. Madden (2017) examined the timeliness of emergency notification decision-making of public safety officials as well as the challenges inherent in implementing their understanding of timely emergency notifications in campus settings. The author found that public safety officials grappled with whether to quantify timeliness or leave it vague to accommodate uncertainties during crises. Another issue was the different opinions of public safety officials about whether urgency or accuracy was more important in emergency

[2] The five warning elements to consider from Mileti and Sorensen's (1990) work are: the nature of the hazard, guidance on protective action to take, location of the hazard, time remaining to take protective action, and the risk information source.

notifications. The results also show that public safety officials' experience influenced how they interpreted timely emergency notifications.

Abukhalaf and von Meding (2021) sought to understand the challenges facing international linguistics minority students during Hurricane Dorian alert. The authors uncovered three challenges: false perceptions of the hurricane hazard and a deficit in disaster knowledge; the university used generic emergency communications for all students instead of tailoring the emergency communications to meet the needs of different groups; and inadequate disaster preparedness. First et al. (2021) studied the barriers to receiving warning information about nocturnal tornadoes and whether those barriers were related to tornado exposure and mental health impacts. The results indicated that barriers to receiving warning information include, but are not limited to, being asleep during the tornado, inability to hear tornado sirens, not having a smart phone to receive alerts, not having a NOAA weather radio for alerts, and language barriers. In addition, the results show that individuals who experienced barriers to receiving warning information were more likely to say they were exposed to tornado impacts (e.g., injury) and experienced adverse mental health outcomes (e.g., depression).

Abukhalaf and von Meding (2020) investigated communication challenges confronting international linguistic minorities in a campus setting and found, among other results, the following challenges: lack of basic weather hazard knowledge among the linguistic minorities, use of a unified communication system that is not tailored to the needs of different groups, over-communication, and lack of coordination. In addition, the campus used social media platforms that were not being used by the linguistic minorities for emergency communication, and broadcast emergency communication in English, making difficult for those that did not understand English well to comprehend the message. While studying how to overcome barriers to social media use, Grace (2021) found that there were no tools to process social media data, there was a lack of trust in the information collected from citizens, and there was insufficient staff to use social media tools. Liu et al. (2020) studied the warning communication strategies for tornadoes used by the NWS, and found, among other findings, that forecasters used the following strategies: avoid using fear appeals, humanize the NWS, and visualize risks.

League et al. (2010) investigated how emergency managers make decisions regarding tornado warning communication. Their results indicated that emergency managers use various weather product to acquire information and used spotters to verify information collected. In addition, emergency managers' mostly used sirens to warn the public about impending tornadoes. Lerner and Bertram (2014) sought to understand the common issues in emergency public information; their findings revealed several issues, such as inaccurate warning messages and news releases, a lack of information coordination among jurisdictions, incomplete internal communication, and the provision of incomplete information to individual callers. Lindell and Prater (2010) studied tsunami preparedness in the Pacific Northwest, and found several issues, such as inconsistent and conflicting messages and misinterpretation of warning messages.

3.1.4 Theme 4: Response to hazards, threats, and false alarms

Ten studies belong to this theme. By false alarms, we mean if an alert or warning was issued for a particular hazard (e.g., a tornado) but the hazard did not occur (Krocak et al. 2021b). Cuite et al. (2021) examined the effect of hurricanes versus Nor'easters on perceived severity and protective actions and found that individuals perceived the former to

be more severe than the latter and that the former led to taking protective action than the latter. Chen and Cong (2022) studied how disasters with different lead times affected individuals' perception of the efficacy of their protective actions. Their results indicated a positive relationship between response efficacy perception and preparedness, short lead-time disasters were less likely to lead to preparedness compared to longer lead-time disasters, and response efficacy perception influenced preparedness for short lead-time disasters in older adults but not among younger adults. Jones and Silver (2020) studied anxiety of twitter users following the Hawaii false missile alert in 2018 and found, among other results, a significant increase in anxiety among Hawaiians that persisted long after the false missile alert was dispelled.

Krocak et al. (2019) explored the relationship between advance notification of protective action for tornadoes and how individuals respond. The authors found, among other results, that individuals responded the same way irrespective of the length of advance notice, and most people engaged in preparation and monitoring, which were not influenced by the length of advance notice. In addition, the authors found that individuals were uncertain about what to do when given 8-h advance notice than when they were given four-hour advance notice. Lim et al. (2019) examined the impact of false alarms on public response to tornado alerts. The authors did not find empirical evidence suggesting that tornado false alarms create a complacent public. In addition, the authors found that "… the higher individuals perceive false alarm ratios and tornado alert accuracy to be, the more likely they are to take protective behavior…" (p. 549). Liu et al. (2019) studied mobile home residents' understanding and response to tornado warning. Using residents of fixed homes as a comparison group, the authors found that mobile home residents had a lower preparedness level, lower efficacy regarding sheltering, lower access to shelter, and lower trust in government provision of adequate shelter compared to fixed home residents.

