An Analysis of the Communication of Winter Road Hazards between the NWS and Its Transportation Partners

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ABSTRACT: Past research indicates that drivers who utilize government sources, such as the National Weather Service (NWS) and the Department of Transportation (DOT), to inform their travel decisions during inclement weather are more likely to change their travel behavior. Therefore, collaboration and communication between the NWS and its stakeholders are vitally important to ensure consistency with road hazard messages. This study aims to obtain insight into the relationships between Weather Forecast Offices (WFOs) and their transportation partners with regard to how road hazard information is passed between these entities. An NWS-wide survey was conducted during winter 2023/24, which collected both qualitative and quantitative data. Analysis of survey data reveals that forecasters are in consensus over who they collaborate with, the communication channels used, the information they provide, and the importance and benefit of utilizing probabilistic guidance within road hazard messages to convey uncertainty. However, participant responses vary regarding strongly worded messages that imply road weather impacts, which suggests differing interpretations of the NWS directives. The level of collaboration WFOs have with DOTs is not consistent between respondents and appears to rely on the needs of the DOT office and their participation within the Pathfinder initiative. Additionally, forecasters appear to prefer probabilistic tools but anticipate interpretation difficulty and misunderstandings of probabilistic guidance by end users. Along with highlighting the current collaborative efforts between the NWS and its end users, the findings from this research will be utilized to inform future iterations of testbed evaluations to mitigate challenges during the development and testing of decision-support tools.

SIGNIFICANCE STATEMENT: Within this study, we evaluate the current collaboration efforts between National Weather Service (NWS) Weather Forecast Offices (WFOs) and their transportation partners in the context of road weather hazard information dissemination. Analysis of survey data from WFO forecasters indicates variations within road hazard message content they distribute and information (e.g., road conditions, road closures) they can repost from their stakeholders to the public. Relationships between the NWS and Departments of Transportation (DOTs) appear to depend on office participation within the Pathfinder initiative and the level of involvement requested by the DOT. Forecasters also differ in what tools they utilize when forecasting road weather hazards but have a slight preference for probabilistic products. However, participants indicate they anticipate end-user interpretation difficulties or misunderstandings with probabilistic guidance.

KEYWORDS: Social Science; Winter/cool season; Communications/decision making; Transportation

1. Introduction

Winter weather poses a significant threat to the health and safety of the driving public due to reduced friction from snow/ice and reduced visibility from blowing snow. In a typical year, over 550 000 vehicle accidents, resulting in around 1000 fatalities, are specifically attributed to winter weather (Road Weather Management Program 2023; Black and Mote 2015; Tobin et al. 2022). A National Academy of Sciences, Engineering, and Medicine (NASEM 2018) report emphasizes the importance of providing consistent and actionable impact-based messages that prevent confusion to those traveling. However, increased accessibility to numerous weather sources continues to result in message inconsistencies (Williams and Eosco 2021). Therefore, effective coordination between those in the weather enterprise responsible for communicating weather that may impact road safety is important. The aim of this study is to investigate National Weather Service (NWS) forecaster perspectives on their communication with transportation partners (hereafter referred to as partners) to assess what is shared and how messages are distributed to the public as a result of these interactions.

To foster this effective communication between the Weather Forecast Offices (WFOs) and a state's Department of Transportation (DOT), the Federal Highway Administration (FHWA) and NWS have partnered to create a voluntary program called Pathfinder (FHWA 2018, 2016; NWS 2019). The goal of Pathfinder is to ensure that public-facing road weather hazard messaging is consistent across agencies and provide a framework of best practices that helps define the relative roles for the various agencies involved with communicating road weather threats to

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the public. While Pathfinder was initially developed with winter weather in mind, it is utilized across a variety of meteorological events such as flooding, fog, fire weather, dust storms, and heavy precipitation (FHWA 2016) or special events like solar eclipses (FHWA 2022) where road conditions, traffic, or visibility are impacted. The expected benefits of this initiative and its associated workshops are more informed drivers as well as improvements to safety and collaboration (FHWA 2016). Notably, Dao et al. (2019) found that the NWS appears to be the preferred source of weather information for DOTs before, during, and after winter events. However, some evidence suggests that merging to a shared narrative between the NWS and its partners (e.g., DOTs, emergency managers, media) remains a challenge (Uccellini and Ten Hoeve 2019; Trujillo-Falcón et al. 2022; NASEM 2018).

The importance of collaborative and consistent messaging between the NWS and its partners for all forms of weather is increasingly acknowledged in the broader weather community (e.g., Klockow and Jasko 2016), including the transportation sector. Barjenbruch et al. (2016) found that drivers who receive information about impacts to roads from a government source (e.g., NWS and DOT) are more likely to alter their travel behavior. They also discovered that when a shared narrative is presented by both the transportation community and the NWS, the public responds by changing their plans (e.g., using different routes or changing departure times). This notion has gained such widespread acceptance that the NWS directives codify that forecasters should coordinate with their state DOT when using call-to-action statements within their public-facing products (NWS 2019).

One complicating factor for communication between the NWS and its partners is the presence of private-sector weather support. To avoid having WFOs infringe on the private sector, the NWS has directives that provide a guideline and identify certain forecast activities as being within or out of scope. Relevant excerpts from the Applied Impact-Based Decision Support Services (IDSS)–Surface Transportation NWS directives (NWS 2019) are provided in appendix A. Actions that are within the scope of the NWS directives include providing consistent messaging of impacts, timing, confidence, and general weather information (appendix A, section a). Conversely, providing information that speaks directly to the current or future road conditions, guidance on road treatment, or road temperature predictions is deemed to be outside of the NWS' scope (appendix A, section a). However, it is evident from several informal conversations that different forecasters and/or WFOs may be interpreting the directives differently as far as what can and cannot be shared or communicated with the public. It is unclear whether or how these interpretations may impact the communication of road weather threats to their partners and the public.

Another complicating factor is the agency-wide introduction of probabilistic guidance, as well as the ongoing discussions over whether nonmeteorologists can effectively use it. Ripberger et al. (2022) completed a comprehensive review of past studies that focus on the inclusion of probabilistic guidance when conveying risk and the impacts it has on the public's decision-making. They found that the literature supports the idea that members of the public can generally understand probabilistic forecasts and make more informed decisions when probabilistic information is presented to them (Grounds and Joslyn 2018; Joslyn and LeClerc 2012), but they may have difficulty personalizing those probabilistic forecasts (Ripberger et al. 2022; NWS 2018). As a result, NWS forecasters express varying degrees of comfort providing probabilities to their partners (Tripp et al. 2023; Karstens et al. 2015). Specifically, some note that they personally have difficulty interpreting probabilistic data and are therefore hesitant to present it, whereas others consider themselves proficient and include probabilistic guidance within their messages regularly.

Differences in the nature of collaboration between WFOs and their partners, their interpretation of NWS directives, and their use and dissemination of probabilistic guidance are reasonable to expect, as individual NWS offices should tune their approach to best fit the needs of their partners. However, these differences can present complications for the development and testing of new decision-support systems if developers are unaware of the broad range of forecaster perceptions and beliefs. The research questions posed within this paper are as follows: 1) Who do NWS forecasters collaborate with in the transportation industry? 2) In what ways do forecaster interpretations of NWS directives affect what content is messaged to communicate winter weather transportation impacts? 3) To what extent do NWS forecasters use a variety of probabilistic tools to assist with messaging winter weather transportation impacts?

2. Survey metadata and methodology

a. Survey metadata

To answer the research questions posed in the previous section, we developed a survey that focused on these three topics. This survey was approved by the University of Oklahoma's Institutional Review Board (IRB) and then distributed through Qualtrics. A recruitment email with a description of the survey and an anonymous link to the survey was sent to the meteorologist in charge (MIC) and science and operations officer (SOO) for all 122 NWS WFOs. Invitees were allowed to share the survey with others in their office, but all participants were active NWS forecasters. To ensure responses remained in the context of winter weather, both the recruitment email and consent form at the beginning of the survey explicitly state that the survey focuses on winter weather road hazards and messaging. Additionally, either the phrase "winter weather" or other winter terminology was utilized within survey questions or response options where it was pertinent. The survey contained 33 questions divided into four sections: 1) participant demographics, 2) the WFO's engagement with their partners, 3) participant interpretations of NWS directives, and 4) how participants message winter weather impacts to the public, particularly through probabilistic guidance. Respondents were primarily asked multiple-choice questions, some of which they could select all that apply to their situation and some open-ended and Likert-scale questions as well. Participation in the survey was voluntary, and all survey questions were optional; therefore, the number of responses varies for each

