Chapter 4
WIST User Needs—Analysis and Conclusions

4.0 Overview

> The conclusion that emerged most clearly and prominently from the WIST study is that weather information that better meets the sector and activity-specific needs of users will reap benefits in improved safety and increased cost-effectiveness of surface transportation activities.

This chapter summarizes the results of, and draws general conclusions from, the analysis of the user-validated WIST needs compiled in the templates in Appendix B. General conclusions, which cut across the sectors, are discussed first, followed by sector-specific results. The chapter ends with four overarching themes about the potential benefits from meeting users' needs for improved weather information and the utility of the WIST templates for guiding this significant national effort. Chapter 5 uses these conclusions and themes as the basis for suggested next steps in six strategic thrust areas for continuing a coordinated interagency initiative on WIST implementation and supporting research.

4.1 User Needs: General Conclusions from the WIST Study

The general analysis of the WIST data across all transportation sectors supports some general conclusions and underscores a set of basic information needs. The four conclusions, which are discussed in the remainder of this section, can be summarized as follows:

- Users recognize the value of weather information.
- Users want weather information tailored to their activities.
- Users' WIST needs cover a broad range of weather elements, thresholds, and lead times.
- Within transportation sectors and subsectors, users differ in their knowledge of how improved weather information could affect their activities and their awareness of WIST sources.

Beyond these general conclusions, the analysis found significant differences in specific user needs among and within the transportation sectors. (As noted in Chapter 1, for this report a user need is defined as a specific combination of weather element, user activity, threshold, and lead time.) These differences provide the basis for the sector-specific analyses in Sections 4.3 through 4.8.

4.1.1 Users Recognize the Value of Weather Information

The value of accurate weather information is well recognized throughout the surface transportation user community. Highway maintenance managers concerned about freezing precipitation, pipeline operators worried about hurricane-induced tidal surge, and vessel captains concerned about keel clearance in shallow water must take actions whose consequences depend critically on accurate and timely knowledge of weather and related conditions. Decision makers, regulators, and operators across the spectrum of transportation activities confirmed the value of

appropriate weather information for improving safety and enhancing the efficiency and effectiveness of their activities. New technologies can improve information systems, maintenance tools, and road weather management practices. This will help transportation officials reduce weather-related costs, provide more accurate and up-to-date information to the public, and decrease the number of weather-related traffic injuries and fatalities.

4.1.2 Users Want Information Tailored to Their Activities

> Repeatedly, users stated needs for information that is much more precise, focused, and relevant to their operations.

Transportation decision makers want detailed, location-specific forecasts and situation reports. They also need multiple ways of getting the information—from radio and television, the Internet and other electronic data links, and other communications media. ***In every transportation sector, users stressed the importance of getting weather information tailored for the activity or decision-making process for which they are responsible.*** This manifested itself in several ways. Users said that large-scale, general-area weather information was inadequate for their needs. Repeatedly they stated the need for information that is much more precise, focused, and relevant to their decision thresholds. The general analysis of user needs shows that they want higher resolutions, both spatial and temporal. At the same time, they demand better accuracy in the forecasts, especially for the longer ranges (from 12 hours out to many days).

An important point made by a number of users is worth emphasizing: ***a forecast of favorable weather is often just as valuable as a forecast of adverse or mission-limiting weather***. This point is sometimes lost on the weather information supplier community, where the focus has been on correctly forecasting the onset, duration, and intensity of "bad" weather. The road maintenance community provides a salient example. In most states, road maintenance is performed by the same crews and trucks that clear, plow, and sand roads in the winter. To perform maintenance work, the trucks must be physically reconfigured from their wintertime duties. Operations managers in these states must be assured of a stretch of "good" weather—at least 5 to 7 days—before they can risk starting a maintenance project.