Walters et al. (2019) investigated the patterns of intended response to tornado warnings. In general, their results suggest that different groups of people respond to tornado warnings differently. Lindell et al. (2015) studied how households responded to the 2009 American Samoa earthquake and tsunami and found, among other results, that individuals' first thought of a possible tsunami occurring was based on the earthquake shaking and knowledge of the earthquake leading to a tsunami. The results also indicated that broadcast media (e.g., television) was the first source of information although, radio, face-to-face communication, and phones were also prominent. Gregg et al. (2004) studied community members' preparedness for lava flows in Kona, Hawaii, and found that little information was provided to residents about how to respond to volcanic eruptions or warnings about volcanic eruptions. Wong-Parodi and Feygina (2018) studied the factors that affect (mal) adaptive responses to natural disasters, and found that individuals exposed to immediate risk took protective action, climate and environmental factors influenced preparation, and mental health and self-efficacy were positively correlated with taking protective action.

3.1.5 Theme 5: Influence of warning information on behavior

This theme, which features seven studies, examines how the provision of public alert and warning information affected individuals' behaviors. Casteel (2016) used an experimental approach to investigate the NWS's Impact-Based Warnings (IBWs) on individuals' behavioral intention to take protective action. They found that the IBWs led to behavioral changes of individuals. Liu et al. (2017) studied whether the inclusion of maps and warning messages can lead to behavioral changes. The authors found that the inclusion of maps

only marginally improved message understanding. Cain et al. (2021) examined the role of maps in conveying warning information to college students. They found that maps alone did not lead to the expected behavioral response, but when combined with more specific warning messages elicited the expected behavioral response. In studying how the communicative behaviors of individuals affect how they respond to tornadoes, Liu et al. (2019) found that the expanded social-mediated crisis communication model successfully predicted individuals' conformity with government's guidance during tornadoes.

Ripberger et al. (2015a) studied the relationship between individuals' perceptions of the accuracy of tornado warning, credibility of the warning, and individuals' response to the warnings. The authors found, among other results, that trust in the NWS increased the likelihood that individuals took protective action in response to a hypothetical scenario. Bean et al. (2022) studied how wireless emergency alerts can help curtail the spread of COVID-19 through changes in people's behaviors, and found that wireless emergency alerts can help to reduce the spread and number of COVID-19 deaths when combined with an order from authorities. Using the storms that occurred in Oklahoma in 2016 as a natural experiment, Robinson et al. (2019) explored the relationship between the intensity of the storms and the sharing of information about the storms by citizens. Their results indicated that the intensity of the storms did not affect the tendency of individuals to engage in citizen-to-citizen information sharing, among other results.

3.1.6 Theme 6: Predictors, preferences, and characteristics of warning information sources

Seven studies fall under this theme. Cong et al. (2017) examined the predictors of the number of warning information sources, and found, among other results, that being older and having an emergency plan are predictors of warning information sources. Babvey et al. (2021) investigated the role of social media in connecting disaster victims to relief agencies. Their results showed that messages from governments and media diffused faster than messages from disaster eyewitnesses. Sansom et al. (2021) examined the influence of warning information source on an individual's willingness to follow emergency guidelines (i.e., shelter-in-place) and found a significant positive relationship between hearing emergency communications from friends and families, and social media and willingness to shelter-in-place. Furthermore, Zhang et al. (2021) studied the fairness of disaster information disseminated by emerging influential contributors in different areas with varying degrees of vulnerable populations. Their results indicated a bias against vulnerable population with respect to disseminating situational awareness information by emerging influential contributors.

Wehde et al. (2019) examined the relationship between location and the sources individuals receive warnings from. The results indicated that the preferred warning source for individuals away from home and those at home for authority-based media sources were automated texts and television, respectively. Additionally, Luo et al. (2015) investigated the relationship between the number of warning information sources and decision making in the context of tornadoes, and found that having multiple warning information sources increased the likelihood of taking protective action during tornadoes. Finally, Sheldon (2018) examined students' perceptions of emergency alert communications, and found that student considered warning messages via text messages to be more serious than warning messages from social media. They also found that students use word-of-mouth as a means of disseminating warning messages and use phones or text messages to notify their

immediate family of a crisis. Also, during a shooting, students preferred to be notified via a phone call, but preferred text messages for notification during a tornado.

