Weather Information Use and Decision-Making by K-12 Schools during Tornado Warnings

Master's Thesis Proposal

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INTRODUCTION

Tornadoes are naturally occurring phenomena. Humans cannot control when and where they occur. Improved tornado forecasting and preparedness can positively influence how these natural phenomena affect daily life decisions and behavior. Meteorologists and forecasting tool developers can benefit from a better understanding of weather-societal interactions and public perceptions associated with tornado risks. The intent is to disseminate effective weather products that the various publics find useful for making decisions relative to severe weather. One reason natural disasters, such as tornadoes, are particularly damaging is because of the lack of collective collaboration and communication between stakeholders and the science community; "disasters are failures of social systems" (Aguirre 2009). Social science research on severe weather is underway, yet little progress has been made on weather-sensitive decision making in institutions; research related to societal impacts across the entire severe weather communication spectrum is needed. This study focuses on one component of the wide spectrum of weather information users: K-12 public schools.

How do school officials use weather information in their decision-making? Answering this question will provide useful information to software developers and forecasters who are trying to effectively communicate what is known about tornado threats. Understanding the preferences and behaviors of authority figures in leadership roles, such as superintendents, principals, and teachers, is an effective way to ensure the safety of large populations since decision-makers of schools are responsible for the safety of their students. Research of schools and weather information use is far overdue. Meteorologists and weather forecasting tool developers need to understand how school decision-makers use current forecasting information including warnings. With that understanding new tools can more effectively address expressed needs.

This study consists of four related research questions:

1) What sources of weather information do key decision makers in K-12 public schools use?
2) How and when do these key decision makers use these sources in the decision-making process during a tornado warning?
3) How do the contexts of non-weather related factors affect decision-making during warnings?
4) What decision support tools would improve school decision makers' ability to keep their school populations safe?

Three hypotheses:

1) School administrators use a variety of weather forecast information. The National Weather Service (NWS)[1] warning products and local emergency manager messages are the most likely sources of tornado warning information.
2) NWS outlooks, watches, and warnings, as well as local emergency management messages play vital roles in school tornado warning action plans and the school administrator's capability to promptly and effectively implement those actions plans.
3) School administrator decision-making is bounded or constrained by external factors, beyond weather, that influence what decisions are made. External factors may include legal obligations, relationships with surrounding schools, bus routes, extracurricular activities, and previous experience/knowledge.

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[1] See Appendix A for a full list of acronyms

BACKGROUND

On any given weekday during the academic year, about 20-25% of the United States population is in a public school (Hull 2010). More specifically, as of 2007, there were over four million school staff and nearly 50 million students enrolled in public schools (Snyder et al. 2010). Besides the large number of people in schools, another reason why schools are especially vulnerable is that students lack legal autonomy and decision-making rights when it comes to their safety. Students rely on the expertise of their authority figures, who are usually teachers, principals, or other administrative staff, to make appropriate decisions for them. Because of the vulnerability of students, faculty, and staff, the impacts of a severe storm in a school setting can be detrimental to their safety and wellbeing.

Social Science Woven Into Meteorology (SSWIM) and Warn-on-Forecast (WoF)

This research study is one of several studies currently underway by researchers working with Social Science Woven Into Meteorology (SSWIM) in the National Weather Center in Norman, Oklahoma. SSWIM promotes collaborative research and partnerships between the social sciences and physical sciences of meteorology and climatology to enhance societal relevance and highlight how stakeholders make weather-sensitive decisions.

This study is funded by the Warn-on-Forecast (WoF) project as part of the National Severe Storms Laboratory (NSSL). WoF is a new method of early tornado prediction that could possibly extend the tornado lead-time by one to two hours by using convection-resolving, Doppler, and numerical models (Stensrud et al. 2009). This new system, which the National Oceanic and Atmospheric Administration (NOAA) anticipates being available by the year 2020 (Stensrud et al. 2009), is a more dependable method of providing enhanced forecasts and predictions of severe weather to the general public, organizations, and stakeholders.

My research is a component of WoF that will assess some of the possible implications of this new prediction system from a social science perspective. The social implications of a possible longer lead-time have not yet been thoroughly evaluated. Social science research may identify a new conceptual understanding of lead-time altogether, since even a slight deviation from current lead-times may completely change how people respond. Research on the sources of weather information is another component of interest to the WoF process.

Warning Definitions

Tornadoes are natural weather phenomena that can damage property and occasionally result in losses of human life. The NWS is responsible for monitoring weather, including severe weather that may result in tornadoes, as well as disseminating valuable information about the onset of possible severe weather to various groups. When atmospheric conditions are positive for the onset of a tornado, the NWS issues a tornado watch. If a tornado has been seen by a tornado spotter or on radar, they issue a warning (NOAA 2011).

LITERATURE REVIEW

Warning Systems Theory and Weather Warning Partnership

Warning Response Model

An effective tornado warning requires more than just the NWS to detect severe weather and issue a tornado warning. Collaboration among several organizations is needed. Mileti et al. (1990) proposed an integrated warning system (IWS) for hazards, comprised of detection, management, and response subsystems. The detection subsystem is responsible for monitoring the environment, detecting the hazard, and linking the detection and management subsystems. The management subsystem acts as the liaison between the detection and response subsystems. This component is comprised largely of emergency managers who are given the role of information interpretation and public dissemination. Lastly, the response subsystem consists of how the public responds to the hazard, including both individual interpretations of the information obtained and unofficial warnings sent among the public themselves (Mileti et al. 1990). This model can be applied to all hazards, including tornadoes.