Another important point about user-specific needs is that observations of current weather (the current values of certain key parameters) are as important to some users as the forecasts for those same parameters. For example, current observations of ice and snow accumulations, temperatures, and severe convective weather are particularly important for road maintenance, school and commercial bus operators, and transit authorities.

These needs for current observations are relevant to two other topics. First is the broad issue of coordinating regional weather/environmental observing networks, sometimes called mesonets, which are proliferating around the country. Although each network may be effective and useful for its original purposes, there is no common standard for the attributes and formats of the data collected from them. This lack of coordination on data compatibility undermines the potential value of "mesonet" data as a finer-scale complement to the national observing systems. For WIST needs in particular, where finer spatial and temporal scales are often critical to meeting users' decision support requirements, these regional observing systems represent a potential wealth of high-resolution weather data. The potential economic value to tailored WIST applications (i.e., applications developed and distributed primarily through commercial providers) could provide an incentive for agreement on voluntary standards, with appropriate leadership on this issue. This topic will be addressed further in Chapter 5.

The second issue related to weather observations is more conceptual for the near term, but it could have important consequences in the longer term. In many cases where users want to know current conditions, they do not actually require ***observations.*** Rather, they only require weather information that is accurate, valid for the current time, and at the scale and resolution that matches their activity. At some point in the future (although not yet), high-resolution, very fine scale forecasts and nowcasts prepared for these users will meet at least some of these needs.

For example, a state or county highway department that needs to know the current depth of snow accumulation along rural highways could use a model-based interpolation of the snow depth along the roadway, based on "anchoring" observations taken at key locations along the road. To the extent that such a model also supports prediction of conditions, even for one to several hours after the latest observations, such nowcasts provide a substitute for strictly observational data. The Advanced Transportation Weather Information System (ATWIS) is providing short-range nowcasting of this kind already (Owens 2000, pp. 11-13). In essence, the users' requirement is for weather information that accurately describes current conditions. Provided that short-range nowcast information is *reliably accurate for the time that a user's decision must be made*, it should not matter to the user whether the information comes directly from an observation or a forecast (based on observational inputs).

4.1.3 WIST Needs Cover a Variety of Weather Elements, User Activities, Thresholds, and Lead Times

Taken as a whole, the WIST needs elucidated by the surface transportation community encompassed many different weather elements, including a range of important environmental conditions that depend on "the weather" as commonly understood but are not always viewed as a part of the weather. Examples include ground surface and rail temperatures, wave height and tidal predictions, and air quality. The WIST needs also cover a broad range of desired lead times and thresholds, as defined in Chapter 1, for various user activities within each transportation sector.

The Weather Elements

Table 2-1 groups the weather elements identified by WIST users during the identification and validation process into seven categories. As noted in Section 2.4, this list contains many traditional meteorological parameters, but it also contains "weather elements" that have not been included in conventional weather reporting and forecasting. "Ice accumulation on structures, in inches" and "rail temperature" are just two examples of these nontraditional elements. Although environmental scientists might categorize these elements as hydrologic, geophysical, or oceanographic data, the users view all of them as need-to-know information intrinsically linked to the impact of "weather" on their operations.

Analysis of Activity–Element Combinations

An "activity" is a grouping of functionally similar or identical WIST users within a transportation sector. For example, WIST user activities within the roadways sector include road maintenance operations, bus operations, state police, and others. The long-haul railways sector has activities for railroad stations and depot operations. Among the activities in the U.S. Marine Transportation System (MTS) are inland waterway recreational boating and open water cargo/freight operations.

The combination of a weather element and a sector activity is a useful level of aggregation for discussing WIST user needs. For example, freezing precipitation (ice) is a weather element that affects 11 roadway sector activities, including road maintenance, truck operations, fleet utility and transport vehicle operations, bus operations, and private vehicles. In the remainder of the report, these combinations of the sector activities impacted by a weather element, as defined in the WIST needs templates in Appendix B, will be called "activity–elements." Each activity–element thus includes all the WIST needs (i.e., combinations of element, sector activity, threshold, and lead time) for one sector activity and weather element. Figure 4-1 shows the count of activity–elements for each of the transportation sectors represented in the WIST needs study.