3.1.7 Theme 7: Tornado warning reception, comprehension, and response

There are seven studies under this theme. Krocak and Brooks (2021) studied the influence of type of weather watch on the quality of tornado warnings and found that the quality of tornado warning depended on the type of severe weather watch. Krocak et al. (2021b) used information from the NWS verification database to investigate tornado warning performance. Their results indicated that when multiple tornadoes occurred on a convective day, forecasters warned people about the first tornado than they did with the middle and last tornadoes. Sherman-Morris et al. (2020) studied how blind people receive and respond to tornado warnings. The authors found, among other results, that effective use of tornado warning information is dependent on having a good verbal description of the message.

Paul and Stimers (2012) investigated the reasons for the high fatality from the 2011 Joplin tornado and found, among other results, that one of the reasons for the high fatality was that some individuals ignored the tornado warning. Furthermore, Nagele and Trainor (2012) examined the relationship between geographic specificity of a home's location and protective action taking. The authors found, among other results, that when the NWS's warning polygon is 50% smaller than the county where they are located, individuals were more likely to take protective action, including sheltering. Ripberger et al. (2019) examined tornado warning reception, comprehension, and response, and found, among other results, that individuals who lived in areas with low tornado risks had lower levels of reception and comprehension compared to those that live in areas with higher tornado risks. In addition, demographics like age and race influenced tornado warning reception, comprehension, and response. Lastly, Ripberger et al. (2020) studied differences among communities in terms of their tornado warning reception, comprehension, and response. The authors found, among other results, differences across communities in how they receive, comprehend, and respond to tornado warnings, and these differences were generally due to tornado climatology.

3.1.8 Theme 8: Channel preference for information

This theme has six studies. We start with a discussion of the study by Guillot et al. (2020) who sought to understand the factors that impact decision-making during weather emergencies. The authors found, among other results, that respondents mentioned broadcast television/news as their preferred source of receiving emergency information. They also mentioned television and radio stations. Chiu et al. (2013) investigated the mortality caused by a tornado outbreak in Alabama on April 27 2011, and found that word of mouth was the most used source of communication of warning information. While studying how emergency information diffuses during a crisis involving a gunman on campus, Egnoto et al. (2013), found that those that knew about the crisis early were more likely to share information and were more trusting of the information received from mass media and through interpersonal messages than those that knew about the crisis late. In addition, the early knowers were more likely to share information than the late knowers.

Furthermore, Mueller and colleagues (2010) studied emergency communication among individuals who are deaf and found that deaf individuals preferred alerts containing American Sign Language video over text-only messages or segmented videos (videos put

together from modular segments). Radford et al. (2013) while studying tropical cyclone warning graphics found that the color-probability-cone was the most preferred graphic. Finally, DeYoung et al. (2016) studied channel preference for information and the demographic factors that predict the number of channels individuals use for collecting information. Their results showed that individuals still relied heavily on television and radio for hurricane evacuation information, Whites relied on one information source than non-Whites, females preferred to collect information from multiple sources than males, and younger individuals preferred more information channels than older individuals.

3.1.9 Theme 9: Evacuation information, awareness, preparedness, and departure

This theme comprises six studies. Collins et al. (2017) studied the influence of social connections on evacuation decision making during a hurricane warning, and found no difference between evacuees and non-evacuees regarding the density and diversity of their networks. In addition, the authors found that those that evacuated perceived their networks as less dependable, and those that did not evacuate perceived their networks as more dependable. In addition, Grajdura et al. (2022) used an agent-based simulation model to understand evacuees' behaviors during the 2018 Camp Fire evacuation in Northern California. The results indicated that the longer the evacuation travel time, the lower the smartphone use, the higher the delay in awareness, and the lower the vehicle access. Grajdura et al. (2021) investigated the predictors of awareness time, evacuation preparation time, and departure time during no-notice wildfire evacuations and found that awareness time was influenced by seeing the fire, familiarity with evacuation procedures, higher incomes, owning a smartphone, etc. In addition, the results indicated that being a long-time resident was associated with longer preparation and departure times.

Furthermore, Strawderman et al. (2012) examined the effectiveness of reverse 911 as a warning system, and found that reverse 911 was a significant predictor of an individual's decision to evacuate. Auld et al. (2012) used a model to predict how a transportation network will respond to the demand caused by evacuation warnings from the government. Their results indicated that individuals were more likely to evacuate when they saw others evacuating, evacuate to friends and families or hotels if the event risk is high, and evacuate to shelters for moderate-risk events. Finally, Zheng et al. (2020) investigated the influence of disaster and evacuation information from multiple sources on individuals' decision making regarding evacuations. The results showed that information from sources that were perceived to be more credible had a larger influence on evacuation decision making than information from sources that were perceived to be less credible.

