Before, During and After Severe Weather: How the Brief Vulnerability Overview Tool May Impact Emergency Manager Decision-Making and NWS Forecaster-EM Communications

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ABSTRACT

People, places, and things vulnerable to severe weather are everywhere and the only people that know where the majority are located are emergency managers (EM). The National Weather Service forecasters know where some are, but because of the large area that they forecast for, it is difficult for them to keep track of the vulnerabilities that some EMs are concerned about. To increase the NWS forecasters' situational-spatial awareness, along with improving the understanding of messaging to EMs and assist in the closing of the information gap, the Brief Vulnerability Overview Tool (BVOT) was created. The BVOT was tested in a NOAA Hazardous Weather Testbed project with 35 forecasters and 38 EMs over a course of six experimental weeks. Each week consisted of eight cases and an end-of-week discussion; each case was made up of three periods: 24–48 hours before the storm, 4–12 hours ahead of the storm, and lastly, a 35-min "storm on the ground" period. These experimental weeks were recorded and professionally transcribed, then qualitatively analyzed using structural and thematic coding. Within this process, the question of whether BVOT serves EMs through NWS forecaster use became the focus, causing the broad ideas to be broken down into more focused themes. This study found that BVOT serves EMs before, by reminding EMs of vulnerabilities, during, by seeing what a storm is impacting, and after, to help them plan for damage assessment and response. BVOT also improved EM-NWS and EM-EM relationships by communicating the BVOT points affected.

1. Introduction

In recent years, the National Weather Service (NWS) has been developing and researching new ways to communicate weather hazards to meet societal needs and improve the watch-warning information gap using a model known as Forecasting a Continuum of Environmental Threats (FACETs). FACETs is made up of seven components: 1) Method and Manner 2) Observation and Guidance 3) The Forecaster 4) Tools 5) Output 6) Response 7) Verification, that interact with each other in a "typical forecast process" (Rothfusz and Coauthors 2018).

Using FACETs as a broad model that addresses all forecasting services, NOAA requested proposals that answer several priorities. Two of those are relevant here: 1) "create skillful and reliable probabilistic thunderstorm and severe hazard threat guidance… in support of the FACETS concept" and 2) use social science to bridge the connection of forecaster guidance to the end-users's understanding of that guidance. The Brief Vulnerability Overview Tool (BVOT) addresses these NOAA priorities by following the components 3, 4, 5, and 6 out of the seven FACETs components. The tool (4), BVOT, was used by forecasters (3) to make them aware of vulnerabilities across their county warning area (CWA) and how they may change their messaging (5) to convey those vulnerabilities to the emergency managers (EM) and how the EMs respond (6) to that messaging.

BVOT, a FACETs-inspired vulnerability tool and impact-based decision support service (IDSS) support tool, was used by NWS forecasters in this research to see if the BVOT tool impacted communication between NWS forecasters and EMs and if it served EMs (Friedman and LaDue 2020). BVOT points and polygons are mapped out by both EMs and NWS forecasters where they identify weather-specific vulnerabilities that "keep [them] awake at

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night." The NWS forecasters' use of IDSS makes communication of weather hazards easier to interpret, along with giving advice on weather events (NWS 2018). BVOT's goals are to assist in the closing of the information gap between the issuance of watches and warnings and improve the delivery of IDSS to the EMs.

The BVOT was used in a NOAA Hazardous Weather Testbed (HWT) project to see the impact on decision-making and communication between the NWS forecasters and EMs with the increase in vulnerability knowledge and situational-spatial awareness. While this background is part of the more extensive BVOT research, this portion of the BVOT study will address the following research questions:

RQ1: How are EMs served by the use of the BVOT by NWS forecasters before, during, and after a severe weather event?

RQ2: How does the BVOT affect EM-NWS relationships, EM-EM relationships, and the information gaps between the two partners?