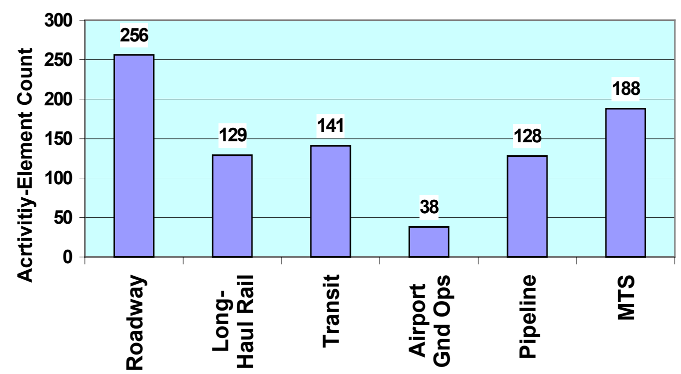


Figure 4-1 Activity-element combinations by sector.

Figure 4-2 shows the distribution of activity–elements among the element groups defined in Table 2-1, for each of the six transportation sectors. Although all the transportation sectors are subject to the same weather conditions, the sectors vary with respect to which groups of weather elements comprise larger or smaller shares of the sector's total weather information needs. The distribution of activity–elements among the weather groups for each transportation sector will be discussed in detail in Sections 4.3 through 4.8. A few general observations about the distribution, as shown in Figure 4-2, are made here.

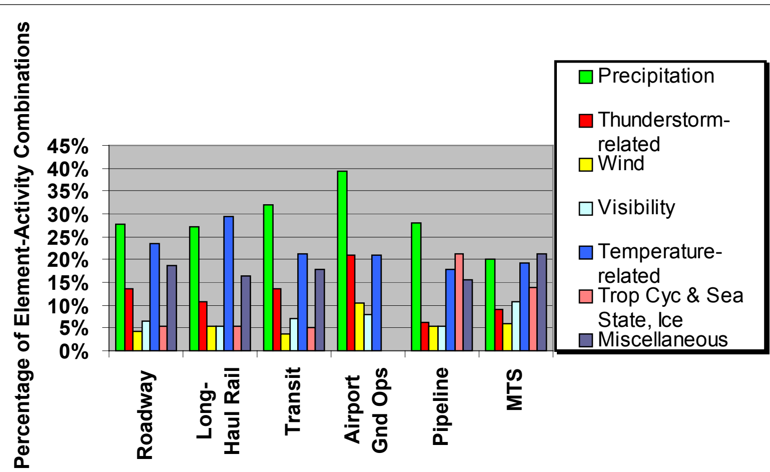


Figure 4-2 Distribution of activity-elements by sector.

A surprising result is the relatively high proportion that tropical cyclone and sea state conditions represent among the activity–elements for the pipeline systems sector. The importance of this group reflects the crucial nature of physical components of the pipeline transportation system that are vulnerable to tropical cyclone–induced weather, including pipeline segments that are buried underwater or in vulnerable flood plains, pumping stations and storage facilities in coastal areas, and similar factors. The small proportion of thunderstorm-related activity–elements for pipelines reflects the fact that most of a pipeline system is below ground and therefore relatively impervious to thunderstorm activity.

The high proportion of long-haul railway activity–elements that are temperature-related illustrates the temperature sensitivity of steel rail—a critical and ubiquitous structural component of the rail transportation system. Finally, conspicuously absent from airport ground operations is the tropical cyclone category. The explanation is that none of the airports that participated in validating the needs templates happened to be in coastal locations where the storm surge or flooding associated with tropical cyclone conditions would be expected. The airports accounted for the impacts of weather elements associated with inland tropical cyclones, such as high winds, heavy precipitation, and low visibility, under the other weather element groups.