3.1.10 Theme 10: Predictors of alert and warning systems use

Five studies were identified under this theme. Ada et al. (2016) studied the factors that influence the intention to use emergency notification system (ENS) during emergencies on a college campus. The authors found that students' use of social network sites (SNS) to receive emergency information was affected by perceived benefit, social influence, and media richness. The authors also found that the use of short-message systems (SMS) was impacted by perceived benefit and trust in the information. Similarly, in their study about understanding rapid compliance with campus ENS among college students, Rogers et al. (2021) found that attitudes and subjective norms were consistent predictors of rapid compliance with campus emergency notifications among college students.

In addition, Johnson (2012) observed that the use of ENS on campus is influenced by attentiveness to the information provided, personal motivation, and the method of notification. In studying the social impacts of the heat-health watch/warning systems, Kalkstein and Sheridan (2007) found that sex, race, age, were social factors that determined whether or not individuals responded to warnings. Finally, Brotzge and Donner (2015) studied the policy for activating outdoor sirens during severe weather, and found among other results that, there was no significant relationship between siren activation policies and geographic location or type of jurisdiction. In addition, the results indicated that perceived hazard, mitigation, and response capabilities of jurisdictions influenced siren policies.

3.1.11 Theme 11: Warning and alert at night versus during the day

Two studies fall under this theme. Mason et al. (2018) examined who the recipient of tornado warning at night are, and found, among other results, that tornado warnings during the day were more likely to be received than tornado warnings at night. In addition, the authors found that television and cell phone alerts were the most common sources of warning information for tornadoes during the day and at night, respectively. Krocak et al. (2021a) analyzed individuals' confidence in receiving and responding to tornado warnings at different times of the day. The authors found, among other results, that individuals were not confident about receiving tornado warning overnight, especially between 12 and 4 am, and that confidence during this period is influenced by age, race, awareness of weather events, weather sources, and the number of nocturnal tornadoes in the area.

3.1.12 Theme 12: Hazard risk, exposure, and vulnerability

This last theme is composed of two studies. Baudoin et al. (2016) examined ways to improve disaster risk reduction via community participation in early warning systems (EWS). They argued that it is imperative to make EWS grassroot-driven by vulnerable communities rather than top-down, and that it is important to tailor EWS specifically to the needs of each group within a community to ensure that inherent inequalities are not exacerbated. Strader et al. (2021) assessed tornado risk, exposure, and vulnerability in the NWS County Warning Area (CWA) and found different regions in the CWA had varying degrees of tornado risk, more unwarned tornadoes, and higher false warnings. They also found that socially vulnerable CWA had shorter lead time for tornado warning.

3.2 Policy and practical implications from public alert and warning system literature

The state of literature on public alert and warning system provides significant opportunities for policy and practical recommendations. The major themes of our findings align with the following:

(1) inclusion and use of non-traditional media use (social media, peer-to-peer),
(2) utilizing targeted alerts based on the population and geographic regions,
(3) education campaigns centered around awareness of warning systems,
(4) risks and specific actions to take,
(5) how wireless emergency alerts (WEAs) can better incite protective actions, and

(6) the reliance on collaborative efforts to get the warning information and education spread across potentially impacted communities.

While many of the studies were focused on specific disasters, there are practical implications that can be applied across emergencies and different types of alerts. The impacts of warnings need to be further studied in order to understand the policy changes that may need to occur, and the practical implications of their use for effectiveness (Strawderman et al. 2012).

3.2.1 Multi-channel emergency messaging avenues

The overarching policy inclusion goal for many articles on this subject was the inclusion and utilization of 'multi-channel' avenues for emergency messaging (Egnoto et al. 2013; Perreault et al. 2014). This means the utilization of multiple methods to send alerts and warnings to the public (e.g., tv/radio broadcast, phone and email technologies, etc.). One of the more commonly used technologies for warnings are short message service (SMS) and simple notification services (SNS) (Ada et al. 2016; Bonaretti and Fischer-Pressler 2021; Robinson et al. 2019; Zheng et al. 2020). However, more importantly, the information when utilizing SMS and SNS must be actionable, relevant, verified, and provide clear protective action recommendations (Grace 2021; Kim et al. 2019; Zheng et al. 2020). Apart from wireless messaging, social media has emerged as a necessary component for public alert and messaging in the last decade (Bui 2019; Guillot et al. 2020; Jones and Silver 2020; Mason et al. 2018). Studies have shown the impact of social media on educating vulnerable communities, reaching wider audiences with key "hashtags", and the importance of utilizing community organizations' social media to reach audiences (First et al. 2021; Liu et al. 2020; Sutton et al. 2015). While the importance of social media has undoubtedly increased in recent years, and use of advertisements is growing, Lindell et al. (2020) reported that social media was still used far less (an average of 1–2 times/day) than local or national news (an average of more than 6 times/day) in 2017 Hurricane Harvey. Lindell et al. (2021) found that local news media are still the most common information channels in hurricanes. As disasters continue to grow and size and scope, so must our emergency messaging avenues.