2. Literature Review

a. EM-NWS Relations

The relationship between EMs and forecasters varies from county to county, but despite that variation, prior research explores the common trends between the two partners. Many EMs rely on weather forecasters heavily for many things, such as clearing up uncertainty and assisting them throughout most of the decision-making process (Kox et al. 2018; Baumgart et al. 2008). To make decisions that enhance the protection of lives and property, Demuth et al. (2012) found that the relationship status between EMs and forecasters worked best as a partnership, instead of a provider and user, which then allows for communication to be improved between the partners.

The partnership EMs and forecasters form takes time and it is sometimes developed the more the two partners communicate with each other (Ernst et al. 2018; Lussenden 2014). When this partnership forms, EMs value their trust and close relationships with their forecasters (Cross and LaDue 2021; Hoss and Fischbeck 2016). This strong tie between the two partners has been demonstrated to be beneficial to both parties, and the community in some instances. For example, Morss and Ralph (2007) demonstrate that if it were not for the EMs' trust in the NWS forecasters, combined with the early lead on flooding from CALJET data, EMs might not have positioned the crew to deal with that event. This event displays how the relationship between EMs and forecasters can play a major role in how society is being protected. Even though some EMs and forecasters have great partnerships, further social science research needs to be conducted between the two in order to improve the communication and so EMs can have a better understanding of what forecasters are trying to convey (Demuth et al. 2012).

b. Information Gaps and Uncertainty

Cross and LaDue (2021) and Ernst et al. (2018) identified common issues in communications with forecasters. They identified a variety of information gaps, including need for increased detail as an event approaches (Ernst et al. 2018), need for confidence/uncertainty of forecast hazards and impacts (Cross and LaDue 2021), and inclusion of plain language content in the briefings (Cross and LaDue 2021). These information gaps have been one of the major issues for EMs identified by researchers that study EM-NWS relations. EMs want these information gaps filled and that due to those gaps they suffer from it (Cross and LaDue 2021; Ernst et al. 2018).

A reason for these information gaps stems from forecasters being uncertain, which leads to EMs not being told the information they need to prepare. Most EMs would rather know about uncertainty, and risk crying wolf or a false alarm, instead of not being prepared at all (Cross and LaDue 2021; Kox et al. 2018). Ernst et al. (2018) even explained in their research, "EMs also experienced a lack of uncertainty information that might have been helpful to identify when thresholds were passed," and that having that uncertainty would have benefitted the decision-making on the emergency management side. Rothfusz and Coauthors (2018) proposed that information gaps can be lessened by communicating uncertainty and by increasing communication through phone calls, a webinar, and other forms. Along with those options, FACETs, as a model, is hoping to also assist in the closure of information gaps (Rothfusz and Coauthors 2018). In addition to Rothfusz and Coauthors (2018), other authors suggest that the NWS forecasters should include EMs in forecast discussions and that NWS forecasters should consider phrasing their briefings in a way that are not too long or complicated for EMs and other partners to understand (Hoss and Fischbeck 2016; Demuth et al. 2012).

Knowing that many EMs care about their partnership with NWS, even though there are some issues in communication, demonstrates why it is so important for there to be social science research and a vulnerability tool, like BVOT (LaDue and Coauthors 2017; Friedman and Wagner 2018; Friedman 2019). BVOT could be used to help close the information gaps and messaging on uncertainty as it provides forecasters the situational-spatial awareness of vulnerabilities that EMs are looking for when they receive IDSS. Being familiar with the relationship held between EMs and NWS forecasters and what BVOT was designed to do, allows this research to explore how EMs are served by the BVOT by NWS forecasters.

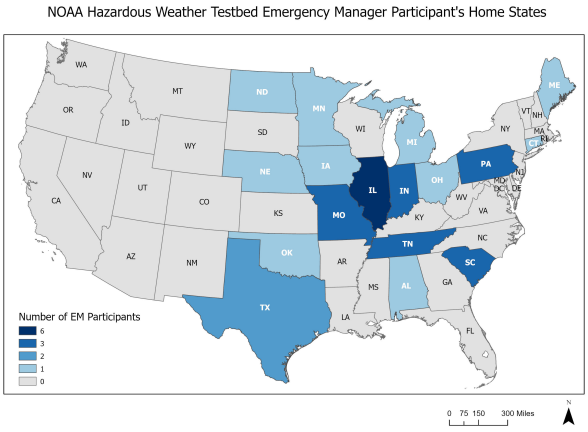

FIG. 1. The home states of the EMs that participated in the NOAA Hazardous Weather Testbed. The darker the blue the higher the number of EMs that participated.