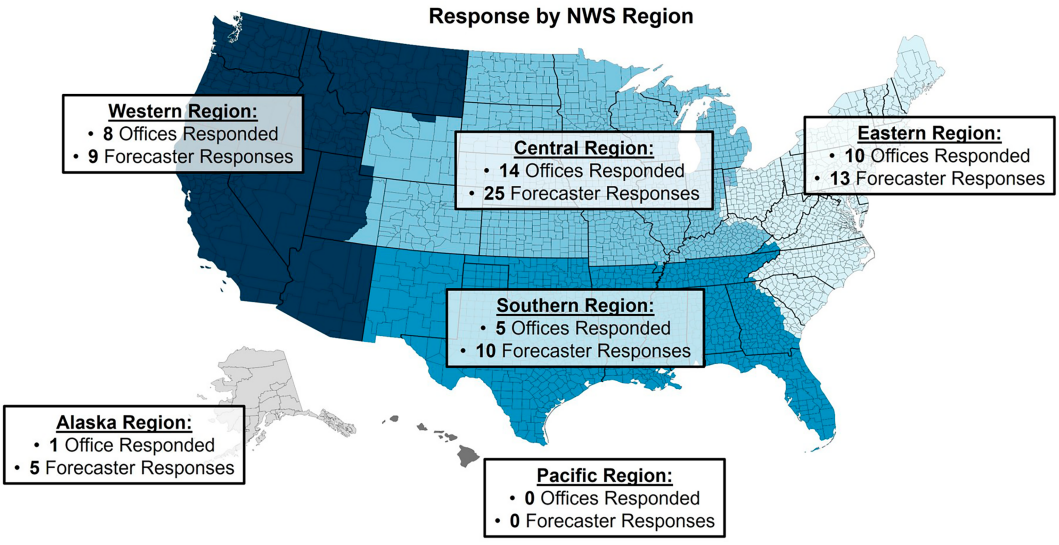

FIG. 1. Number of survey responses from both individual WFOs and total forecasters with respect to NWS region (QB4.1).

question. The number of collected responses (*N* value) for the questions discussed in the results section is included within their corresponding figures. On average, participants completed the survey in 20 min. The survey was available from 14 November 2023 to 31 January 2024. This study will focus on a subsection of the survey questions, 20 out of 33, as some did not yield relevant results for this discussion. A list of these survey questions is provided in appendix B, and the referenced question number (Q#) is included in each caption.

b. *Participant demographics*

Figure 1 shows the number of responses in each of the six NWS regions. Thirty-eight NWS offices are represented, with a total of 99 respondents. Central and eastern regions have the most responses, followed by western and southern regions. One response is provided from the Alaska region, and the Pacific region has no respondents. Twelve WFOs also have submissions from multiple employees within the same office.

The current position held by each respondent at the time of the survey is provided in Table 1. Most have General Schedule 11/12 (GS 11/12) or SOO titles (Department of Commerce 2025), but all positions are represented in the participant pool. The number of years of operational experience for each participant was also queried (Table 2), with the majority of respondents having over 15 years of experience.

TABLE 1. The number of respondents categorized by position, where GS is government service and WCM is warning coordination meteorologist.

GS 5/7/9	GS 11/12	Lead forecaster	SOO	WCM	MIC	Other
5	19	11	17	13	11	1

c. *Methodology*

Qualitative and quantitative methods are used to analyze the survey output. Specifically, qualitative thematic analysis is used to reveal themes within the open-ended response questions by inspecting the responses for similar phrases or thoughts. Grounded theory (Patton 2002), or the generation of a theory utilizing the data itself, is used to create thematic codes. Multiple choice and Likert scale questions are analyzed quantitatively by calculating the response frequency for each question. These methodologies are used to analyze the dataset in its entirety, by NWS region, and between individual WFOs.

3. Results and discussion

Through the quantitative and qualitative methods described, an analysis of the dataset as a whole revealed three key themes: 1) Various relationships exist between the NWS and its partners, 2) there are differing interpretations of NWS directives, and 3) there are differences in what and how winter weather impacts are messaged. Results that fall within each theme are described and discussed below.

a. *Relationship between the NWS and its partners*

Respondents were asked to choose among a list of options with which partners they collaborate. The word "collaborate" was used to distinguish an active collaborator from a passive receiver of weather information. All but one respondent noted that they collaborate with state DOTs (Fig. 2a). This is

TABLE 2. The number of respondents categorized by their years of operational experience within the NWS.

1–5 years	6–10 years	11–15 years	15+ years
15	12	9	40

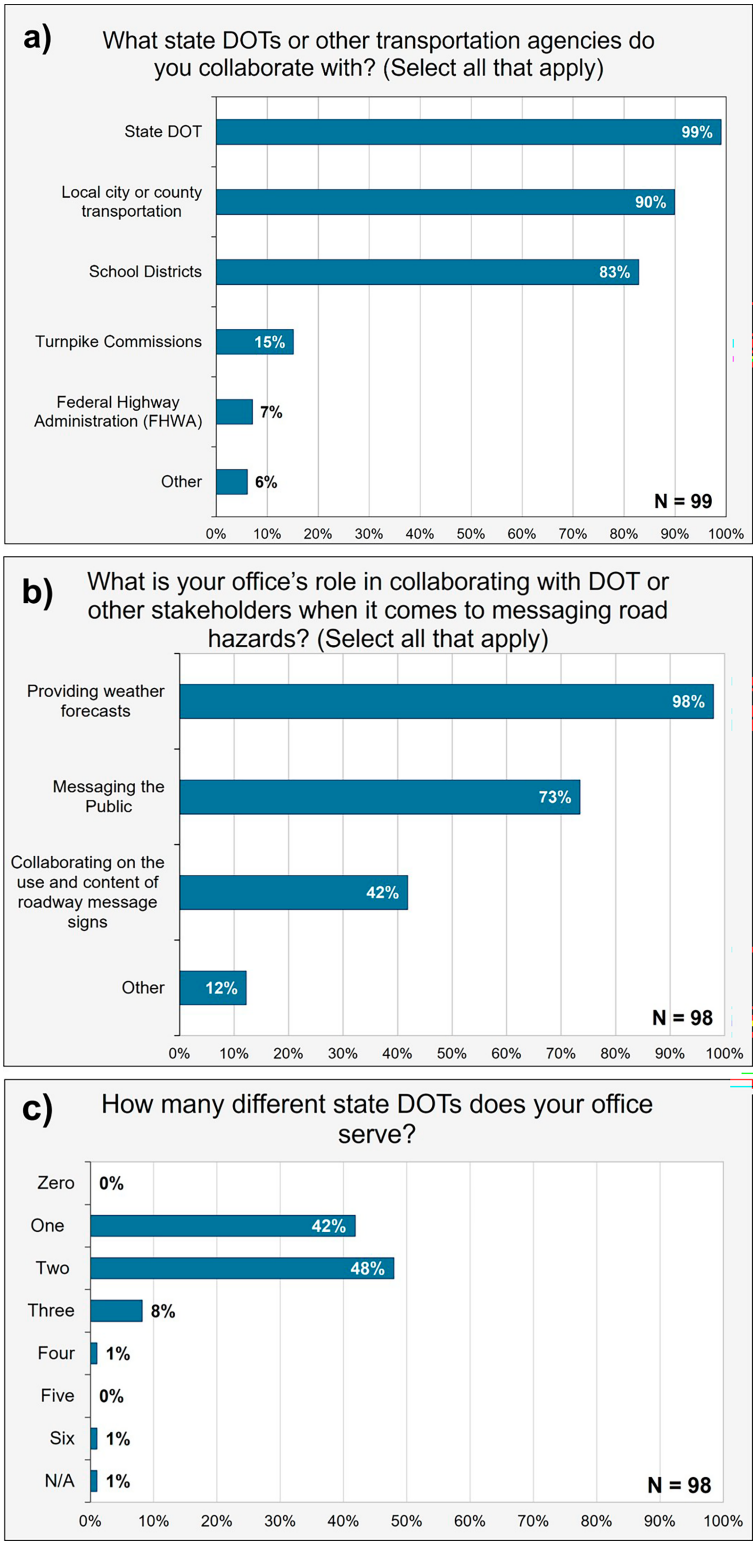

FIG. 2. NWS survey responses to the following prompts: (a) What state DOTs or other transportation agencies do you collaborate with (QB1.1)? Respondents were asked to select all that apply. (b) What is your office's role in collaborating with DOT or other stakeholders when it comes to messaging road hazards (QB1.4)? Respondents were asked to select all that apply. (c) How many different state DOTs does your office serve (QB1.2)?