3.2.2 Audience-centered targeted messaging

Another major insight that emerged from the literature for policy and practical considerations was the curating and targeting of communication to appropriate audiences (Ada et al. 2016; Pelfrey 2021; Rogers et al. 2021). Similar to the use of multi-channel methods of providing information, understanding how people prefer to receive their emergency information based on their communication patterns and lifestyles, whether it involves using meteorologists or technologies, can impact the acceptance, use and milling habits (Johnson 2012; Liu et al. 2019a, 2019b). One sentiment echoed by many scholars was ensuring that no matter the method of communication, standardized templates using non-technical terms, maps along with messages, and universally common graphics. However, Lindell (2020) did find that even within the 'commonness' of graphics, demographics played a part in interpretation, as well as an inherent understanding of the maps themselves. These methods are still necessary because consistency impacts how the information is received (Cain et al. 2021; Ernst et al. 2021; Jung et al. 2015; Radford et al. 2013; Sattler et al. 2011;

Sherman-Morris et al. 2020). This lends to the argument that the clarity of the emergency message, including sequenced messages that provide exact directives for actions, have a positive impact on whether people accept and act on information that is disseminated to them (Jauernic and Van den Broeke 2017; Kalkstein and Sheriden 2007; Sutton and Woods 2016; Walters et al. 2019; Wood et al. 2018). For instance, using imperative sentences to provide surety to the message, or building an emergency notification that uses related (and longer) messages that provide more detail and possible steps to take, provide amplification of and clarity to the message (Elsass et al. 2016). Rogers et al. 2021; Sutton et al. 2015; Sutton et al. 2018; Wood et al. 2018).

3.2.3 Curated and detailed information, education, and programming

Building on the understanding of the target population, Cuite et al. (2021) indicated that emergency messages should be crafted with a 'starting point' of the audience in mind. This means ensuring that there is a tiered notification system based on the severity of the impending emergency, and the diversity of the types of messaging based on the diversity of the community (Abukhalaf and von Meding 2021; Ahn et al. 2021; Schildkraut et al. 2017; Wang et al. 2020). However, Eachus and Keim (2020) noted that social media should be used with caution to ensure that the 'false alarm' effect does not disengage followers. These implications echo the sentiment that technical information and campaigns should be tied to social campaigns in order to tailor how different demographics receive and understand information (Collins et al. 2017; Cong et al. 2017; Ripberger et al. 2015; Rogers et al. 2021). For instance, Sutton et al. (2021) found that people wanted to know information about an emergency's potential impacts, such as the likelihood of injury/death or property damage during a specific event. Emergency management agencies should actively work with their communities to curate information, education, and programs accordingly (Baudoin et al. 2016; Collins et al. 2017; Cong et al. 2017). This includes more common standards and protocols for sirens (Brotzge and Donner 2015).

3.2.4 Geographic visuals

Along with targeted and clear communication, many scholars highlighted the positive impacts of providing better geographic awareness/impact area maps as a part of public alert and warning messages (Bonaretti and Fischer-Pressler 2021; Grace 2021; Liu et al. 2017; Sutton et al. 2018). Liu et al.'s (2019) study found that the utilization of 'in this area' was not specific enough for many respondents when thinking about taking protective action if a tornado warning was issued. The use of more specific visuals to accompany warnings was reiterated by many studies (Cain et al. 2021; Jon et al. 2018; Krocak et al. 2020; Sutton et al. 2018; Walters et al. 2020). As emergency management agencies examine how they send out emergency notifications with actionable information for certain events, they should consider the potential inclusion of visuals that provide more precision of the impact area. It is critical to note however, that people's interpretation of these geographic visuals inevitably vary based on perceptions and understanding of the maps themselves (MacPherson-Krutsky et al. 2020; Lindell 2020). MacPherson-Krutsky et al. (2020), discussed this understanding, or "comprehension" with a study of college students, and did find that even for basic map understanding, the participants made errors in understanding the displays, unless the image had a legend always visible for reference. What this indicates is that having helpful technical features (e.g., legend) are a necessity for geographic visuals for public

alerts and warnings, but further studies must be undertaken with a greater representative sample.