3. Methods

a. Participants

Data used in this research were from the BVOT Hazardous Weather Testbed Project, which took place virtually over a period of six experiment weeks with a total of 35 NWS forecasters and 38 EMs from across the United States. Of the 38 EMs that were selected for research, some had limited availability during their experiment week, therefore the data presented will represent the EMs that were available in the cases that were qualitatively analyzed. Regarding the type of jurisdiction, 22 were county, 9 university, 3 city, and 1 each were state, hospital, fire, or military. The majority of EMs were located in the Midwestern United States, as indicated in Figure 1.

b. About the Project

Each week consisted of eight weather cases and introductory and summary discussions. Weather cases ranged in severity and expected hazards, and each case consisted of three periods, the first being 24–48 hours before the storm, the second being 4–12 hours ahead of the storm, and lastly, a 35-min "storm on the ground" period. The forecasters were paired with the EMs to share information, if and as needed, during the different periods within a case. At the end of each week, there was an end-of-week discussion where EMs discussed what went on throughout the week and provided thoughts and feedback. All sessions were recorded with the participants' permission. This study was conducted under the purview of The University of Oklahoma's Institutional Review Board.

c. Data Used in This Study

For this analysis, all discussions of the BVOT tool were extracted from the EM session recordings and professionally transcribed, as were the end-of-day debriefings on Day 3 and the end-of-week discussions. Analysis began by reviewing an instance of Case 5 to understand better the nature of the data and activities participants engaged in. Structural coding was then done on extracted BVOT-relevant data to capture broad topic areas while writing memos to capture initial analysis of the data and identify emerging themes (Saldaña 2021). Second-pass coding then followed by reviewing structurally coded data segments in their context. Thematic codes were inductively created during this process of reanalyzing the data to answer the research questions.

4. Findings

To focus on BVOT and its effects on EMs, the most saturated code, BVOT_General, was broken up into subcodes for second-pass coding. The five subcodes that most closely addressed the research questions and were moderately saturated were BVOT_Before, BVOT_During, BVOT_After, Mutual_Aid, and EM_NWS_Partnership. Besides the five subcodes, it was also noticed that EMs' views on BVOT changed during the week as they gained more experience.

a. Progression of Thought

Some EMs stated during the end-of-week discussions that BVOT could serve them more than they originally thought. In order to demonstrate the progression of EMs' thought processes, the EM had to be present in at least 75% of the cases that were analyzed and had to show some change in thought-process related to BVOT. Out of the 38 EMs, 17 were present in 75% of their week's cases, and five of the 17 showed progression of thought on BVOT. Only three of the six cases were represented in this theme. The other 12 EMs that did not show a progression of thought usually kept their same opinion on BVOT or did not verbally state their opinion on BVOT even if they were present in the case.

How an EM's thought process on BVOT changed is shown when a county EM, referred to as County 1, at the beginning of the week stated,

> If it's local, I'm gonna hear that and I'm gonna understand where that's at for me and be able to make my decision on that. I don't need them. . . I don't specifically need them looking for a target in a tornado warning.

After the EM has made it through the other cases and was starting to understand how BVOT could be beneficial, the EM's opinion changes by the end-of-week discussions:

> Yeah, I think it's a great tool. And like [the other EM] said, for the forecasters to have it so that it gives them some reminders... I kind of forgot about that over there. So, [BVOT] would be a great tool to have that outlined in a map. And then it would also help us in exercising. Because then we could talk about those things and have it already there. (County 1)

While this is only one example out of the five EMs that outwardly showed progression of thought about BVOT, they did not all have the same progression idea. Some EM thoughts that showed progression were: periods of time when BVOT was useful, what weather events that BVOT could be used in, and if BVOT was even useful to realizing that it could produce situational-spatial awareness in EMs and NWS forecasters. To demonstrate how the ideas of progress were different: County 6 originally thought BVOT would only be useful during a storm to then viewing it as useful before as well; Fire 1 also saw it as only useful during a tornado, but eventually realized it could be used during wildfires and flooding; and lastly, County 8 originally thought BVOT would create "tunnel vision" for forecasters but eventually saw that it could create situational-spatial awareness.