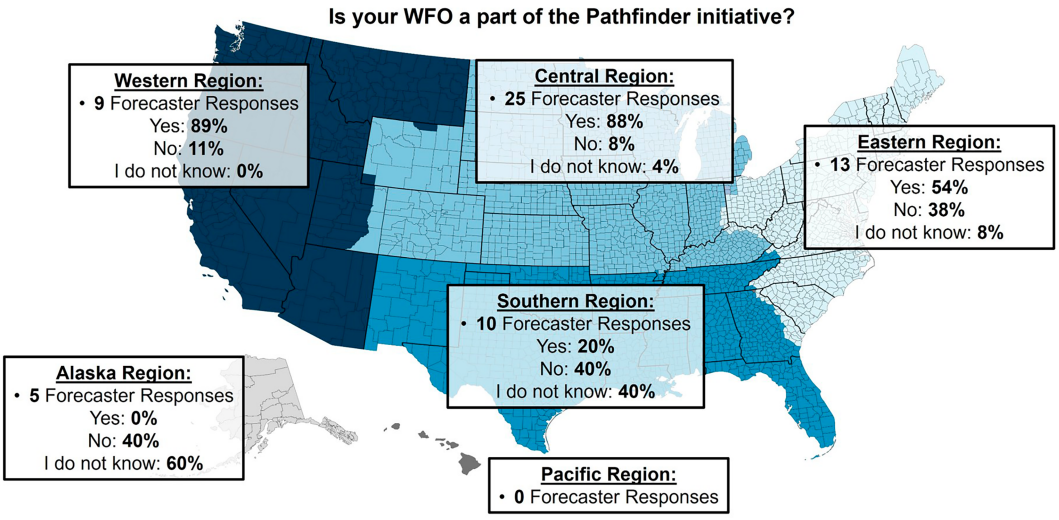

FIG. 3. Forecaster responses from survey QB4.2 asking if their WFO is part of the Pathfinder initiative. Responses are broken out by region and the number of forecasters who selected each option.

unsurprising considering that DOT agencies can cover large geographic areas and must coordinate their response to maintain safe roads and communicate hazards to the traveling public, which may include a large number of nonlocal travelers. Fewer respondents reported collaborating with city or county officials and school districts. The turnpike commission's option likely has a low response rate because not every county warning area (CWA) has a turnpike. The FHWA option also has a low response rate, but this is not an operational entity responsible for maintaining roads, so collaboration with them is less likely. Six respondents added other entities with which they collaborate, including airport authorities, other NWS offices, and state highway patrol.

Forecasters also perceive themselves as having multiple responsibilities when collaborating with their partners (Fig. 2b). Nearly all participants considered providing weather forecasts as their role. While developing collaborative messaging for the public, including those displayed on roadway message signs, falls within the scope for forecasters and is considered part of their responsibility [appendix A, section a(2), list item 5], less than half of the respondents selected this option (Fig. 2b).

Other roles the respondents considered to be a part of their collaboration duties include coordinating safety campaigns, obtaining feedback on services, and giving weather briefings/press conferences.

The lower response rate for contributing to roadway message signs highlights that there are different levels of service being provided by WFOs. It may be that individual WFOs refrain from participating in certain decisions unless they are expressed needs of their partners. In one of the open-ended survey questions, forecasters were asked how services they provide differ between DOT offices. Some participants suggested that they "provide more briefings to one state than another, as requested by [the DOT]" or that they "tailor according to [the DOT's] needs." Fifty-eight percent reported working in an office that serves multiple state DOTs (Fig. 2c), and 44% indicated they provide different services to each DOT. Many of these respondents noted that they have a strong relationship with one of the DOTs in their CWA, but they have less communication with the other(s). An additional finding through this open-ended survey question showed that in some instances, this is because the WFO in question is the state liaison for one DOT but not for the other(s). Some participants also stated that one DOT participates in the Pathfinder initiative, while the other(s) do not. Therefore, it appears that the DOT may play a meaningful role in establishing the level of collaboration between its office and its local WFO.

Participants reported varying involvement with the Pathfinder program, with 65% of them saying that their WFO participates, 22% saying they do not participate, and 13% saying they are unsure. A breakdown of participation in Pathfinder by NWS region shows that a majority of central and western region respondents indicated that their office participates (Fig. 3). Responses vary more in the eastern and southern regions. The southern and Alaska regions also appear to be the most uncertain if their WFO participates in Pathfinder. The central and western regions may have more response consistency as they regularly experience winter weather events, which was Pathfinder's initial focus. These regional variations could be improved upon through the continuation of Pathfinder workshops to help increase awareness of this initiative, improve collaboration and communication, and potentially aid in forming new partnerships.

Of note, some respondents from the same office answered the question of Pathfinder engagement differently. For the 12 WFOs that had multiple participants respond, three had interoffice disagreements about whether they participated in Pathfinder. In one extreme example, an office with five respondents had one "yes," two "no," and two "I do not know." It may be that some offices have a subset of individuals who are responsible for collaborating with state DOTs and others in that same office have limited awareness of what that entails. There are

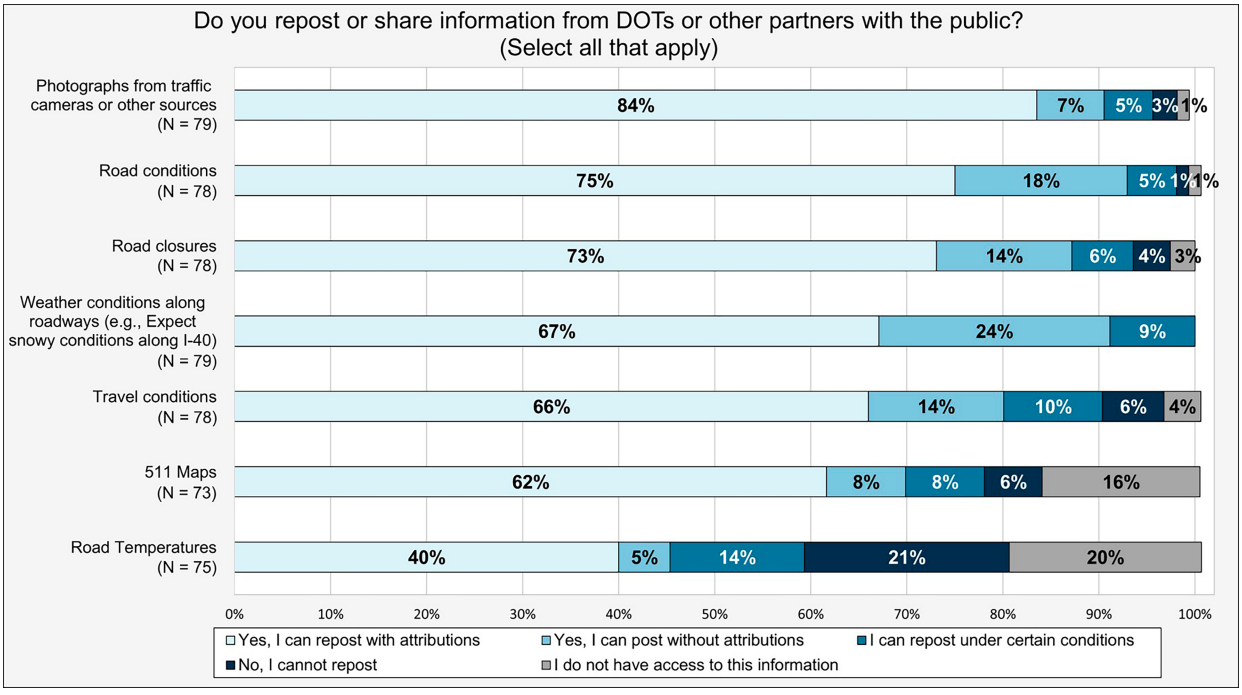

FIG. 4. NWS survey responses to the following prompt: Do you repost or share information from DOTs or other partners with the public (QB2.3)?

important implications of this hypothesis, if true. Some decision-support capabilities are under development and intended to help NWS forecasters effectively collaborate with state DOTs by assessing the current communication level between these entities. However, testbed evaluations of these capabilities may not be robust if the participants have limited to no engagement with their state DOT(s). Additionally, offices may not participate in Pathfinder or associate with the name, but they continue to deploy Pathfinder-like approaches when collaborating with their partners (R. Abtahi 2024, personal communication). Additional Pathfinder workshops or outreach could result in more WFOs associating with the Pathfinder name, consistent messaging to end users, more informed drivers, and enhanced lead time for resource allocation and procurement.

b. Interpretation of NWS directives

As noted in section 1, our anecdotal exchanges with NWS forecasters suggest they interpret the directives differently and may refrain from providing certain forecast information or messages to the public as a result. To ascertain whether this is true, survey respondents were provided with seven different kinds of information generated by either DOTs or their private-sector weather support in the survey. Respondents were asked to sort these as follows:

- Yes, I can repost without attribution,
- Yes, I can repost with attribution,
- I can repost under certain conditions,
- No, I cannot repost, or
- I do not have access to this information.

Most respondents believed that they could repost, with or without attribution, content such as traffic camera imagery, road/travel conditions, and road closure information (Fig. 4). However, a nonnegligible percentage of respondents indicated they do not have access and thus no ability to share certain information, namely, road temperatures (20%) and 511 interactive travel condition maps (16%). While the NWS directives do encourage forecasters to run and use road temperature models internally within the NWS [appendix A, section a(1), list item 2], the variation in the "road temperature" responses in Fig. 4 could be due to the NWS directives. For example, the NWS directives state that "dissemination of specialized road temperature modeling output to either the public or core partners" falls outside the scope of NWS forecasters (appendix A, section b, list item 3). As for 511 maps, it should be noted that not all states refer to their DOT's travel impacts map as "511." Therefore, some of the respondents who selected "I do not have access to this information" may utilize their DOT's maps but do not associate it with the 511 name. Nevertheless, a majority of the respondents (70%) still reported that they can repost 511 information with and without attribution and an additional 8% noted that they can repost under certain conditions.