Weather Warning Partnership

The weather warning partnership is an adaptation of the IWS model by Mileti et al. (1990), geared specifically towards severe weather warnings. Doswell et al. (1998) and Golden et al. (2000) discuss the concept of an integrated warning system that integrates warning detection and dissemination among the NWS (detection subsystem), news media and private sector meteorologists, emergency management officials and storm spotters (management subsystem), and the general public (response subsystem) (Figure 1). This severe weather focused model consists of forecasting and detecting severe weather, disseminating vital information, and understanding public response. An IWS stresses the concept that weather warnings are not effective unless the entire system functions collectively, with each component putting in sufficient effort to prepare for a severe weather event *before* it happens, as well as communicating effectively *during* a weather warning (Doswell et al. 1998).

Each component of the IWS has different responsibilities. The NWS is responsible for the initial forecasting of weather and the relay of this information to the other collaborators of the IWS (Doswell et al. 1988), with the mission of protecting life and property and the enhancement of the national economy. The NWS disseminates warnings via the NOAA weather radio, as well as storm-based warnings, otherwise known as threat-based polygon warnings (Department of Commerce 2011). The media, emergency managers, and private sector meteorologists are then responsible for providing the weather information to the general public. The media is the leading source of weather information, with the television being the main primary *and* secondary source of weather information (Hayden et al. 2007). Additionally, emergency managers are a vital source of weather information for the public (Baumgart et al. 2008; League et al. 2010; Dawson 1993). They are responsible to communicate warning information by initiating an emergency alert system, activating sirens, and advising schools and hospitals of appropriate actions to take (League et al. 2010). To a large extent, emergency managers work closely with the NWS and rely heavily on the information they provide.

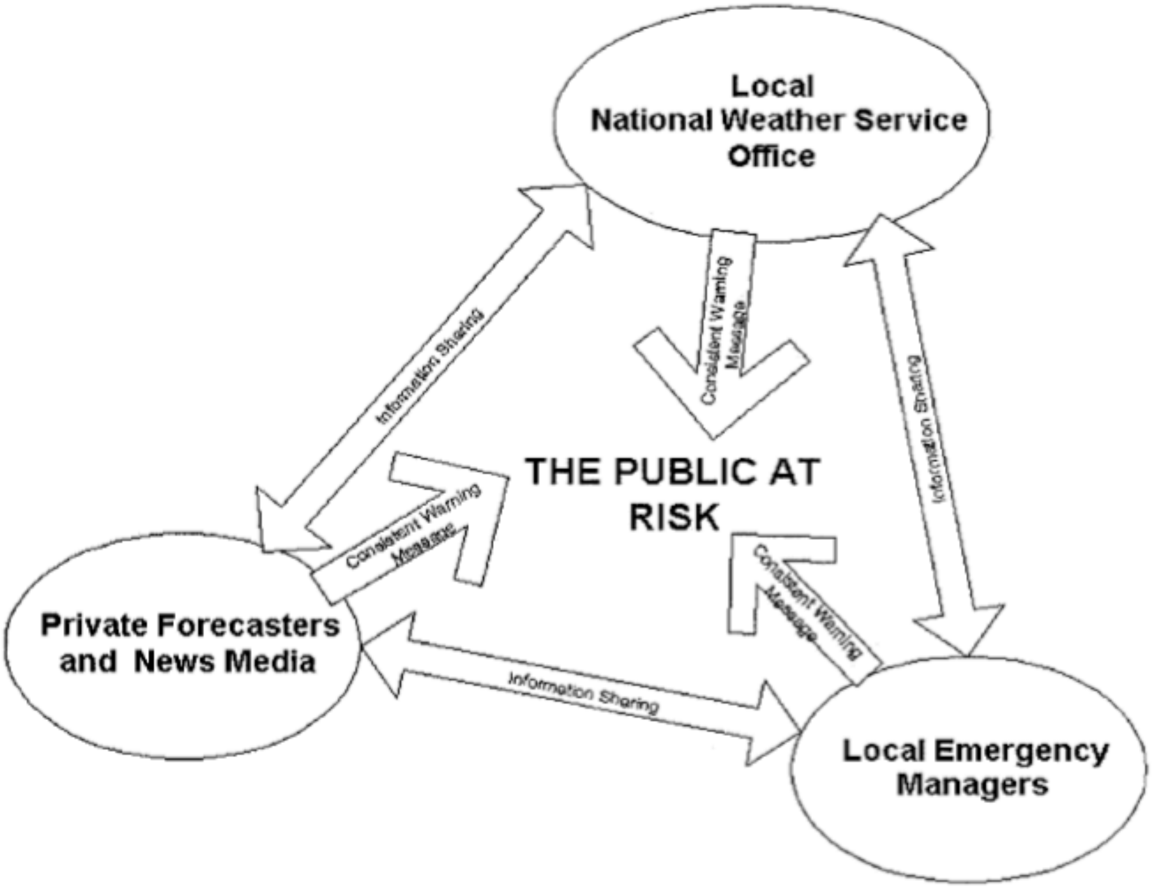


FIGURE 1: Weather Warning Partnership of the National Weather Service, Local Emergency Managers, and Private Forecasters and News Media (Golden et al. 2000).