While some EMs had progression, others may not have stated their opinions about BVOT for it to be analyzed, but there is a possibility their opinion did change, as one university EM said,

> I mean, definitely my opinion has kind of changed with some of the products and stuff from day one. I mean, I think for all of us, we probably didn't really fully understand their use, and I've definitely seen, like, the advantages to it. (University 1)

b. Before the storm

When EMs expressed which time period BVOT would be useful, the majority expressed multiple time periods. Many EMs stated that BVOT could provide some assistance before a storm. The definition for this code was "when BVOT is being seen as useful before a weather event".

Across the 27 discussions on BVOT over the six weeks, this code was used 15 times and 11 EMs out of the 18, that expressed an opinion, said BVOT was useful then. An example of when this code was used,

> It would really be helpful to anticipate what's going on, what's gonna happen, so that you can help a little bit more, too, and be a little more proactive instead of reactive. Be proactive. (County 2)

For the EMs to be more proactive, they would consider using BVOT before for: preparing for "flooding events" (County 2), being aware of "vulnerable places" (County 3) such as schools, "care centers, hospitals" (County 3), areas with "communication outages" (University 2) or mobile homes and communicating the threat to them sooner, canceling events that have a dense amount of people, like "football game[s]" (University 1), where a storm will impact and notifying schools of a weather hazard to get students and faculty home before the storm hits. While there were many reasons to find BVOT useful before a storm, EMs also found BVOT useful during and after.

c. During the storm

Using BVOT during the storm was the most popular amongst the EMs that expressed their opinions, with 12 EMs out of 18. The definition to code BVOT_During was "when BVOT is being seen as useful during a weather event" and was used 17 times similar to,

> So we pretty much know, based on time of year where it's going to come from. But we don't know the impact and [the storm direction] could change. So there are a lot of variables as far as that goes. We could anticipate, we could predict, but we know what happens with predictions. (County 4)

Additional reasons EMs found BVOT useful during an event were: to see if "my neighbors are going to take a hit" (County 5), where "the vulnerabilities and stuff" are (County 3), and "figure out where you're sending your resources" (Fire 1).

The majority of the time when an EM mentioned finding BVOT useful during a storm, their main focus was on tornadoes (the focus of this project). The EMs noted that having the ability to track the storm and see locations that were being impacted would support their communication with their resources that are out, such as paramedics. A university EM said, in response to being notified where the tornado was headed,

> They just posted the Momakat Rescue would be right in the path, looking at the downstream. So... the ability to identify which of my response resources are about to be run over. That's well above any capability we've had before. (University 3)

When NWS forecasters had BVOT and there was a storm on the ground it was common for them to communicate the specific, vulnerable locations to EMs.

d. After the storm

For the final time period, nine emergency managers found BVOT useful. The definition for this code of

BVOT_After was "when BVOT is being seen as useful after a weather event" and was coded 12 times. At this point, an EM's focus shifts to response mode:

> After the storm is through, then you're looking at all that critical infrastructure and also those areas that need attention first if the bad things really did happen in your county. (University 4)

EMs said BVOT was beneficial afterward to point "EMS, ambulances, and recovery" (County 3) to critical infrastructure that was impacted by the storm. BVOT would also help them work with NWS forecasters to identify the locations of the impacted areas to the mutual aid coming in from surrounding counties to know where to go for "damage assessment" (City 1), and verify warning locations for the NWS forecasters.

e. EM-NWS Relationships

Prior research has shown that the relationship between EMs and NWS forecasters takes time to form and that in order for it to form, there must be communication between the two parties (Ernst et al. 2018; Lussenden 2014). That same research applies as some EMs either felt a great appreciation for their forecasters, especially with the use of BVOT, or had a decent relationship but did not trust them as they are not familiar with their forecaster completely. To capture this idea of EM-NWS relationship, it was coded as EM_NWS_Partnership, defined as "when an EM is talking about their relationship/partnership with a forecaster in this testbed and how they appreciated or did not appreciate something in their communications." An example of an EM that seemed to have a great appreciation for their forecaster said,