3.2.5 Weather emergency alert system enrollment

A significant practical implication of the use of 'other' methods of public alert and warning was the focus on peer-to-peer engagement or WEAs. For the peer-to-peer or word-of-mouth communication, studies found that many groups were engaged in warning their networks, which spread information faster (Chiu et al. 2013; Wehde et al. 2019). Emergency personnel noted that the ease of subscription or enrollment in WEA service was an important consideration for getting more people signed-up for the alerts. Many scholars found that the 'opt-in' system for many of the alerting systems that utilized a "user-initiated registration" (Schildkraut et al. 2017, p. 618) could lead to low numbers of registration or outdated contact information. Making it easy to subscribe to WEAs, educating about the system, or simplifying the enrollment criteria for notification systems were beneficial methods to increase the reach of notifications (Ada et al. 2016; Pelfrey 2021; Schildkraut et al. 2017). One study even suggested an 'opt-out' system rather than 'opt-in', where the notifications would automatically be sent out, unless someone went into the system to remove their information (Egnoto et al. 2013). Most studies were focused on a university setting, where populations like students can be more vulnerable, and campus emergency management is tasked with protecting those that live on campus, as well as those that commute (Sattler et al. 2011). Another issue with WEAs is that technology can go down at any moment, and should not be used as a panacea for all emergency communication—because not everyone may have access to mobile technology (Bean et al. 2022; Grajdura et al. 2022; Johnson 2014; Luo et al. 2015). The studies that called for more clarity and conciseness of warning information that is disseminated specifically noted that WEAs need to maintain that same trend of providing clear directives for action (Casteel and Downing 2016).

3.2.6 Public alert and warning education and community diversity

The education and programming of warning information should intertwine with community organizations (Baudoin et al. 2016). Public education and awareness about alert and warning systems and emergency plans must be considerate of the population of the area, especially with the growing ethnic diversity of communities that impacts their beliefs and processes (Johnston et al. 2005; Jung et al. 2015; Kim et al. 2019). A few studies looked at the impacts of language, cultural, race, income and age on residents' understanding of and action-taking for disaster scenarios and found that there should be targeted education campaigns even across these minority areas and for those with language barriers (First et al. 2021; Grajdura et al. 2021; Guillot et al. 2020; Jung et al. 2015). Lindell and Perry (2004) found that because of these demographic variables that can impact how a warning is heeded, "it is advisable to identify the variables that intervene" (p. 88). These variables are nuanced and can include not just singular differences, but how those impact other demographics. For instance, they talked about gender impacts on warning responses, along with family status (i.e., single, married, etc.). Or, how age and income together impact evacuation outcomes. Working with multicultural organizations and engaging in equitable practices to provide information to vulnerable populations includes the understanding and expectation that emergency management is not one-size-fits-all approach (Abukhalaf and von Meding 2021; Whitmer and Sims

2016; Wong-Parodi and Feygina 2018; Zhang et al. 2021). As emergency management policies are updated, understanding the demographics of a community, along with the needs of the population for alerts and warnings should be a key consideration in communicating information.

3.2.7 Multiple awareness and education methods

Along with the overarching goals for practice implementation that can spur more effective implementation of public alerts and warnings, the literature also emphasizes specific education and awareness measures. Scholars like Chiu et al. (2013) and Cong et al. (2017) noted that the most basic should be to encourage the public to have their own emergency plans and familiarize themselves with those that exist within their governments. From the standpoint of emergency management professionals, having multiple awareness methods and providing education about the alert systems in place is a growing necessity because warning systems can be integrated for more widespread flow of information across different channels (Babvey et al. 2021; Guillot et al. 2020; Madden 2015; League et al. 2010; Walters et al. 2020). For the notification of the alert systems in place, this can include redundancies, such as regular tests and drills that normalize and reiterate the alert systems, making it a requirement for registration (for students), and engaging local weather forecasting offices for geographic specificity (Abukhalaf and von Meding 2020; Paul and Stimers 2012; Rogers et al. 2021; Strader et al. 2021). The goal of awareness is to build public buy-in into disaster event impacts, and this requires community engagement, connectivity, trust and routines/procedures that reiterate responsive behaviors to alerts and warnings that are issued (Krocak et al. 2019, 2020; Ripberger et al. 2019). A majority of the studies focused on the education of alert and warning system, amplifying the risk perception of certain disasters, and university students (Cain et al. 2021; Chen and Cong 2022; Sheldon 2018). Examples of this include using prior examples to engage people to take protective action and targeting orientation and freshman life-learning courses (Johnson 2012; Walters et al. 2019). Other ideas that emerged in the literature were the use of advertisements on tv and radio, as well as billboard advertisements to share additional information (Gregg et al. 2004; Lerner and Bertram 2014).