Public Response and Behavior Theories

Public Response to Warnings Model

Public awareness and response is a vital component of the IWS. Understanding how the general public uses weather information during severe weather warnings to make decisions is just as significant as the initial warning dissemination. The public does not respond unanimously to weather warnings. Rather, individuals will interpret the same information very differently, making it difficult for weather experts and emergency managers to gauge public behavior (Mileti et al. 1990; Sorenson 1991). Mileti and Sorenson developed a public response to warnings model that shows how people follow a similar process when confronted with a hazardous situation. The first stage is hearing the warning (Mileti et al. 1990). There is a relatively large amount of literature on public *daily* weather information use, however the samples in these studies were small and therefore not generalizable to the larger public (Lazo et al. 2009; Harris Poll 2007; Bussum 1999; Sink 1995; Saviers et al. 1997; Krenz et al. 1993; and Legates et al. 1999). There is relatively little research on how the public becomes aware of tornado warnings.

The remaining phases of public response are understanding, believing, personalizing, deciding and responding, and confirming the hazard (Mileti et al. 1990). Several factors play a role in influencing how an individual proceeds through this decision process, including their risk perception and awareness of the hazard, their socioeconomic and education levels, and their cultural and environmental surroundings (Aguirre 2000). A significant criticism of Mileti and Sorenson's model is that it depicts the flow of information unidirectionally, not allowing for the response subsystem, the public component of the IWS, to interact with or respond to the detection and management subsystems. The public is no longer submissive. Rather, they actively seek information about the hazard, which the Mileti et al. model fails to recognize. The model also assumes that emergency managers do not follow the six thought processes that the general public goes through during a hazardous situation, which may or may not be true (Rodriguez et al. 2007).

Protective Action Decision Model (PADM)

The Protective Action Decision Model (PADM), a theory of risk communication taken from social psychology, recognizes the shortcomings of the Mileti model (Lindell et al. 2004). This multistage model assembles several key decision theories that depict how individuals respond to environmental cues and social messages, such as warnings. The PADM produces a behavioral response by incorporating eight questions that individuals are inclined to ask themselves during a warning (Table 1). It includes crucial pre-decisional processes such as the awareness and interpretation of environmental cues and social messages, as well as perceptions of threat and protective action (Lindell et al. 2004). Table 1 illustrates how the Mileti et al. (1990) public response to warnings model correlates with the PADM. Mileti et al.'s six different public responses to warnings are paired with the appropriate PADM activity. Stage 0 is an adaptation to depict how the *hear* and *understand* stages of the Mileti et al. model parallel the PADM's pre-decisional processes. The PADM model more realistically encapsulates actual human behavior by effectively incorporating societal and cultural influences, behavioral choice, and hazard response (Lindell et al. 2004). It highlights the protective action steps people take when confronted with a hazardous situation.

Utility Models and Bounded Rationality Theory

Behavioral decision-making theories describe the process by which people choose to take protective action. There is more to the process than simply the PADM model, however, and

TABLE 1: PADM Warning Stages and Actions (Adapted from Lindell and Perry 2004). The right column depicts the correlating public responses to warnings stated by Mileti and Sorenson (1990). The X's depict no available comparisons between models.

Protective Action Decision Model (Lindell and Perry 2004)				**Public Response to Warnings Model (Mileti and Sorenson 1990)**
Stage	Activity	Question	Outcome	
0	Pre-decisional stages			Hear and Understand
1	Risk Identification	Is there a real threat that I need to pay attention to?	Threat belief	Believe
2	Risk Assessment	Do I need to take protective action?	Protective motivation	Personalize
3	Protective action search	What is the best method of protection?	Decision set (alternative actions)	X
4	Protective action assessment and selection	What can be done to achieve protection?	Adaptive plan	X
5	Protective action implementation	Does protective action need to be taken now?	Threat response	Respond
6	Information needs assessment	What (additional) information do I need to answer my question?	Identified information need	Confirm
7	Communication action assessment and selection	Where and how can I obtain this information?	Information search plan	
8	Communication action implementation	Do I need the information now?	Decision information	

certain economic theories have provided the framework under which protective action behavior is carried out. According to Expected Utility Theory, decision-makers assess all possible outcomes and choose what actions to take that will maximize their net benefits (Burton et al. 1993). This principle is entirely objective and applies only to marginal situations, into which severe weather warnings do not fall (Kunreuther et al. 1978). Consequently, the Subjective Expected Utility Theory, was developed that although still emphasizes maximizing net benefits, it allows the decision-maker to *subjectively* choose the value of probable outcomes (Tobin et al.

1997). This theory provides a subjective platform upon which each individual can make decisions based off of their own personal circumstances (Burton et al. 1954).

The Subjective Expected Utility Theory, however, has its shortcomings. First, this theory assumes that the individual is provided with all the information on a particular hazard, when in reality, people are not always aware of all the associated risks. Second, this theory is rational only in static situations, and does not apply to extreme hazards, including tornado warnings (Slovic et al. 1974). Simon (1957) acknowledged these limitations and recognized that "the degree to which decision making is rational seems to be *bounded* by cognitive [and conditional] limitations" (Lindell and Perry 2004 33). This Bounded Rationality Theory, from the geography discipline, explains how people make decisions when bounded by the law, societal norms, and cultural circumstances. Decision-makers bounded by factors such as these might act irrationally from an economic perspective, but feel as though their actions are most appropriate according to their personal boundaries and limitations.