> [The forecaster] did a wonderful job providing as much detail as she could as often as she could, so I appreciate that. I know initially, once we had a confirmed tornado on the ground, the first thing she did was send me the vulnerability communities that she had identified. (County 6)

While another EM that seemed to appreciate them, but with some drawbacks to not being too familiar stated, "I think it was pretty professional, pretty straightforward. We obviously don't have a relationship with them." (County 7). While these are only two comments from the EMs, it does demonstrate the general relationship that some EMs experience in this research with their forecasters. It also displays how the lack of familiarity between the EMs and forecasters may have impacted the potential closing of the information gap with BVOT.

f. EM-EM Relationships

Although the goal of this research was to improve understanding of messaging to EMs and assist in the closing of the information gaps, the inductive, thematic coding revealed that it is not just the EM-NWS relationship and communication that BVOT can improve, but also EM-EM relations.

Many EMs made comments about using BVOT to help out their neighbors if they saw that a storm was devastating that county. In order to capture this idea of mutual aid, comments made by an EM or NWS forecaster were qualitatively coded at Mutual_Aid. When an EM would discuss mutual aid, the majority said something similar to:

> Something that just popped into my head is that if I'm looking at this and realizing that my neighbors are going to take a hit, I can look at the BVOT and figure out what kind of damage they were gonna have, potential casualties, so forth, and what support I might be able to provide them if I don't take a hit. (County 5)

The ways that some EMs saw using BVOT to assist in mutual aid was by looking at the impacted EM's county and saying, "he's got this, he's got this, he's got that. I need to look at this and look at that" (County 3) and then "send[ing] select people to other locations" (County 5) to assist that county's response and recovery.

While the purpose of this research is to focus on EMs, one case that was analyzed demonstrated that even forecasters can use BVOT for mutual aid by stating,

> If other offices are doing backup for another office, having the BVOT will be really helpful for getting quick situational awareness if you have to go into backup and you don't know the area. (Forecaster 1)

The NWS has a continuity of operations plan (NWS 2022) through which another office will take over forecast and warning responsibility if an office loses communication or capability to provide their services. However, a backup office is not likely to have detailed local knowledge.

g. Information Gap

The FACETs model states that information gaps can be closed by increasing communication between NWS forecasters and EMs (Rothfusz and Coauthors 2018). BVOT, being a FACETs-inspired tool, the goal was to use it to assist in the closing of information gaps. In the 27 transcripts, four EMs across five transcripts expressed a point in time where they were not receiving information or there was a lag in getting information from their forecaster. One EM stated,

> The only thing official that we had was at 9:00, other than that 11:30, you know, tornado watch

> in three fourths of the state, and then the next thing that we know, I'm getting notified by the forecaster that we have a confirmed tornado on the ground. And this is, you know, the vulnerabilities that are already on its path. So somewhere in between there, whether there's a short briefing that should come out, or at least a conversation on what our new realities look like. (County 6)

Despite the other three EMs mentioning something similar of not receiving information or a lag of information, the majority seemed to agree that the forecasters had a lot on their plate and that if it were their own county they would have reached out more since some of them have a good relationship with their forecasters. Another EM even mentioned that "at this point, we're really not so much dependent on direct communications with NWS other than the watches and warnings," (County 4) which demonstrates that some EMs have become accustomed to the information gaps that they rely on other resources, while other EMs may just reach out to their resources.

5. Discussion

The progression of thought observed in this research demonstrates how some EMs changed their minds about BVOT over the course of a week. While there may have been more EMs that had changed their minds, they may not have verbally expressed it. This section shows that the introduction of a new tool, such as BVOT, takes a while for people to adapt to and feel out. Although some grew to like the use of BVOT in different ways, one EM explained that it is hard to have a full understanding of its potential and use without using it in the real world in real-time.