Table 4-1 Lead Time Categories

1 =	Current to less than 3 hours (includes observations)
3 =	3 to less than 6 hours
6 =	6 to less than 12 hours
12 =	12 to less than 24 hours
24 =	24 to less than 48 hours
48 =	48 hours or more

Lead Time Analysis

Another way to examine the similarities and differences among the WIST needs of the transportation sectors is to look at the ***lead times*** required by the activities in each sector. The lead time is the amount of advance notice of a weather-related event or condition that a user needs to plan or respond effectively. For this analysis, the lead times specified by each sector activity for each weather element were grouped into the six categories shown in Table 4-1. Note that the first category includes data or information required from "now" up to three hours in advance, which means this category includes current weather observations, as well as forecasts with lead times up to three hours. The last category includes all WIST needs for which the requested lead time was 48 hours or more.

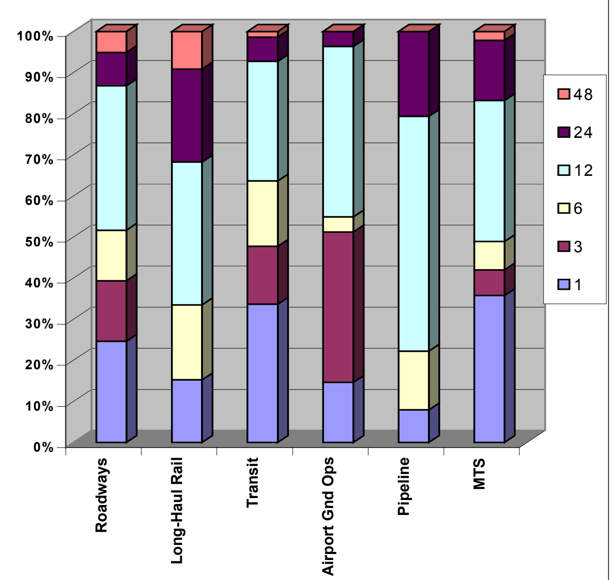


Figure 4-3 Distribution of lead time categories (Table 4-1) by transportation sector.

Figure 4-3 shows the distribution of lead times among the six categories, by transportation sector. Each bar is normalized to 100 percent of the element–activity–lead-time combinations requested by users within that sector. (The actual counts of these combinations vary widely from sector to sector, ranging from 333 for roadways to 82 for airport ground operations.) One important pattern that can be seen in the graph is the dominance of the block with lead times of 12 to less than 24 hours. For three sectors (roadways, transit, and MTS), the second largest lead-time category is the first, from current observations to less than 3 hours. The lead-time requirements for these sectors have a bimodal character, reflecting a pattern in which users need WIST data with 12 to 24 hours lead time to prepare for an event. They can follow up with execution decisions and operations for which more immediate information (0 to 6 hours) is useful.

Another interesting aspect of Figure 4-3 is the small proportion of WIST needs, in every sector, for lead times of 48 hours or more. This suggests that the decision processes now prevailing in surface transportation communities could be better served by highly accurate and timely forecasts out to 2 days (48 hours) than by longer-term forecast services and products with lower forecast skill.

The bimodal character of the lead time distribution becomes more apparent when the counts of element–activity–lead-time combinations by transportation sector are plotted against the lead time categories, as in Figure 4-4. All sectors except pipeline system operations show a bimodal pattern, although the trough between the preparation peak at 12-24 hours and the shorter-term operational decision peak is shifted in some sectors. For airport ground operations, the lead-time for influencing operational decisions appears to be somewhat longer, peaking at 3 to 6 hours, although the preparation peak at 12-24 hours still holds.