3.2.8 Collaborative efforts across sectors

Lastly, the literature emphasizes the need to work collaboratively. Whether it is at a university level or community wide, specific disaster or all-encompassing, emergency management policies going forward should be mindful of and encourage collaborative processes to prepare and respond. Elsass et al. (2016) specified that having faculty and staff buy-in to the alert system can motivate students to do so. First et al. (2021) noted that building partnerships is key to creating policies and practices that are equitable, while Sansom et al. (2021) noted that outreach efforts in this manner can lead to better health and safety outcomes. Some studies provided examples of collaboration, such as uniformed staff (e.g., police), weather forecasters, and organizations with high credibility (Liu et al. 2019; Zheng et al. 2020). Including different organizations and people to ensure public alert and warning information is understood and heeded can lead to better outcomes, and in the long run, improved safety.

4 Discussion

In this section, we recommend some topics that future research could consider based on our understanding of the current state of research on public alert and warning systems. We also recommend some public alert and warning lessons for policy and practice.

4.1 Future research recommendations

The themes and their discussion above provides significant insights on the public alert and warning system research topics that researchers have studied so far as well as the major findings from public alert and warning system research.

4.1.1 More studies on public alert and warning systems for man-made hazards

Most of the studies in this review focused on natural hazards. A majority of these studies examined public alert and warning systems for tornadoes mostly; some studies looked at hurricanes, tsunamis, severe thunderstorms, nor'easters, earthquakes, wildfires, flooding, and volcanic eruption. A very small number of studies in this review focused on man-made hazards like school shootings. Huang, Lindell, and Prater (2016) did provide a longitudinal study on the hurricane evacuation decisions across a period of 23 years, with data from 38 hurricane situations. While this study was a longitudinal look at specific natural hazards, the meta-analysis was focused on the actual evacuation, or hypothetical decisions that would be made. Huang, et al. (2016) stated the need for additional research to highlight how people process hurricane warning messages. There is an urgent need for additional research exploring public alert and warning systems for man-made hazards, such as active shooter incidents, oil spills, civil unrests, riots, etc. Conducting research on these man-made hazards can help to improve our systems for alerting and warning the public when these hazards become emergencies or disasters.

4.1.2 More studies on public alert and warning systems for nighttime emergencies

Among the studies reviewed only two focused on nighttime emergencies, and specifically tornadoes. Nighttime emergencies typically catch people unaware, and as a result, wreak havoc on communities. For instance, tornadoes that occur at night cause twice as many fatalities as tornadoes that occur during the day (Mason et al. 2018). Despite the potential for huge loss from emergencies occurring at night, little research has been done on this topic. For example, in our review of 100 studies, only two focused on nighttime emergencies. This is why other researchers have called for additional studies (e.g., Mason et al. 2018). Future research can examine how individuals respond to alert and warning systems and take protective action for nighttime emergencies. Future research can also investigate why individuals are not confident about receiving emergency alert at night according to the study by Krocak et al. (2021a).

4.1.3 Research on the impact of the pandemic on public alert and warning systems

The COVID-19 pandemic has caused unprecedented impact on the global community, including the USA. (Sadiq and Kessa 2020). No study among those reviewed focused on the relationship between the pandemic and public alert and warning systems. The

pandemic has created a huge research gap that must be filled. Several potential topics in need of answers include, but are not limited to the following. What is the impact of the pandemic on individuals' response to public alert and warning for other emergencies? Does the pandemic influence individuals' perceptions regarding the efficacy of public alert and warning systems? What are the benefits and costs associated with the implementation of a public alert and warning system at the local, state, and national levels in the USA.?

The combined risk of the pandemic (and how the disease is transmitted) with disasters that require decisions like evacuation, created newer alert and warning challenges. Pei et al. (2020) built a hypothetical hurricane model to test the impacts on Covid-19 case numbers, and found that inevitably the numbers went up. They added that public alert and warning systems would have to account for areas with low transmission and be able to direct evacuees more efficiently, which requires the use of "trusted sources of information" to send out more curated evacuation information (p. 9). With the increasing polarization of how to respond to the Covid-19 pandemic, it is critical that the perceptions of public alert and warning systems are held to facts and the reiterated goal is to keep people safe, while reducing exposure to the virus. This pandemic has and will continue to impact the evolution of public alert and warning systems to further study the potential impacts of this combination of disasters together, as well as consider how decision-making impacts the perception of those alerts and warnings.