Prospect Theory (PT)

Besides Bounded Rationality Theory, Prospect Theory acts as an additional alternative theory to the Expected Utility Theory described above. This theory, created by Kahneman and Tversky, more realistically attempts to model real-life situations and choices by describing how individual decision-makers measure potential losses and gains when *risk is involved* (Kahneman and Tversky 1979). Kahneman and Tversky note that "in expected utility theory, the utilities of outcomes are weighted by their probabilities," however "people's preferences systematically violate this principle" (265) and decisions are not always made according to what is most optimal. Instead, people often make irrational decisions depending on how they personally view the risk involved, or depending on how the risk is framed to the individual. Risks that are framed as being potential losses make the individual more inclined to gamble than risks that are framed as potential gains. In other words, people tend to be risk-averse when gaining, and risk-seeking when losses are involved (Table 2). This is known as the framing effect (Kahneman and Tversky 1979). Similarly, "the response to losses is more extreme than the response to gains," (Tversky and Kahneman 1981 454) shown by the steeper decreasing slope in the "losses" quadrant of Figure 2.

TABLE 2: A tabular representation of Tversky and Kahneman's description of Prospect Theory. In situations that involve potential gains or losses, people tend to be risk averse or risk seeking, respectively (denoted by the X's) (Tversky and Kahneman 1979).

	Risk Seeking	**Risk Averse**
Gains		**X**
Losses	**X**	

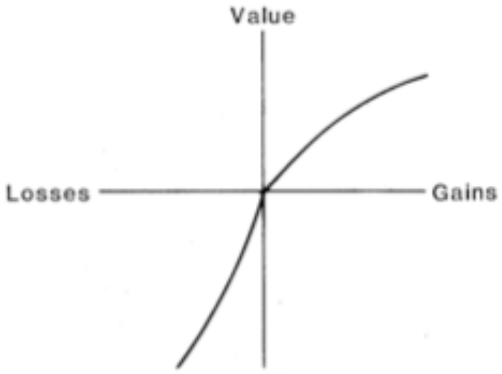
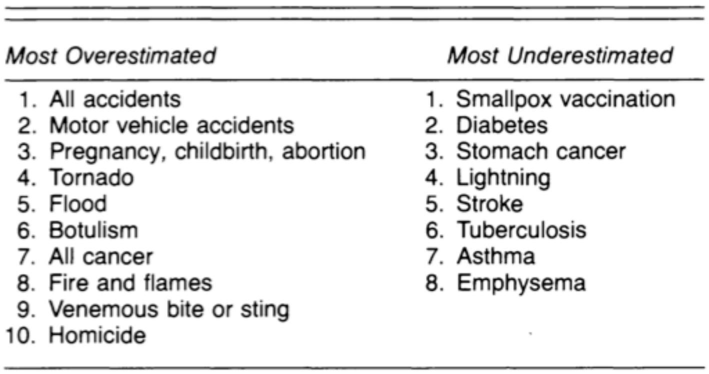


FIGURE 2: A hypothetical value function (Tversky and Kahneman 1981).

Prospect Theory is best explained with an example: a study conducted on students in two universities. The students were to imagine that the U.S. is considering enacting one of two different programs to mitigate the impacts of a new and deadly disease (the percentage of students who chose each option is in brackets). "If Program A is adopted, 200 people will be saved [72 percent]. If Program B is adopted, there is a 1/3 probability that 600 people will be saved, and 2/3 probability that no people will be saved [28 percent]" (Tversky and Kahneman 1981 453). As noted, the majority of students chose Program A, and is therefore risk averse. To them, knowing that they would be saving 200 lives is more of a gain than risking saving no lives, even though each program is of *equal expected value*. Another group of students were then given the following options: "If Program C is adopted, 400 people will die [22 percent]. If Program D is adopted there is 1/3 probability that nobody will die, and 2/3 probability that 600 people will die [78 percent]" (453). Most students in this case were risk takers, meaning that they would prefer to take the risk of everyone dying, than knowing that they would kill 400 people automatically. These cases illustrate that "choices involving gains are often risk averse and choices involving losses are often risk taking," (453) even if the expected values are equal. Tversky and Kahneman note this pattern among many different groups of respondents, "including university faculty and physicians" (453).

Another way that Prospect Theory differs from the Expected Utility Theory is regarding probability. According to Prospect Theory, "low probabilities are overweighted, moderate and high probabilities are underweighted, and the latter effect is more pronounced than the former" (Tversky and Kahneman 1981 454). In other words, people tend to put more weight on events that are not likely to occur, and less weight on events that are more likely to occur (Fox and Hadar 2006, Slovic et al 1979). For example, as seen in Table 3, people are inclined to overestimate deaths by botulism, an extremely rare disease, and underestimate deaths from diabetes and stroke, which are much more likely reasons of death (Slovic et al. 1979). One possible explanation for this could be the increased attention to overestimated hazards in the news media (Comb and Slovic 1979). Regarding natural disasters, tornado risks tend to be overestimated (Table 3, Comb and Slovic 1979), dreaded, and relatively unknown to the public (Figure 3, Hoekstra et al. 2011).