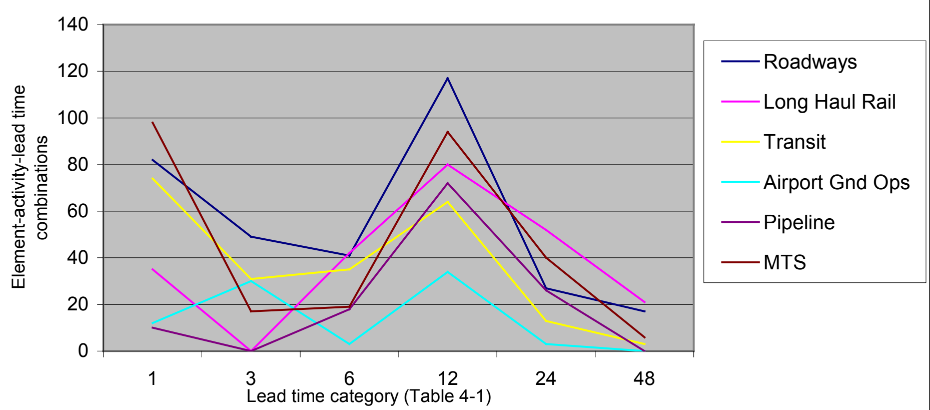


Figure 4-4 Bimodal Lead Time Distribution

4.1.4 Users Differ in Their Knowledge of Weather Impacts and Awareness of WIST Sources

> Users vary in their understanding of how weather information could affect their operations, and thus in their ability to articulate that understanding in specific WIST needs.

Several significant observations on users' knowledge about weather impacts and sources of WIST emerged from the needs identification and validation effort. First, even within a sector activity, users varied in their understanding of how weather information could affect their operations and thus in their ability to articulate that understanding in specific WIST needs. With the exception of highway maintenance operations (in which users from many states had a good-to-excellent grasp of their weather information needs), this variability occurred across all the transportation sectors. Within any given sector, there were users with a clear understanding of how information on weather and weather-related conditions could make a difference in the efficiency and effectiveness of their operations, as well as users with lesser degrees of awareness. The latter category of users knew how the weather affected their operations; they just had not considered how better information about the weather would be useful. In many instances, once users had an opportunity to discuss the subject, they quickly saw how timely and more accurate weather information could be of benefit.

A second observation is that users varied widely in their knowledge of what weather information was available and where they could get it (information sources). Many users were fully attuned to the wealth of information sources, ranging from dedicated Internet suppliers (including commercial providers) to National Weather Service sources, to simply watching the weather on television. However, other users were unaware that weather information useful for their transportation activities was available from sources other than the commercial radio and television reports.

Closely related to this second observation is a third: There is a tremendous range in users' sophistication in exploiting weather information and products. Examples at one end include users (e.g., airline companies) that have meteorologists on-staff who are an integral part of the organization's planning and daily operations. Others purchase sophisticated decision-assistance products from commercial weather service providers. At the other end of the spectrum are users who rely on the information in the weather report during the evening news on television.

An important general conclusion from these observations is that understanding how weather affects an activity does not automatically give users an understanding of how better weather information can benefit that activity. Education of potential WIST users, including interactions between the users and providers of weather information, must be part of the WIST service delivery process. A second conclusion is that, the more sophisticated the decision process is for responding to weather information, the more beneficial periodic interaction between information provider and consumer becomes. These interactions promote understanding of both the users' needs and the capabilities that the provider can offer, as well as increasing awareness, by both sides, of the value of weather information that is accurate, timely, and tailored to users' specific needs.

Weather Information Sources and Communications—Today and Tomorrow

During the collection of WIST needs data and the subsequent template validation with various federal, state, and local agencies, a sample of the participants were asked a series of questions about their weather data and products. These questions requested information about their data sources, how they received and displayed the data, what changes they envisioned for the future, and related issues. The answers bring to light some interesting similarities, as well as differences, between and within the transportation sectors.