Forecasters were also given a series of statements that include information about the weather as it applies to travel and asked to choose one of four options:

- Yes, I can say this,
- Yes, under certain circumstances,

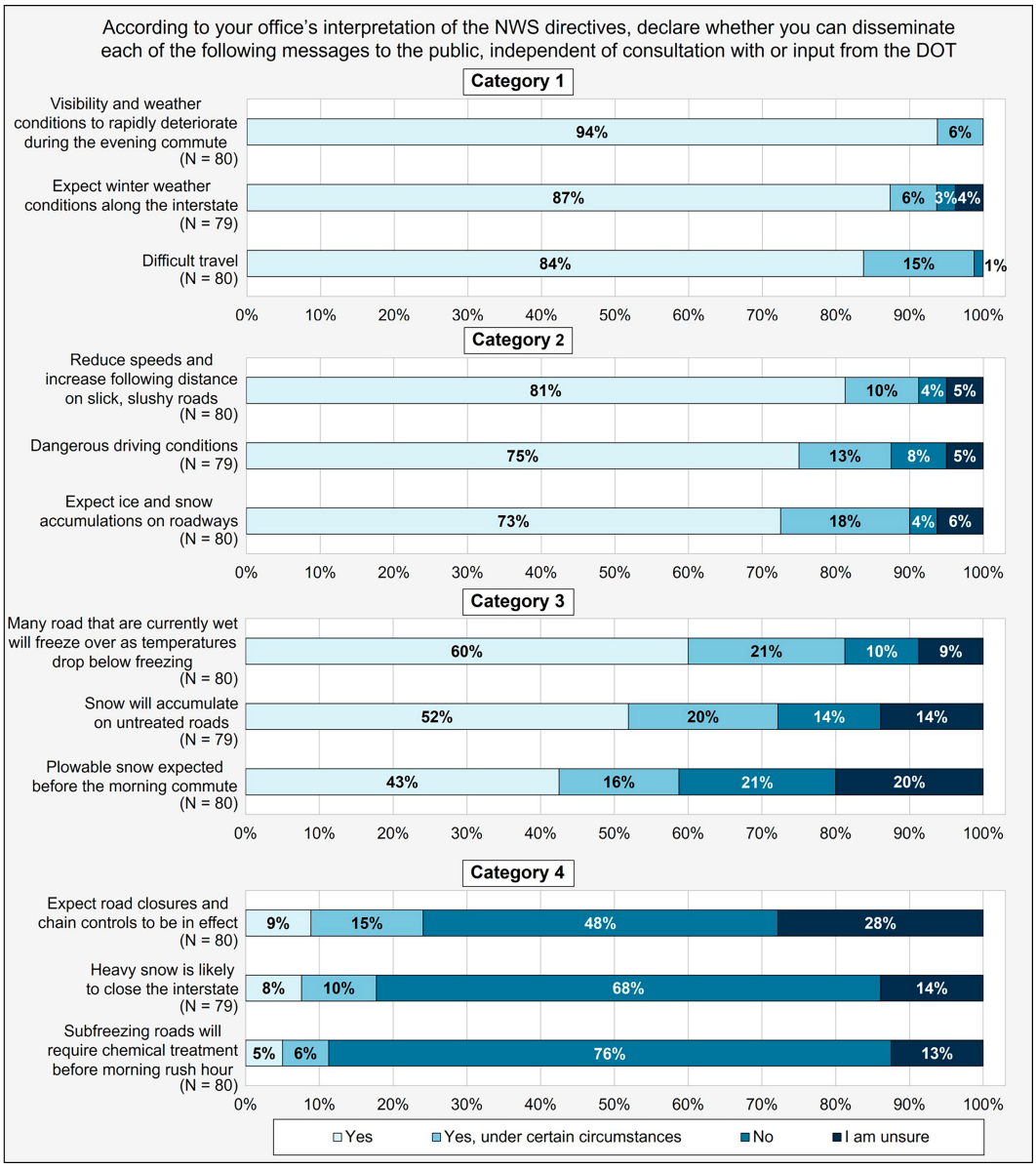

FIG. 5. NWS survey responses to the following prompt: According to your office's interpretation of NWS directives, declare whether you can disseminate each of the following messages to the public, independent of consultation with or input from the DOT (QB2.4).

- No, or
- I am unsure.

The statements included a spectrum of comments ranging from vague suggestions of how the weather may impact road safety to statements that specifically address the business needs of the stakeholder (Fig. 5). These statements are broken into four categories.

- Category 1: These statements focus on meteorological information such as amounts/timing/location and do not specify the impacts to roads (e.g., "Visibility and winter conditions to rapidly deteriorate during the evening commute"). Most respondents (84%–94%) said they could freely disseminate such content to the public (category 1 in Fig. 5).
- Category 2: These statements issue calls to action or make references to road conditions (e.g., "Reduce speeds and increase following distance on slick, slushy roads"). An increasing fraction of respondents (19%–27%) felt they could not freely disseminate such content publicly (category 2 in Fig. 5).
- Category 3: These statements reference how precipitation on roads, such as freezing or accumulating snow/ice, will be impactful and may allude to mitigative actions that the DOTs could/should take (e.g., "Snow will accumulate on

untreated roads"). Between 40% and 57% of respondents believed they cannot freely message such statements (category 3 in Fig. 5). About 16%–21% of the respondents chose no to indicate they cannot message this content, even conditionally.

- Category 4: In this category, strong language about people's ability to safely travel or business decisions of their partners is presented (e.g., "Subfreezing roads will require chemical treatment before morning rush hour"). The majority of respondents (91%–95%) believed they cannot freely message these kinds of statements (category 4 in Fig. 5). Between 48% and 76% of respondents stated they cannot message such statements, even conditionally.

It should be noted that most of the verbiage for the chosen statements reflects those that appear in official NWS watches, warnings, or advisories (Tobin et al. 2022). Exceptions include some of the statements in category 4, such as referencing chemical treatments of the road.

If forecasters chose "Yes, under certain circumstances" for any statement in Fig. 5, they were invited to explain. The following four thematic codes were developed from the 38 open responses provided: 1) required coordination with their DOT, 2) depended on forecast confidence, 3) out of scope for the NWS, and 4) case/event dependent. Half of the forecasters who suggested they could share information under specific circumstances indicated that coordination with the DOT is needed before messages can be disseminated. Specifically, they noted they would be able to share travel information if their DOT is messaging similar information to the public or if they are okay with the WFO sharing that information. Selected quotes that highlight this perspective are

> [We] would consider posting these if our partners at the DOT are also messaging in a similar fashion.

> We would message these statements as long as it matches the messaging that is being distributed by the DOT. Many times, this comes in the form of a retweet or sharing a Facebook post to our NWS social media.

Nearly one-third of respondents also noted that they would likely message these statements if it is expected to be a high-impact event or when they are confident in the forecast.

> We would use these for high-confidence, high-impact events (high end Winter Storm Warnings or Blizzard Warnings).

Seven respondents specifically suggested that the messages are out of scope for the NWS.

> As soon as the precipitation hits the ground, the information is OUT of our jurisdiction and needs to be avoided. This is the job of the private industry.

> [It] likely depends on how we frame the wording to ensure we do not get too far into the private sector's arena.

Last, they noted that their ability to share these messages is case or event dependent.

> It would probably depend on the actual situation and messaging for that event.

One unexpected result from this section of the survey was the lack of consensus by WFO forecasters. No single statement had a uniform response by the respondents, as every option was selected by at least one respondent for every statement, save for the first and third statements within category 1 in Fig. 5. Perhaps most striking are the four yes responses for the question regarding chemical treatment (third statement within category 4 in Fig. 5). This example was included by the researchers to capture a "clearly out of bounds" statement with regard to the directives (e.g., providing public-facing forecasts that imply future road conditions or travel impacts) (appendix A, section b, list item 2). Their free responses to this question imply they are aware of the directives and are intentional about respecting those boundaries, but they may interpret the directives differently or struggle to apply the directives to specific scenarios. Regardless, such a result suggests that the amount of detail and kinds of calls to action that are messaged to the public vary by forecaster and perhaps by office as well. This also has implications for the testing of new capabilities. Some forecasters may not feel the product is something they can use/message, given their interpretation of the directives. This, in turn, may impact how new products are rated in testbed evaluations or similar testing environments.