TABLE 3: Hazards or events that are over and underestimated (Slovic et al. 1979 16).



Most Overestimated	*Most Underestimated*
1. All accidents	1. Smallpox vaccination
2. Motor vehicle accidents	2. Diabetes
3. Pregnancy, childbirth, abortion	3. Stomach cancer
4. Tornado	4. Lightning
5. Flood	5. Stroke
6. Botulism	6. Tuberculosis
7. All cancer	7. Asthma
8. Fire and flames	8. Emphysema
9. Venemous bite or sting	
10. Homicide	

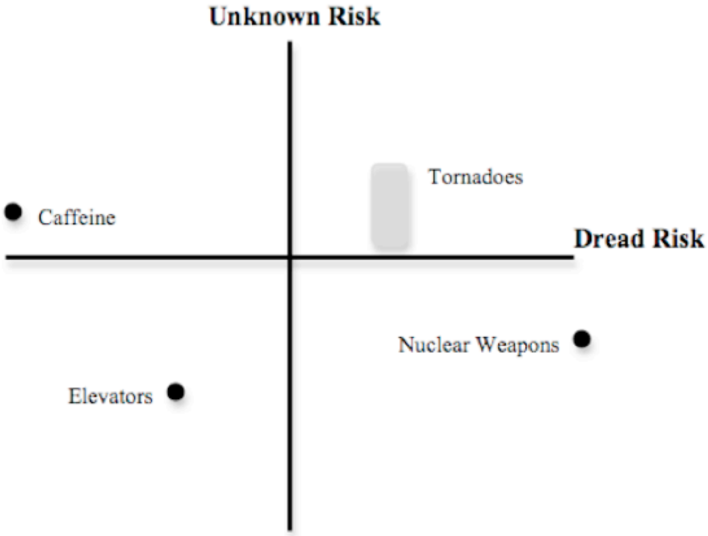


FIGURE 3: Simplified version of Slovic's (1987) risk factor map, depicting risk perception as a function of the degree to which the hazard (several examples depicted in the graph) is "unknown" or "dreaded" (Hoekstra et al. 2011). Hoekstra et al. hypothesize tornadoes to fall within the light gray region, as relatively unknown and dreaded by the general public.

Kahneman and Tversky's main argument is that normative theories, such as the Expected Utility Theory, should not be the sole determinants in evaluating judgment and decision-making since these theories do not provide the framework to assess actual and realistic human decision behavior. Consequently, Prospect Theory is an alternative theory that explains why decision-makers make irrational decisions and do not always choose the option with the greatest expected value or optimality. This is often the case for decision-makers in leadership positions, such as school administrators confronted with high-risk scenarios who often have to evaluate conflicting values and consider external factors when making decisions. Such decision-makers may act irrationally and make more risky decisions when the situation is associated with potential loss. Prospect Theory denotes that a decision made to avoid a loss will be a bolder and more aggressive decision than one taken to merely achieve a gain (Tversky and Kahneman 1981).

Public School Roles During Warnings

Decision-makers in schools serve as a fitting example of a group that is bounded by factors out of their control. During tornado warnings, for example, schools (those in areas prone to severe weather) have more to consider than simply evacuating students or sheltering in place. Some hypothesized constraints (whether positive or negative) of school officials are legal obligations, architectural layout and structural integrity of the campus, and communication with bus drivers and parents. I expect that the main priority of these decision-makers is *not* to maximize economic benefit; they are more concerned with maximizing student safety all while upholding legality and interacting cooperatively within the community. Non-weather related factors can have a substantial effect on behavior (Schultz et al. 2010), which is an often forgotten attribute of warning research.

It is unclear where schools fall in the IWS. An important objective for future research is to pinpoint where school institutions are placed within the spectrum of weather information users. One study showed that schools receive calls from their local emergency managers when severe weather is expected (League et al. 2010), who provide the needed information to initiate school emergency plans, whether that is closing the school, evacuating students, or transporting students to predetermined shelters. However, important questions include: Is this the *only* source schools use? How are schools bounded by cognitive and conditional limitations? What information do school officials *want*?

A multidisciplinary study conducted on schools during an unusual tornado occurrence on May 22, 2008 highlighted the importance of societal factors in decision-maker perceptions and behavior (Schumacher et al. 2010). This was the first study that applied Mileti's public response to warnings model to *decision-maker* behavior, instead of solely to the general public. The authors conducted interviews with local decision-makers, concluding that interpretations of warnings differed among decision-makers, and having previous knowledge led to altering perceptions and interpretations. This study also called attention to the many complexities that exist in the severe weather communication process, emphasizing that lead-time is only one factor in the warning communication process and the need for future research to consider more than just lead-time influences is necessary (Schumacher et al. 2010).