Sources of Weather Information

> What is the current source(s) for the weather information used in your operations (e.g., NOAA's National Weather Service, Weather Channel, private provider, other)? Do you envision this changing in the future?

Twenty of the state transportation departments responded to the above questions on their sources of weather information; the results are shown in Figure 4-5. Nearly every respondent listed at least one commercial weather service provider, and some listed multiple providers, making commercial providers by far the most common source of their information. This category was followed closely by the National Oceanic and Atmospheric Administration's (NOAA's) National Weather Service (NWS), which was listed by about 70 percent of the state transportation departments. After the NWS were Internet access to web-based resources and The Weather Channel, both at 35 percent. Almost 70 percent of these transportation departments said they did not envision changing their sources in the future. By contrast, in a (much smaller) sample of trucking companies the primary sources of weather information were The Weather Channel and NWS maps delivered as an adjunct to another (non-weather) information management system.

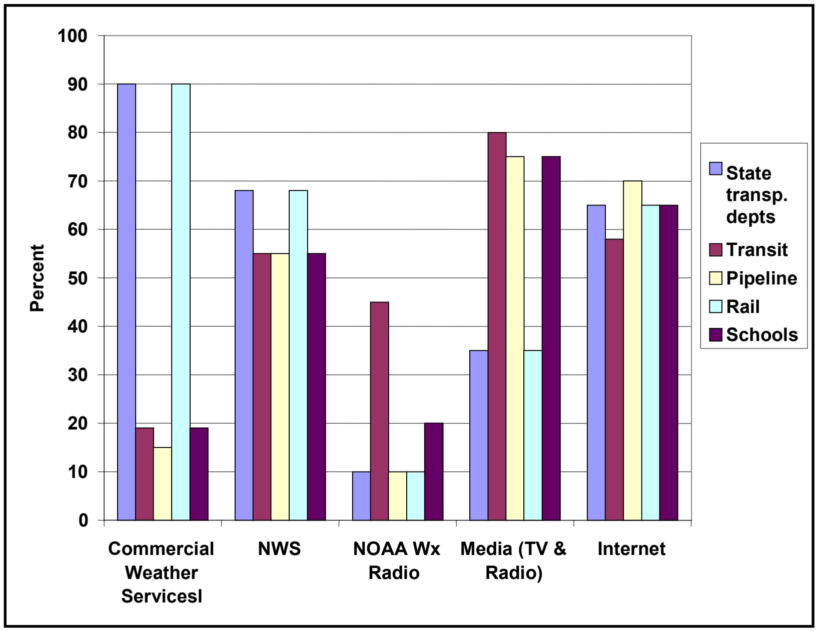


Figure 4-5 Sources of weather information reported by respondents.

Thirty-one rural and urban transit authorities responded to the questions on information sources. Their responses highlight interesting differences between these two major user groups. In contrast to the transportation departments, only 19 percent of the transit agencies rely on commercial weather service providers; 80 percent listed radio and television (including The Weather Channel) as a primary source of information. Next in frequency of response were access to Internet-based sources at 58 percent and NWS products and services at 55 percent. These transit agencies listed communication with drivers in the field as a primary information source 26 percent of the time, whereas only one state transportation department did so. However, as the transportation departments install state-of-the-art air and pavement sensing systems on their vehicles, this source will probably be used more frequently. Among the transit authorities, NOAA Weather Radio was used as a source by 45 percent, compared with only 10 percent of the state transportation departments.

The public school systems that were sampled gave responses similar to the pattern from the transit authorities. The school systems rely chiefly on commercial radio and television for weather information but also make some use of Internet-based sources. At least one school system, the Charlotte–Mecklenburg schools in North Carolina, added local utility companies and the local airport weather information to their list of sources.