When asked whether they had any considerations when messaging winter road hazards to the public, 32 forecasters (44%) indicated that they are unsure where the "line" lies between messaging the weather and messaging potential impacts (Fig. 6a). When asked this same question about the DOT, 41 respondents (60%) expressed uncertainty about the boundaries implied by the directives (Fig. 6b). This difference may be a reflection of the nature of Pathfinder—it takes time for individuals from different agencies to learn how to best collaborate with each other. An interesting finding in Fig. 6b is that 25 of the respondents felt that they lacked meaningful insight into relevant road information. This highlights an important consideration regarding road weather—the impact is not a function of the weather alone. Impact can be increased or decreased by nonmeteorological controls. For example, increased traffic volume on highways around the holidays can lead to more accidents, or the application of road treatments, such as salt or brine, can mitigate travel impacts. These nonmeteorological controls, such as access to adequate infrastructure for road maintenance, are not the same everywhere as they can change on a regional, state, or local basis. Additionally, one of the roles of the NWS is to provide IDSS [appendix A, sections a(1) and a(2)]; however, challenges may arise if forecasters feel like they do not have sufficient information to assess potential impacts.

c. *Use of probabilistic weather forecasts*

Finally, respondents were given a selection of operational and experimental decision-support tools (Table 3) and asked to rank these as not helpful, neutral, very helpful, or not something they use to gauge potential impacts from winter weather on roads (Fig. 7). The products indicated as most helpful are all probabilistic. These are probability of ice (Weather Prediction Center 2025), probability of snow (Weather Prediction Center 2025),

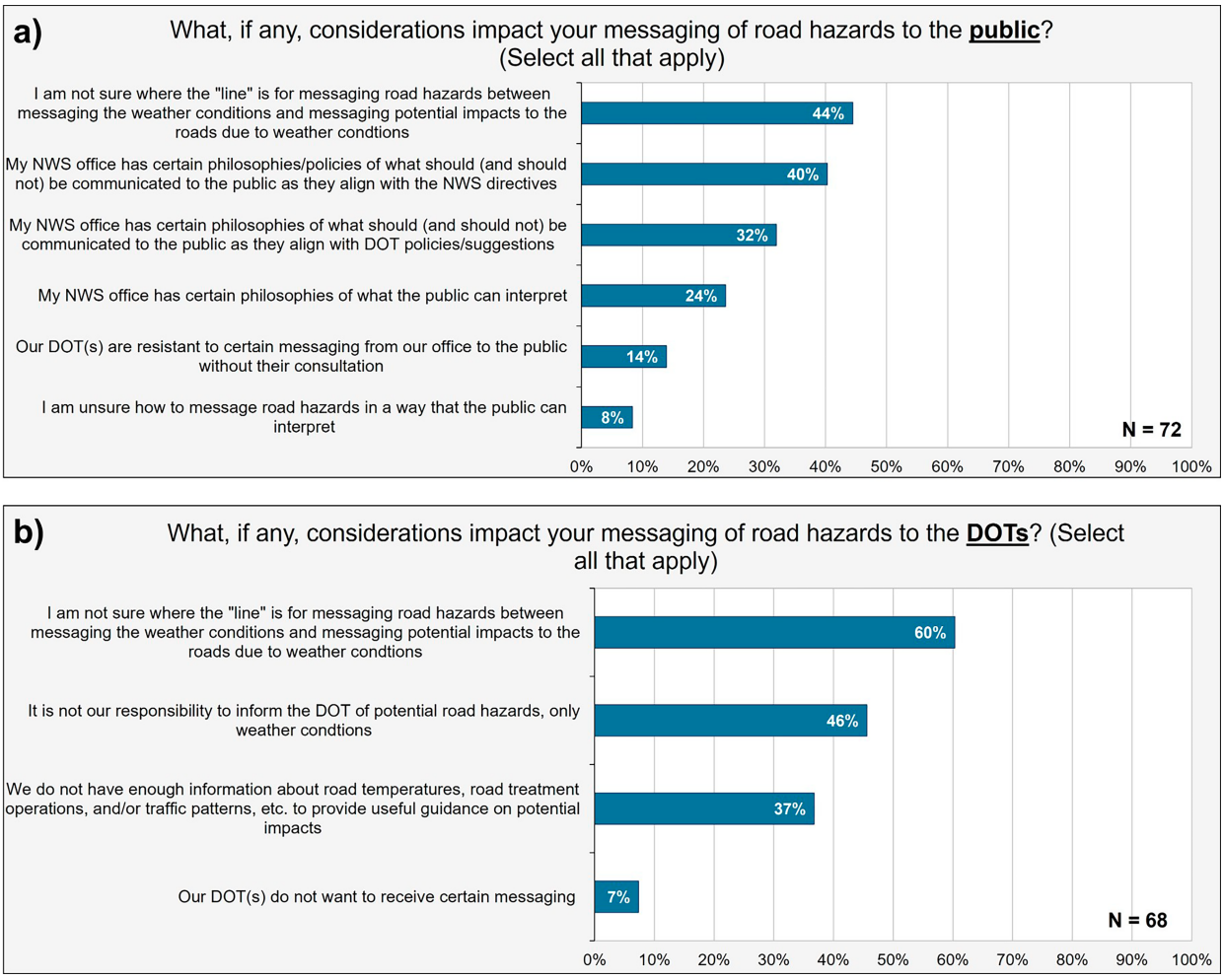

FIG. 6. NWS survey responses to the following prompts: (a) What, if any, considerations impact your messaging of road hazards to the public (QB2.2)? Respondents were asked to select all that apply. (b) What, if any, considerations impact your messaging of road hazards to the DOTs (QB2.1)? Respondents were asked to select all that apply.

National Blend of Models (NBMs; NOAA 2025), and probabilistic winter storm severity index (WSSI-P; NOAA 2023a). Three of the options are experimental and, therefore, not as heavily used. Respondents are more neutral toward these products, presumably because they are not as familiar with them. Forecasters also may be uncertain if they can utilize or disseminate information from experimental products since they may still be in development or in the testbed phase.

The majority of respondents (89%) indicated that they incorporate probabilistic guidance in their messaging to both their DOTs and the public (QB2.6). Sixty-eight respondents noted they have experienced challenges with messaging probabilistic guidance on winter road hazards (QB2.7), while 84% said that they have had success (QB2.9). Respondents were also asked what specific challenges they have experienced with probabilistic messaging. Seventy-six respondents said they anticipate end users will have difficulties interpreting this guidance, while only one forecaster indicated they personally have challenges understanding probabilistic information (Fig. 8a). Another 51% noted a lack of tools specifically designed for messaging probabilistic output, and 27% indicated that probabilistic information can be misleading. It may be that forecasters feel they have enough guidance for themselves to understand the meteorology and forecast uncertainty but that these decision-support aids are too esoteric for nonmeteorologists to easily interpret and apply to their own situations. Such a finding is not unique to this study—several other investigators have noted that forecasters struggle with how to message probabilities in a way that helps rather than hinders decision-making by their partners (Tripp et al. 2023; Grounds and Joslyn 2018; Joslyn and LeClerc 2012). In spite of the challenges of probabilistic forecasting, most respondents noted that partners benefit from probabilistic guidance. They believe that probabilistic guidance helps partners better prepare for the possible range of outcomes (93% of respondents) and that they recognize when the forecast is more uncertain (82% of respondents, Fig. 8b). Respondents (72% and 59%, respectively) also believe the public benefits in these same ways. Such findings are an important consideration

TABLE 3. Descriptions of the forecast tools that forecasters were asked to rank based on how helpful they are when forecasting winter weather impacts on roads.

Forecast tool	Description
Probability of snow	The probability that a location will receive snowfall accumulations greater than or equal to a specified threshold within 24 h (Weather Prediction Center 2025)
Probability of ice	The probability that a location will receive ice accretion greater than or equal to a specified threshold within 24 h (Weather Prediction Center 2025)
NBMs	An NWS and non-NWS-blended numerical weather prediction model that provides hourly forecast guidance (NOAA 2025)
WSSI-P	A gridded forecast product that provides the probability of minor, moderate, major, and extreme winter weather impacts (NOAA 2023a)
Deterministic WSSI	A gridded forecast product that provides the potential level (minor, moderate, major, or extreme) of winter weather impacts within a 24-h period (NOAA 2023b; Kastman et al. 2025)
Model of the Environment and Temperature of Roads (METRo)	An experimental gridded numerical forecast model that utilizes RWIS data and the National Digital Forecast Database (NDFD) forecast (Crevier and Delage 2001)
Hourly WSSI	An experimental 6-h gridded forecast product that provides the potential maximum level (minor, moderate, major, or extreme) of winter weather impacts (Tobin et al. 2024)
Probability of subfreezing roads (ProbSR)	An experimental product that provides hourly probabilities that the road surface is subfreezing (Handler et al. 2020)

for product development moving forward. The developer may need to first identify who this tool is supposed to help. Is it for forecasters to understand the weather, or is it for forecasters to message the weather, or both? If the tool is intended for the public, there is a special need for social-science-based evidence that it is beneficial for the public in order for forecasters to accept it as a reliable way to communicate threats.

Last, respondents were asked to choose from a list of options the probabilistic guidance their partners are most receptive to (Fig. 9). These are sorted into three categories.