4.1.4 Additional research on public alert and warning systems decision-making

Existing research suggests that governments do not uniformly issue public alert and warnings. Alert and warning systems, including the speed of issuing and disseminating warnings, varies both by type of warning system and by type of emergency (Mileti & Sorensen 1990; Rogers & Sorensen 1988). Some hazards, such as a hazardous chemical release, require quick responses so that individuals know whether it is safe to evacuate or shelter in place, while other hazards, such as flood events often have more time for dissemination and preparation, which could explain some differences in the speed of public alter and warnings (Mileti & Sorensen 1990; Sorensen et al. 2004). However, other research suggests that even with one type of hazard, there is a wide range of when warnings are disseminated. For example, Sorensen et al. (2020) found that between 1979 and 2008, local hurricane evacuation warnings spanned a range of 85 h, after the National Hurrricane Center issued a hurricane warning. In some instances warnings were issued before a hurricane warning, but in other cases warning were not issued until over 70 h (nearly three days) after the hurricane warning. Rogers and Sorensen (1988) suggest that organizational characteristics, such as the speed of organizational decision making can also impact how quickly warnings are issued, but more research is needed on how decisions regarding issuing public alert and warning are made. A better understanding of the decision-making process can help to improve public alert and warning systems at the local, state, and national levels. For example, by studying the decision-making process, inefficiencies, redundances, etc., can be identified and improvements made. Questions that can be studied on this topic include, but are not limited to the following. What factors influence the ability of a decision maker to issue alert and warning information in a timely manner? What are the obstacles that cause delay in relaying alert and warning information to the public?

4.2 Policy and practical recommendations

Based on the systematic literature review of the articles undertaken, there were eight themes that emerged on policy and practical recommendations for future consideration. We discuss these policy and practical recommendations below. In regard to multi-channel avenues to reach the public with alerts and warnings, emergency personnel should continue to utilize social media, especially in partnership with organizations that are embedded within their communities. This ensures that there are multiple methods of educating the public and normalizing response to alerts (Lindell and Prater 2010; Liu et al. 2020; Perreault et al. 2014). Additionally, as alert and warning messages are being created for the public emergency personnel should consider how different groups (e.g., students, the elderly, non-English speakers, etc.) within the public prefer to receive messages. While some prefer the traditional broadcast, others might prefer text messaging or peer-to-peer dissemination. Concurrently, curated messages should also engage the public by providing detailed information about the situation in the alert. This is contradictory to studies that highlighted brief messages highlighting the impending hazard as sufficient for warning (Lindell et al. 2015; Wang et al. 2022). However, studies that found brief messaging effective also had respondents that utilized either peer confirmation, personal inferencing, or combining the messaging acknowledgement and action with other methods of receiving the information (e.g., broadcast). On the other hand, sequenced messages that may be longer, but provide more detail about the situation, targeted location information, and actions to take, were seen as desirable in other studies, rather than short and terse messages that provide limited information on their own (Kim et al. 2019; Sutton et al. 2015).

The support for geographic maps and visuals when sending out alerts and warnings was evident as well, aligning with the concept of providing more detailed information about impending or occurring disasters. Lastly, simple yet effective means to encourage attention to alert and warning messages is to ensure that the systems utilize 'opt-out' rather than 'opt-in' services. This reduces the difficulties that may ensue with user-end registration for the systems, and reduces the likelihood of outdated contact information (Egnoto et al. 2013). Many of these recommendations are practical in nature, and can be incorporated into current alert and warning systems, as well as impact future standardization and updating of policies on the subject matter.

5 Conclusion

This paper systematically identified and reviewed 100 studies on public alert and warning systems to synthesize major findings and practical lessons to improve public alert and warning systems research and practice. This study also outlined a path for continuing research in this space for the foreseeable future. This study, of course, is not without limitations. First, this study only examined articles published in the USA. It would be beneficial for future work to systematically review public alert and warning systems in other countries. Second, despite efforts to develop a keyword search that was both broad enough to cast a wide net on and narrow enough to increase efficiency, it is possible that the authors missed some studies that met the selection criteria. Nonetheless, this paper offered critical insights into the research findings on public alert and warning systems

that provide practical ways to improve how communities' alert and warn their residents before, during, and after emergencies.

Appendix 1: List of studies included

1. Abukhalaf, A. H. I., & J. Von Meding. 2020. "Communication challenges in campus emergency planning: The case of hurricane dorian in Florida." *Natural Hazards*, 104(2), 1535–1565.
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