The pipeline companies generally relied on television and Internet-based sources, while the sources for long-haul railroads more closely resembled the state transportation departments in using commercial weather service providers extensively, in addition to television and The Weather Channel as sources. State police organizations reported using a variety of sources, including the NWS, Internet-based sources, radio and television, and commercial providers. The Bonneville Power Administration has a resident meteorologist, who uses a full suite of NWS products received through a NOAAPort terminal connection.

Of the 22 percent of the state transportation departments and 56 percent of the transit authorities who envisioned changes in their sources of weather information, the most frequent theme was anticipation of increased use of robust Internet applications providing real-time information. Second in frequency were changes from infusion of new technologies.

Means of Communication

> By what communication means is weather information received now for your operations? By what means do you envision receiving weather information in the future (e.g., National Weather Service Family of Services, television, radio, the Internet, facsimile, or others)?

The second set of questions asked about the means of communication by which respondents receive their weather information now, and how they planned to receive it in the future. Again there are noteworthy similarities and differences between the state transportation departments and the transit authorities. For both groups, the most prevalent means for receiving weather information is radio and television (including The Weather Channel), used by 75 percent of the responding transportation departments and 84 percent of the transit authorities. Next are Internet-based applications, at 65 and 55 percent, respectively. The response patterns diverge after this point. Transportation departments are more likely to receive information by email (40 percent versus 6 percent) and by telephone (52 percent versus 16 percent). However, 39 percent of the transit authorities receive data by facsimile, as opposed to only 15 percent of the state transportation departments. While 26 percent of the transit authorities use NOAA Weather Radio, only 5 percent of the transportation departments do. Participants in the template review noted that some highway departments are now using custom satellite delivery of weather information.

School-system decision makers seem to receive their weather information by much the same means as do the transit authorities. They rely for the most part on radio and television, followed by Internet-based sources and NOAA weather radio. Secondary means include cell phones and pagers, as well as two-way radio networks connected to local emergency management centers. One school system, Fairfax County Public Schools in Virginia, placed particular importance on talking directly with the NWS meteorologists at their local Weather Forecast Office. For the future, school-system managers envision more reliance on the Internet and regional intranets, as well as increased contact with emergency management agencies and local transit agencies.

The responses of pipeline operators to these questions again resemble those of the transit authorities, with primary dependence on radio, television and Internet-based sources. The long-haul railroads employ a more robust suite of communication tools, including television, radio, the Internet, facsimile machines, and dedicated direct-line communications.

Of the 40 percent of respondents who envision future changes in their means of communication, more than half expect to rely on the Internet or Internet-based solutions as the next evolutionary step. The remaining responses were distributed among a variety of technologies and practices, ranging from direct satellite read-out to pagers and cell phones.

The Recipients of Weather Information Within a WIST User Entity

> Where is weather information currently being received in your operations (e.g. dispatch/operations center or other)? Do you envision this changing in the future?

The third set of questions asked to whom in the organization weather information and products are routed for display, analysis, and decision-making. The response from the transit authorities was almost univocal; 94 percent of those that responded indicated that the weather information was routed to an operations center or a dispatchers' office. The state transportation departments were almost evenly split between routing the weather information to a central location, such as an operations center, and sending it directly to shop and garage foremen and supervisors in the field.

Here again, the school system responses parallel those from transit authorities. Although school systems do not customarily have operations centers, many do have transportation dispatch offices for the school buses. The key similarity is that the decision-making occurs at a central point and the weather information is routed to that person or activity for use in informing decisions.

Similarly, pipeline operators route weather information to their control/operations centers. The railroads do this as well but also provide the information directly to locomotive cabs.

4.1.5 Significant Differences Exist Between and Within Transportation Sectors

The user groups that participated in this study come from nearly all 50 states, and they thus represent the full geographic and climatic spectrum of the United States. Consequently, there is significant variation in specification of WIST needs, both between the transportation sectors and within a sector. Often these differences exist even within a specific activity for the same weather criteria. An example is drifting snow. Some state highway maintenance agencies require notification for drifting snow of any amount; others (primarily in the snow belt) are only interested when it is 8 inches or deeper. Likewise, extreme high temperatures in the desert Southwest do not create the same magnitude of difficulties that those same temperatures do in regions with more moderate climates. Thus, the thresholds at which a weather element is seen as having substantial impact on a transportation activity, possibly requiring response preparation and implementation, vary with geography, as well as varying by sector and (sometimes) activity within a sector.