- Category 1: These are simple, easily interpreted products such as maximum/minimum probabilities, probability of exceedance over an area, and timing information. The majority of respondents (83%–88%) felt their partners are receptive to this content.
- Category 2: These are more nuanced forms of guidance, such as point forecasts and probabilities of rarer phenomena (e.g., freezing rain). Only 55%–67% of respondents felt their partners would be receptive to this content.
- Category 3: These are relatively new decision-support aids and include probabilities of impacts or address particularly

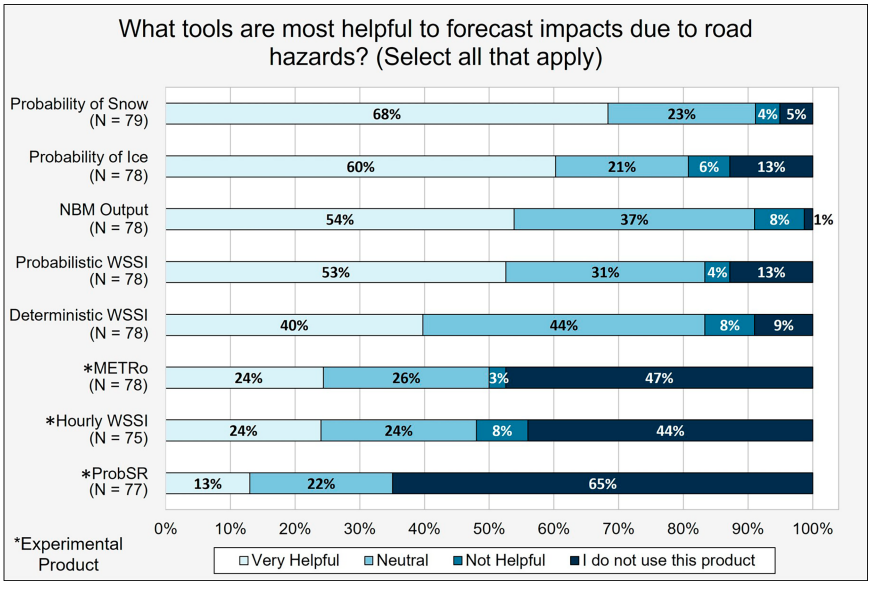

FIG. 7. NWS survey responses to the following prompt: What tools are most helpful to forecast impacts due to road hazards? Respondents were asked to rank the following tools as not helpful, neutral, very helpful, or I do not use this product (QB3.1).

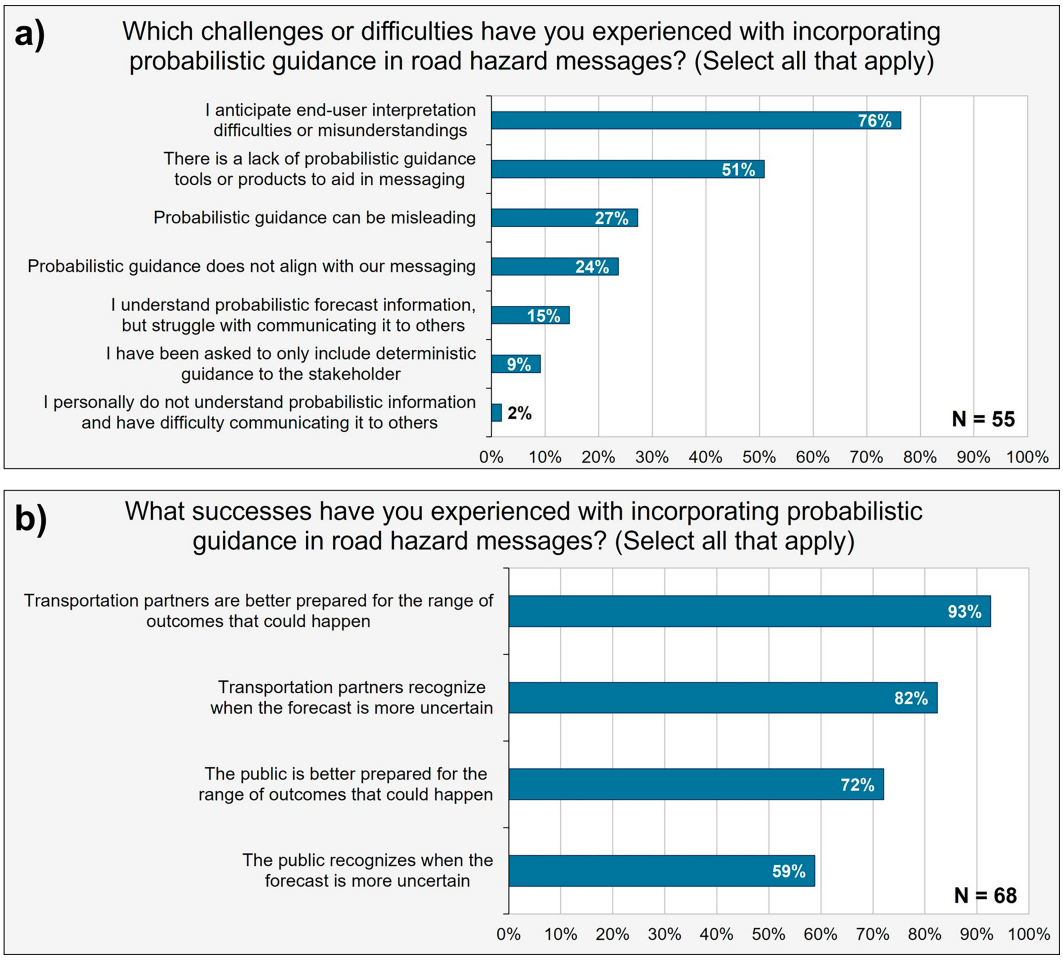

FIG. 8. NWS survey responses to the following prompts: (a) If yes above (QB2.8), which challenges or difficulties have you experienced? (b) If yes above (QB2.10), which successes have you experienced?

rare phenomena. Only 26%–37% of respondents felt their partners would be receptive to this content.

This kind of information points to two potential motivations on the part of the respondents. First is their desire to produce content that is easily digested so that the stakeholder can make quick decisions rather than spend time trying to interpret the weather. Second is the desire to disseminate "tried and true" graphics to their partners. We suspect that the respondents in this survey are reluctant to make their partners unwitting participants in experiments to identify what does or does not work.

4. Conclusions

In this study, we investigated the collaboration between NWS forecasters and their partners using an NWS-wide winter road hazards survey. Ninety-nine forecasters representing five out of the six NWS regions responded to the survey. They represent a spectrum of positional titles and years of experience. Questions were designed to understand 1) who NWS forecasters collaborate with in the transportation industry, 2) how forecaster interpretations of the NWS directives affect what winter weather road hazard content is messaged, and 3) the extent in which forecasters utilize probabilistic guidance to assist with messaging winter weather road impacts to transportation partners.

The majority of respondents consider state DOTs, city/county transportation officials, and school districts to be their primary collaborators. The kinds of services the respondents bring to the collaboration vary—some partners have a higher level of engagement and are more receptive to input from the NWS on their decisions than others. Respondents were asked about their engagement with Pathfinder, an NWS/FHWA initiative that provides a template of best practices to help DOTs, NWS forecasters, and private-sector agencies (if applicable) collaborate effectively. More than half of the respondents said their office participates in Pathfinder, but a significant fraction said they either do not participate or are unsure how to use the system. A reason for this could be that the label "Pathfinder" is unknown to them, but their office is still acting in the spirit of the initiative. Forecasters also highlight that cohesive messaging between DOT and NWS is essential when messaging road

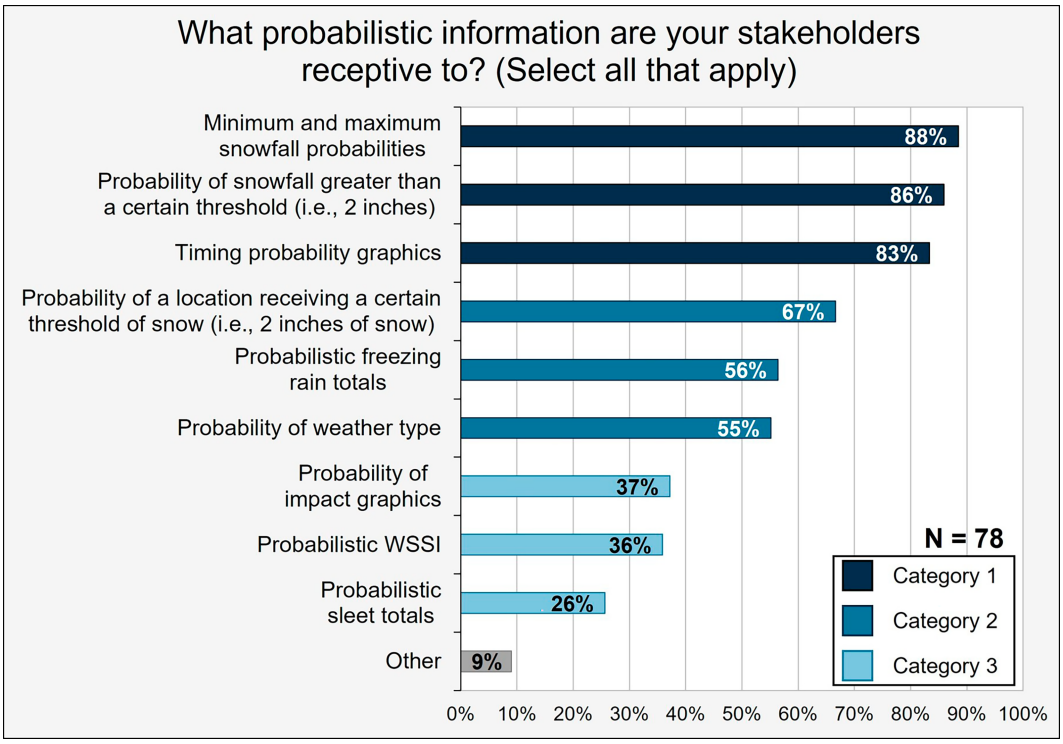

FIG. 9. NWS survey responses to the following prompt: What probabilistic information are your stakeholders receptive to (QB3.2)? Respondents were asked to select all that apply.

hazards. However, the information included in messages or the information participants are allowed to share appears to depend on the forecaster. Hesitancy about whether content generated through Pathfinder collaborations can be publicly shared also exists on the part of the respondents. Depending on the information being disseminated, some forecasters stated they are allowed to repost or share and others believe they cannot.