Other studies, though focused on limited populations, have shown that having a longer lead-time may not be beneficial to the public. A recent study found that the ideal tornado lead-time was 34 minutes for the *general public*, and a lead-time of more than one hour was associated with the situation feeling more life threatening (Hoekstra et al. 2011). Similarly, administrators of schools and nursing homes preferred tornado-warning lead-times of no more than 30 minutes (Ewald et al. 2002). Additionally, Simmons and Sutter's (2007) empirical investigation of tornado casualties showed that an optimal lead-time is about 15 minutes, with longer lead-times not reducing fatalities. Most of these studies, however, asked the participant for the amount of time they needed to complete actions they *currently* take. A much better question to ask is how would a longer lead-time *change* what they currently do. For example, what would they *like* to do if given more warning time? Knowing this can help in understanding how changes in lead-time will affect the context in which decisions are made. In addition, attention to the assumptions made in these lead-time studies may affect their results; this study will consider new understandings of the *whole* notion of lead-time.

SIGNIFICANCE

As forecasts and technologies continue to improve, the warning paradigm will shift to longer lead-times (Stensrud et al. 2009), and current warning response will have to evolve. Before this transition occurs, it is vital to understand *current* warning response in order to improve the effectiveness of future systems. Researching schools, one subset of the warning communication spectrum, and their response to warnings, is one step in the right direction in gathering this information. Although researching schools and weather warnings cannot answer all the questions pertaining to weather-sensitive decision-making, it can bring forecaster and software developer attention to one small subset of stakeholder perspectives. Research calls for a more thorough consideration of contextual factors that influence decision-making. This acknowledgment often goes ignored, yet human decisions and behavior are based on weather conditions, forecasts, and many other factors. This study will focus on the effects of these external forces that may influence decision behavior within school settings.

METHODOLOGY

This study will consist of three in-depth case studies of public schools that are under a tornado warning during the spring 2011 severe storm season. Case studies are an effective tool to use for exploratory studies, or studies that have not been thoroughly researched before. They allow for an in-depth understanding of the interplay of many of the variables that may influence decision-maker behavior, as well as a comprehension of the experiences and behind-the-scenes decision making of the participants. Additionally, they are the preferred method when the researcher has little control over the events, in this case being tornado warnings, and when the researcher is constrained to a two-year Master's thesis timeframe (Sofaer 1999).

Sampling Methodology

During the Spring 2011 severe weather season, I will closely monitor the weather utilizing several weather information sources to pinpoint any schools that may fall within a tornado-warning polygon. I will be in constant contact with the Storm Prediction Center in the National Weather Center in Norman, OK, to stay informed of any particularly severe weather days. I receive regular email alerts from the NWS including convective outlooks for up to eight days, as well as tornado/severe thunderstorm watch alerts. I am also an active user of NWSchat, an instant messaging program designed for weather-informed and interested individuals to share critical warning information and other important weather information.

The most important source I use, however, is the Iowa Environmental Mesonet (IEM), which collects and stores environmental data from a variety of networks, including daily summary images of storm-based warnings and archived NWS watches and warnings. The archived text information provided by the IEM allows me to create a database of the date and time of the warning (issuance and expiration times), as well as the forecasting office location that issued the warning(s). The IEM also provides storm reports (a list of damages, injuries, fatalities), radar images, history of the warning (duration, change of time/location), intensity of the storm, and recommended precautionary actions of the particular warning.

Once I have a list of all the tornado warnings on a particular day, I can pinpoint which school districts are under each warning by overlaying these archived warning polygons from the IEM with Google Earth Place data (public school districts) (Figure 4 and Figure 5). This overlay technique provides spatial verification that a school district is located within a tornado-warning polygon. Additional information from the affected school district is obtained in order to ensure that Google Earth's placement of the district is accurate; cross-referencing is vital, for even Google Earth makes mistakes. Displaying warnings in the shape of a polygon is a relatively new technique, first being tested in Spring 2004 by the Polygon Warning Team established in 2003. A particularly useful component of this new warning display is that geopolitical boundaries are ignored, allowing for only a pure representation of the area being affected by a warning without influence from other variables (Waters 2004).

Data Collection

After pinpointing a school district that is under a tornado warning, I will contact the superintendent from that district post-event. I will email special cases (i.e. school districts under multiple warnings, schools on the edge of warning polygons, etc.) first. If I do not hear back from those cases, I will assign a number to each remaining warning and use a random number generator to compile an order in which I will email each district; this is to ensure a completely unbiased sample set. I anticipate a low response rate given the busy schedules of school officials. The superintendent, upon willingness to participate, will then suggest initial faculty and staff with whom to conduct in-depth interviews, using semi-structured interviews. Interviewing post-event will allow for complete recollection of memories, and will allow the researcher to gain insight as to the actual behavior of the decision makers rather than their idealized behavior. These in-depth interviews will each last about one hour. I will interview approximately 2-5 people with varying positions, including superintendents, administrative staff, principals, teachers, or anyone who played a part in the decision-making process during the tornado warning, from each school.