Previous findings on EM-NWS relationships and the information gaps that EMs experience were mostly demonstrated in this research. Throughout this research, EMs solely relied on their forecasters to help support their decision-making. Before the storm, EMs were listening to their forecasters on what to expect and making note of areas that were vulnerable on the BVOT. When the storm was on the ground, the forecasters were giving locations the storm may impact so EMs could start communicating those locations to their resources on the ground and organize recovery resources for once the storm passes. Then lastly, they used the points that were mentioned by forecasters during the storm and locations mentioned in the storm reports to send their team out for recovery and damage assessment.

This project demonstrated how the use of the BVOT enhanced the communication between EMs and forecasters. While it enhanced some of their communication by making forecasters more situationally-spatially aware, some EMs were unable to build trust with their forecasters. As Ernst et al. (2018) found, it takes time for that relationship to be built.

While this tool's main focus was on the improvement of EM-NWS communication, many EMs across the transcripts expressed using BVOT to assist in mutual aid if a neighboring county was impacted by a storm but their county did not. EMs discussed that by looking at a neighboring county's BVOT points and watching the storm go through, they can assist in preparing their own recovery resources to aid that county once a storm has passed.

This theme of mutual aid was prevalent as EMs explained that they look out for each other when a severe event has occurred. In the one case that included forecasters, mutual aid was also demonstrated as a forecaster acknowledged that by having another office's BVOT points if that office gets shut down due to the storm, the other office can come to their aid and continue to communicate how the weather might be impacting vulnerable points to the EMs.

One of BVOT's goals was to assist in the closure of the information gaps that EMs experience during severe weather. This research discovered that despite that being a goal, the goal was not met as expected. With the four EMs that described not being given a heads up or experiencing a lag in information, it can be inferred that other EMs may have had a similar experience and did not mention it. Some of these EMs were in the experimental condition where their forecaster did not have the BVOT for a particular case. Either way, the factors that could have come into play to still allow information gaps is that EMs were not familiar with their forecasters enough to reach out to ask questions about what is going on and not being familiar with the vulnerabilities, geography, and BVOT.

The findings presented in this paper answer the research question of how well EMs are served by the use of BVOT by NWS forecasters. Emergency managers are served by being provided vulnerability points that the forecasters are looking at that could be impacted before, during, and after the storm, and providing the specific location that needs to have emergency resources sent to first. While they are served during different periods of storm events, they are also served in improving the communication between EMs and forecasters as forecasters include the specific points that EMs must be aware of.

Finally, due to this research being conducted in a testbed, some limitations may have affected what the data may have looked like in the real world in real-time. The limitations of this research were that most of the EMs were self-selected, which may lead to more of the EMs having more experience or knowledge about weather. Other limitations included that there were only a small number of participants, EMs did not have access to some things they are used to using for their decision-making, like their own radar displays, and the EMs were unfamiliar with the area used which could have affected decision-making

time. Lastly, and most importantly, the BVOT was tested on a limited range of potential tornado cases, though the BVOT also has layers for other hazards. Despite these limitations, some grew to like the use of BVOT in different ways, one EM explained that it is hard to have a full understanding of its potential and use without using it in the real world in real-time:

> Put it in real time, hand it to us and let us destroy it a little bit, then hand it back and say, yup. We broke it. Want to fix this and send it back?... A lot of what we do. We get stuff and tear it up and say, yeah. That didn't work out quite as you said it would work out, so if you could fix that little bit there and send it back, that would be just outstanding, thanks. (County 3)

6. Conclusion

The Brief Vulnerability Overview Tool being used by forecasters was able to serve EMs before, during, and after a storm, along with impacting the NWS-EM and EM-EM relationships and the information gaps experienced by EMs. This conclusion was made after completing qualitative analysis, which included structural coding and second-pass coding from data that was gathered over six experimental weeks and 38 EMs. This research demonstrates that BVOT assists EMs in different weather periods, which allows EMs to make decisions about the communities they are most concerned about. It also shows how the communication between EM-NWS and EM-EM changes for the better in order to benefit the partners and their counties.

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