Respondents also appear to have widely varying interpretations or applications of the NWS directives, and many are uncertain about what is allowed as it relates to winter weather hazard messaging. The sharing of road temperatures with end users seems to result in a polarized response from forecasters, potentially due to their misinterpretation of an NWS directive that notes that disseminating road temperature modeling output is out of the NWS scope. Most respondents reported that they are more hesitant to share messages when strong road weather impact wording is utilized; however, some indicated they could share these statements. This suggests that forecasters may interpret the NWS directives differently when messaging road hazard impacts, resulting in diverse severity and descriptive language used in their messages. This is exemplified by a majority of the respondents indicating they are not confident about the delineation between messaging road weather conditions and messaging potential road impacts caused by weather. Some respondents specifically noted that certain messages should not be communicated to the public by the NWS as per the directives, with several that stated that it is not the WFO's responsibility to inform the DOT of possible winter road hazards.

Finally, respondents were asked what forecasting tools they find most useful. Generally, they have a slight preference for probabilistic tools, such as probability of ice and snow, and are more neutral with experimental products that they may not be as comfortable utilizing. With regard to the inclusion of probabilistic guidance within road weather messaging, a majority of the respondents noted that they provide probabilistic guidance to their end users, indicating that their partners are better prepared for the range of outcomes and understand how likely a given scenario is. The same benefits were expressed in regards to probabilistic guidance disseminated to the general public, but respondents stated they are worried that the public will not be able to interpret and apply probabilistic information and that effective tools for messaging this content do not exist. Therefore, forecasters appear to produce content that is easily interpreted and tend to favor products such as minimum and maximum snowfall probabilities, snowfall threshold probabilities, and timing graphics. This is an important implication to consider for product developers to ensure they are creating products that are not only user friendly but also help the forecaster easily convey information to the end user in their road hazard messages.

Based on these results, there are three key considerations to note during the implementation of any future improvements to the communication and messaging of winter weather road hazards and the development of new IDSS tools:

1) Not all forecasters are equally conversant about the needs of the partners, and not all partners want the same level of interaction.

- Depending on which forecasters participate in an evaluation of a given tool/product, there may be high enthusiasm or a more tepid, maybe even slightly negative, reception. Understanding each forecaster's exposure to collaborative decision-making with their partners is recommended.

2) Application of the NWS directives is a source of disagreement or confusion among forecasters.
   - Differing interpretations of NWS directives could impact forecaster evaluations of emergent technology. Some participants may question whether they are allowed to use or message output from some forms of decision support, and this, in turn, could influence how they evaluate the technology.
3) The respondents in this study appeared less comfortable messaging output from products they were less familiar with, expressing uncertainty about whether the recipient could faithfully apply that knowledge to their own decisions.

   - Tools that are intended to support forecast creation may be evaluated differently than ones that are intended to be used in public-facing messages. This is where robust end-user evaluations by social scientists are needed. A new tool serves no useful purpose if the forecasters are unwilling to use it as intended because of their fear over whether it is useful.

The considerations above could have particular utility in shaping the future design of synthetic decision-making environments such as NOAA testbeds. Similar testbeds exist for other hazards such as summertime convection, fire weather, and use of emerging technologies. A testbed that focuses on wintertime collaboration between NWS offices and the transportation sector could be a highly effective tool to test and validate the findings of this study. For example, building tools that consider the forecasters' responses and evaluating them within a simulated decision-making environment could highlight where additional research or product development is needed. Furthermore, adding stakeholder engagement to future testbeds would provide end-user perspectives of their collaboration with the NWS, insight into their crucial decision-making criteria, and ideal modes to receive this information. These findings may also have applications to other specialty areas also covered by Pathfinder, such as flooding and fire weather, which would maintain their collaborative relationship year-round and ensure forecasters understand the needs of their partners in various weather situations. Additionally, these results could foster new communication pathways between the WFOs and their partners or help improve upon relationships that already exist.

This research provides foundational insights into the current state of winter road hazard communications between the NWS and its partners, highlighting specific areas for improvement both within the NWS and in future collaborations with external partners. These deficiencies or gaps would be addressed very effectively through future NOAA testbed initiatives with a specific focus on understanding their partners' perspectives about their interactions with the NWS, developing best practices for NWS and partner engagement based on robust social science research, and assisting forecasters with communicating road hazard impacts probabilistically.

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Data availability statement. In accordance with the University of Oklahoma's (OU's) Hazardous Weather Testbed (HWT) Institutional Review Board (IRB), the distribution of human-subject data outside of key OU research personnel and non-OU collaborators is not permitted.

APPENDIX A

Relevant Portions of NWS Directives on Road Weather

Direct quotes from the Applied IDSS–Surface Transportation NWS directives (NWS 2019) outline NWS actions that are considered within and out of scope as they pertain to road weather.

a. Roles within the scope of NWS personnel

1) FORECAST AND IDSS PROVISION

1) Provide IDSS focusing on meteorological and hydrologic conditions and hazards that would affect travel on roadways, including timing, uncertainty, snowfall and rainfall amounts, flooding, and the general potential for adverse travel conditions. NWS support will also occur in certain nonroutine situations that may be critical to public safety, such as dense smoke from wildfires, hazardous material incidents, heavy fog, and dangerous conditions that fall below the criteria for issuance of, or are not well covered by, standard NWS products.
2) Road temperature models may be run internally by the NWS, but it is not encouraged. Output should only be utilized internally to help assess potential general road impacts, improve situational awareness, and craft IDSS and call-to-action messaging for both support to DOTs and the overall public weather program.
3) On rare occasions, and in accordance with NWS instruction 10–401, NWS personnel may provide a site-specific forecast upon request of any local, tribal, municipal, or state DOT official who legitimately indicates that the forecast is essential to public safety.

2) FORECAST AND MESSAGING COLLABORATION

1) Initiate or respond to routine or episodic contact with DOTs and their contracted private weather service

providers and respond to questions regarding weather events. These interactions should focus on helping to ensure an understanding by DOTs of our forecasts and their impacts and of the evolution and timing of hazardous weather conditions.
2) Collaboration and coordination through NWSChat, telephone conference calls, and webinars are encouraged.
3) If offered from DOT-employed meteorologists or DOT-contracted private-sector providers of weather services, utilize their forecast expertise on expected road conditions to help craft general impact messaging for NWS products and IDSS, without relaying overly specific road condition forecasts. If publicly available, NWS may pass along these road condition forecasts (with attribution) or direct the public to DOT sources.
4) Collaborate with DOTs and their contracted private-sector providers to ensure consistent, effective, and actionable messaging related to anticipated impacts.
5) Call-to-action statements in NWS watch/warning/advisory products should be coordinated for consistency with DOT messaging systems, such as social media or 511 systems. DOTs can assist with getting out consistent messaging by putting NWS information on highway variable message signs.
6) When multiple DOT support providers [including America's Weather and Climate Industry (AWCI)] are present, NWS will be flexible in the level and/or type of IDSS provided, seeking input from core partners as to what support is needed and what level of coordination is required.

3) RELATIONSHIP BUILDING/OUTREACH

1) Interact with DOTs via meetings, training exercises, and workshops such as Pathfinder, integrated warning teams, pre- and postseason reviews, office seminars, after-action reviews, and other in-person meeting opportunities.
2) Participate in efforts to structure and enhance consistent messaging on social media and websites.
3) NWS may work to help DOTs understand how to access or interpret existing products for use in local 511 (traveler information) systems. Creation of specialized products for local 511 systems would be left to the DOT and its weather support.
4) Participate in efforts to structure and enhance the use of variable messaging signs to communicate NWS watch/warning/advisory products and other coordinated messaging to promote appropriate action by the public to mitigate their exposure to hazardous driving conditions.
5) Collaborate on research efforts, including sharing of information via publications and presentations.
6) NWS may provide DOTs with basic weather and SKYWARN training, including training on how to access and use standard NWS products of all types (e.g., observations, warnings, forecasts, hydrologic and climatological information, and seasonal forecasts).