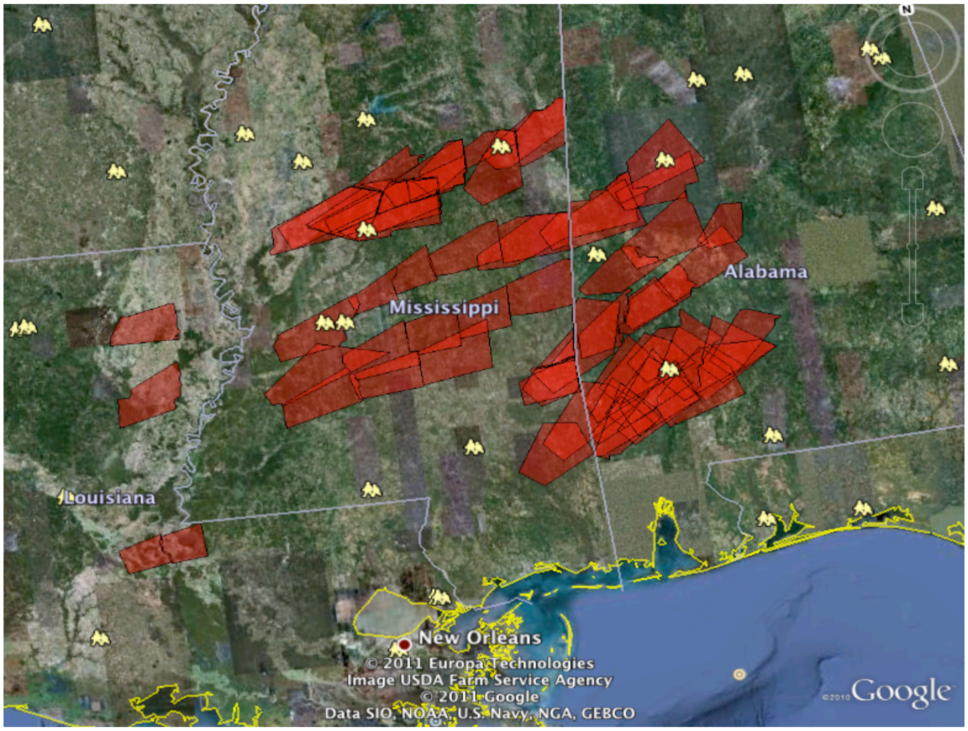


FIGURE 4: An overlay of NWS warning polygons with school data from Google Earth. These particular warnings were issued on April 15, 2011. The yellow icons represent schools.

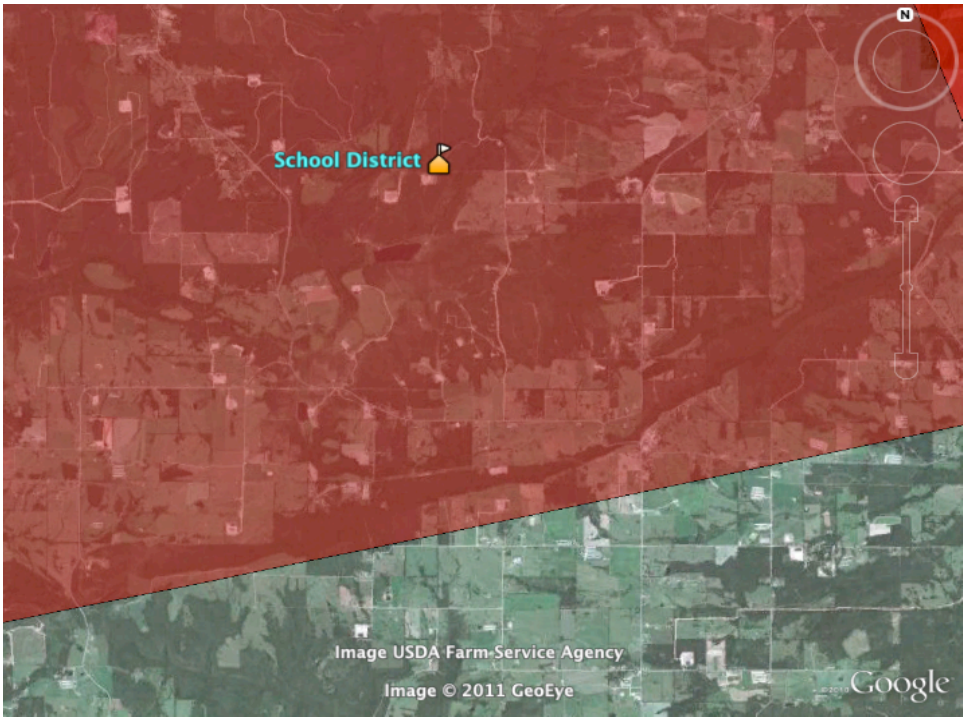


FIGURE 5: A zoomed-in view of a warning polygon encompassing a school district in Arkansas on April 24, 2011. Zooming in allows for the school district icons to appear.

If needed, I will make use of snowball sampling to gather more data from a wider spectrum of people involved in the process. This will be initiated by asking my initial interview participants to refer anyone in particular who they feel were vital decision-makers during the warning event. Using snowball sampling is a preferred method for exploratory, qualitative studies aimed in obtaining information on sensitive topics and difficult to reach participants. One disadvantage of snowball sampling is that the sample population becomes non-random. However, by the nature of this study, the sample population was never meant to be random since I will be using purposive sampling with certain decision-makers already in mind to interview (Faugier 1997).

Semi-structured interviews are especially useful when interviewing several people who have different job titles, such as in a school setting (Longhurst 2010). They initiate collaboration between the researcher and the interviewee, allowing the interviewee to guide the interview and feel free to express their own views and perspectives. Semi-structured interviews are a reliable data collection method, allowing for comparisons between participants (Longhurst 2010). The semi-structured interview in this study will include questions on demographic information, sources of weather information, warning response and decision-making, and weather product preferences. I recognize that the questions asked in the interview will be slightly altered depending on the interviewee, which is one of the advantages to using semi-structured interviews. This study will use phone interviews.

Sampling Criteria

The schools selected to take part in this study will be *public* schools in central and eastern United States. I initially wanted to focus on central Oklahoma school districts (Cleveland and Oklahoma City Counties), but archived warning information has shown that there have only been two warnings for both of these counties during school hours in the last *three* years; I could not take the risk of counting on warnings to occur *this* year. Therefore, I expanded my sampling location criteria nationally. The three case studies will be one elementary school, one middle school, and one high school from the *same* district. This provides a deep understanding of the inner-workings within a school district as well as insight into how schools within one district coexist and collaborate. Studying three different types of school (elementary, middle, and high schools) allows for comparing weather preferences and behavior in relation to school size, student age, and differing regulations among the school types.

An additional selection parameter is that the schools being researched must be under a tornado warning that resulted in a false alarm or close call; selected schools will not be physically impacted by the tornado. It is important to recognize the need for reassessment of how false alarms are evaluated; false alarms may not necessarily reduce an individual's likelihood to respond, and may provide training opportunities and improvements in procedure (Barnes 2006). Lastly, and arguably the most important selection parameter, warnings must occur during school hours, which I consider as 1130 through 2000 UTC time (IEM warning information is given in UTC time). This is equivalent to approximately 7:30 am through 4 pm, in the Eastern Time zone; adjustments to this time range are made according to the time zone in which the warning is issued.

Data Analysis and Framework

This study will use the Protective Action Decision Model, combined with the bounded rationality theory, as a framework to understand the contexts in which schools make decisions during hazardous situations. The PADM details the steps involved in preparing to take protective action during a hazardous situation. As described in the literature review, it consists of eight questions that people tend to ask themselves during a threatening situation (Lindell et al. 2004). These questions will act as guidelines for the interview questions. Integrating the bounded rationality theory with the PADM will serve as a basis for pinpointing external limitations that school decision makers face when making important decisions that are not included in the PADM. The combination of the PADM and bounded rationality theory thus provide a sound framework for a study involving complex organizations and human behavior.

I will be using qualitative method techniques to analyze the interview responses, and will be using a type of computer coding program, such as *MindManager* or *TAMS analyzer*. My prospective plan is to analyze each case study *separately*, followed by comparing and contrasting *all* three case studies. I will be performing latent content analysis, a form of content analysis, which involves exploring the data for common themes and patterns (Dunn 2005). This form of analysis uncovers the true significance of responses, instead of just noting the surface content. This data analysis method of sorting responses into themes acts as a type of coding (Dunn 2005), which is the overall qualitative method I will employ for data analysis. I will categorize the results of this study into themes centered primarily on the PADM and bounded rationality theory.

DELIVERABLES

I will construct dynamic timelines and graphics of participant responses that temporally outline their series of actions taken during the warning. I hope that these conceptual models will act as hypotheses for future work on this topic, just as the PADM acted as an initial hypothesis or framework for this study. The models created using participant responses from this study will allow for an applied version of the PADM that focuses on actions taken specifically by *decision makers*, and not by the *general public* upon which the PADM is based. The study conducted by Schumacher et al. (2010) was the first study to apply Mileti's six public responses to warnings model, which is a more narrowed version of the PADM, to decision makers during tornado warnings; this study will be the first to apply the PADM to decision makers.

In addition, the results from this study will be presented to both weather experts and school administrators. My study along with the work conducted by my colleague, Amy Nichols, on decision-making during tornado warnings at the university level, will be presented at the 2012 Warn-on-Forecast Workshop, as well as at the "brown bag" lunches in the Development Laboratory as part of the Hazardous Weather Testbed. Additionally, if possible, I intend on presenting my results to the school administration of the district I select for this study, to provide them with a summary outline of their statements and the future implications of their participation in this study.

The overarching aim of this project is to help change the research to operations equation. Meteorologists and software developers should not create new technologies simply because they are the logical next steps, but rather they should create new technologies that *respond* to the expressed needs of the publics and stakeholders. Although this study focuses on a very narrow subset of stakeholders, knowing the effects of lead-time and external factors on decision-making is still beneficial to software developers as it provides evidence of how these specific schools researched in this study use weather information to make decisions during tornado warnings in the context of their specific complexities and circumstances. This study will help shift the research to operations equation from its current state of being top-down, to becoming more horizontal, closing the gap between research and operations.

TIMELINE

Spring 2011	- Complete literature review - Write interview questions - Complete IRB application - Complete full research proposal - Monitor weather to pinpoint schools under warnings - Conduct interviews
Summer 2011	- Complete interviews - Start data analysis on interview data - Present at the Weather Warnings and Communication Conference in OKC
Fall 2011	- Complete data analysis - Begin writing results/discussion/conclusions sections of thesis
Spring 2012	- Finish writing thesis - Defend thesis - Present at AAG/AMS

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APPENDIX A: Acronyms

Name	Acronym
National Weather Service	NWS
Social Science Woven Into Meteorology	SSWIM
Warn-on-Forecast	WoF
National Severe Storms Laboratory	NSSL
National Oceanic and Atmospheric Administration	NOAA
Integrated Warning System	IWS
Protective Action Decision Model	PADM
Prospect Theory	PT
Iowa Environmental Mesonet	IEM