4) OBSERVATIONAL COOPERATION IS PERMITTED AND ENCOURAGED

1) Initiate calls with DOTs to validate actual observations with available automated observations and to obtain severe weather and storm verification (e.g., via downed tree reports, snow accumulation amounts, and road closures from flooding).
2) Coordinate siting and placement of DOT automated weather stations [e.g., road weather information system (RWIS)]. Ultimately, it is the responsibility and decision of the DOT where to site sensors.
3) Interact with DOTs to obtain and share observed weather conditions (e.g., weather spotter reports, Citizen Weather Observer Program, plow driver reports, connected vehicle information, Cooperative Observer Program, hydrologic/river stage reports).

b. Beyond the scope of NWS personnel

If DOTs request any specialized services (outlined below) beyond the scope of NWS activities, they should be referred to AWCI. AWCI often provides specialized weather support to DOTs including, but not limited to, customized road weather and pavement information, alerting services, radar and communication devices, and consulting services. The NWS web pages (http://weather.gov/im and http://weather.gov/enterprise) list AWCI resources for those who wish to use these sites. NWS personnel will not provide certain types of specialized services including, but are not limited to, the following, which may be available from AWCI:

1) Site-specific forecasts or direct forecasting support to local, tribal, municipal, or state DOT officials when the support is not related to the immediate promotion of public safety and/or the protection of life and property.
2) Specialized roadway surface conditions or customized consulting services to DOTs (e.g., forecasts of road surface temperatures, guidance on road treatment options, direct forecast support to DOT operations such as a plow driver).
3) Dissemination of specialized road temperature modeling output to either the public or core partners.
4) Provision of public-facing roadway surface condition hazard mapping that implies a forecast of road or travel conditions.
5) Customized products (e.g., customized seasonal forecasts) for the purpose of supporting DOTs with their business planning (e.g., optimizing preseason salt purchases).

APPENDIX B

Survey Questions

This section lists the relevant survey questions provided to NWS forecasters and discussed within this study.

a. CWA and DOT information

B1.1 What state DOTs or other transportation agencies do you collaborate with? (select all that apply)

1) State DOT
2) Federal Highway Administration (FHWA)
3) Local city or county transportation
4) Turnpike commissions
5) School districts
6) Other (fill in the blank below)

B1.2 How many different state DOTs does your office serve? If your office does not serve any state DOTs, please put 0.

B1.3 If you serve more than one state DOT, do the services that you provide differ between them?

1) Yes (please explain in the box below)
2) N/A

B1.4 What is your office's role in collaborating with DOT or other stakeholders when it comes to messaging road hazards? (select all that apply)

1) Providing weather forecasts
2) Messaging the public
3) Collaborating on the use and content of roadway message signs
4) Other (fill in the blank below)

b. Messaging

B2.1 What, if any, considerations impact your messaging of road hazards to DOTs? (select all that apply)

1) Our DOT(s) do not want to receive certain messaging (e.g., forecasts of specific road conditions or travel conditions)
2) It is not our responsibility to inform the DOT of potential road hazards, only weather conditions
3) I am not sure where the line is for messaging road hazards between messaging the weather conditions (e.g., snow rates, snow accumulations, visibility reductions from snow or blowing snow) and messaging potential impacts to the roads due to weather conditions (e.g., slippery roads, snow-covered roads, dangerous travel)
4) We do not have enough information about road temperatures, road treatment operations (e.g., if roads were treated or what the effective temperatures of those treatments are), and/or traffic patterns to provide useful guidance on potential impacts

B2.2 What, if any, considerations impact your messaging of road hazards to the public? (select all that apply)

1) Our DOT(s) are resistant to certain messaging from our office to the public (e.g., forecasts of specific road conditions or travel conditions) without their consultation
2) My NWS office has certain philosophies/policies of what should (and should not) be communicated to the public as they align with DOT policies/suggestions
3) I am not sure where the line is for messaging road hazards between messaging the weather conditions (e.g., snow rates, snow accumulations, visibility reductions from snow or blowing snow) and messaging potential impacts to the roads due to weather conditions (e.g., slippery roads, snow-covered roads, dangerous travel)
4) My NWS office has certain philosophies/policies of what should (and should not) be communicated to the public as they align with the NWS directives
5) I am unsure how to message road hazards in a way that the public can interpret
6) My NWS office has certain philosophies of what the public can interpret

B2.3 Do you repost or share information from DOTs or other partners with the public? For each option below, please select "yes, I can repost with attributions," "yes, I can repost without attributions," "I can repost under certain conditions," "no, I cannot repost," or "I do not have access to this information, so I cannot repost."

1) Weather conditions along roadways (e.g., expect snowy conditions along I-40)
2) Road conditions (e.g., roads are snow covered)
3) Travel conditions (e.g., delays, pileups)
4) Photographs from traffic cameras or other sources
5) Road closures
6) Road temperatures
7) 511 maps
8) Other (fill in the blank below)

B2.4 According to your office's interpretation of the NWS directives, declare whether you can disseminate each of the following messages to the public, independent of consultation with or input from the DOT by choosing yes, yes, under certain circumstances, no, and "I am unsure."

1) Expect winter weather conditions along the interstate
2) Expect road closures and chain controls to be in effect
3) Expect excessive delays
4) Avoid or limit travel
5) Travel will be impossible
6) Difficult travel
7) Dangerous driving conditions
8) Expect ice and snow accumulations on roadways
9) Visibility and weather conditions to rapidly deteriorate during the evening commute
10) Reduce speeds and increase following distance on slick, slushy roads
11) Snow falling overnight will produce slippery roads and a slow morning commute
12) Many roads that are currently wet will freeze over as temperatures drop below freezing
13) Plowable snow expected before the morning commute
14) Subfreezing roads will require chemical treatment before morning rush hour
15) Heavy snow is likely to close the interstate
16) Snow will accumulate on untreated roads

B2.5 For the messages you categorized as "I am permitted to share under certain circumstances," please explain what those circumstances entail.

B2.6 Do you currently incorporate any probabilistic guidance (i.e., snowfall, ice accumulation, precipitation type probabilities) within your road hazard messages that are sent to DOT partners and/or the public?

1) Yes, both
2) Only to the DOT(s)
3) Only to the public
4) No

B2.7 Have you experienced any challenges or difficulty with incorporating (or trying to incorporate) probabilistic guidance in messaging road hazards?

1) Yes
2) No

B2.8 If yes above, which challenges or difficulties have you experienced? (select all that apply)

1) I personally do not understand probabilistic forecast information and have difficulty communicating it to others
2) I understand probabilistic forecast information but struggle with communicating it to others
3) I anticipate end-user interpretation difficulties or misunderstandings
4) There is a lack of probabilistic guidance tools or products to aid in messaging
5) Probabilistic guidance can be misleading
6) Probabilistic guidance does not align with our messaging
7) I have been asked to only include deterministic guidance to the stakeholder
8) Other (please explain below)

B2.9 Have you experienced any successes in incorporating probabilistic guidance in messaging road hazards to the DOT and/or the public?

1) Yes
2) No

B2.10 If yes above, which successes have you experienced? (select all that apply)

1) Transportation partners are better prepared for the range of outcomes that could happen
2) The public is better prepared for the range of outcomes that could happen
3) Transportation partners recognize when the forecast is more uncertain
4) The public recognizes when the forecast is more uncertain
5) Other (fill in the blank below)

c. Useful tools

B3.1 What tools are most helpful to forecast impacts due to road weather hazards? Please rank the following tools with "very helpful," "neutral," "not helpful," or select "I do not use this product."

1) Deterministic WSSI
2) Probabilistic WSSI
3) Hourly WSSI
4) ProbSR
5) METRo
6) NBM output
7) Probability of snow
8) Probability of ice
9) Other (fill in the blank below)

B3.2 What probabilistic information are your stakeholders most receptive to? (select all that apply)

1) Minimum and maximum snowfall probabilities
2) Probability of snowfall greater than 2 in. (or other threshold)
3) Probability of a location receiving 2 in. of snow (or other threshold)
4) Timing probability graphics
5) Probability of weather type
6) Probabilistic WSSI
7) Probability of impact graphics
8) Probabilistic freezing rain totals
9) Probabilistic sleet totals
10) Other (fill in the blank below)

d. Demographics

B4.1 Which CWA are you affiliated with? Please provide the city and state.

B4.2 Is your WFO a part of the Pathfinder initiative?

1) Yes
2) No
3) I do not know

B4.3 How many years of operational experience do you have with the National Weather Service?

B4.4 What position do you currently hold?

1) GS 5/7/9
2) GS 11/12
3) Lead forecaster
4) SOO
5) WCM
6) MIC
7) ITO
8) Other (fill in the blank below)

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