Other factors that produce differences in WIST thresholds include the scale of an agency's "mission," the scale of the decisions being made at a particular time, and the uniqueness of the mission or transportation activity. For example, movement of spacecraft and critical components by the National Aeronautics and Space Administration (NASA) to the launch facilities occurs on intermittent schedules, which may be greatly affected by a weather element. Differences in regulatory or policy guidance, such as local policy that is more restrictive than federal guidance, can also produce varying needs with respect to thresholds and lead times. Finally, related to the observations in section 4.1.4, users with greater sophistication about the utility of weather information, the sources of information, and the means of acquiring it often specify needs that may be more stringent and precise, with a sequence of thresholds to trigger a sequence of actions on their part.

4.2 Introduction to Sector-Specific Analyses of Weather Impacts, Mitigation Actions, and Information Needs

The remainder of Chapter 4 consists of a sector-by sector analysis of the WIST needs compiled in the templates in Appendix B. Each major section starts by listing the set of transportation activities, defined by the users from that transportation sector, for which the survey sought WIST needs. Next is a brief analysis of the distribution of activity–element combinations for the sector among the major element groups defined in Table 2-1. The third subsection is a detailed discussion, by weather element group, of the impacts of specific weather elements on the sector and the mitigation actions that users identified as potentially useful, *if they have accurate information at the thresholds and lead times specified.* These discussions highlight just some of the key impacts and actions for important activity–element combinations. More comprehensive details for all weather elements, sector activities, thresholds, and lead times are contained in the templates.

Users and operators of transportation systems (everyone from individual motorists to transit authority managers) make daily decisions that are designed to mitigate the effects of weather on their activities. Mitigation can range from simply increasing awareness of the conditions or forewarning operators and travelers of impending events to taking specific ameliorative actions, up to and including curtailing or suspending normal operations. All of these mitigation actions are intended to avoid unnecessary cost, damage to property, or health and safety risks. Some of the effects of weather simply cannot be overcome. In these cases, the most appropriate action may be to avoid exposure to the weather event or to conditions affected by it. In other cases, specific actions can lessen or overcome the effects of adverse weather conditions.

> The objective is to provide accurate information about current or future weather conditions to those making transportation system decisions, to aid them in mitigating the adverse impacts of weather as much as possible

A WIST need is defined by (1) the weather element involved, (2) the transportation activity affected, (3) the threshold(s) at which information is useful, and (4) the lead time(s) needed to take effective mitigation action. The objective in defining user needs in these terms is to give those who must make decisions about these actions the information they need, in time to inform and guide their decisions. Users' decision processes include many variables other than just weather information. Therefore, the weather may not be the sole factor in a mitigation decision. Moreover, decisions not within the control of a transportation agency can undo what would otherwise have been a sound transportation decision to mitigate weather impacts. For example, the insurance and banking industries of Hartford, Connecticut are mindful of how difficult travel becomes for their employees when it snows. In the past, once snow began to fall, regardless of the predicted duration, coverage, or accumulation, Hartford companies in these industries would often release their employees at 11:00 a.m., without regard to the regularly scheduled public transportation slow-down between the morning and afternoon rush hours. The result was a tremendous demand for transit service at the very time that capacity was at a minimum, with consequent delays and overcrowding. The discussions of WIST user needs in the remainder of this chapter will illustrate some of the decisions that can be made, and actions that can be taken, to mitigate or obviate the effects of adverse weather conditions on various transportation systems.

4.3 Roadway Sector

4.3.1 Sector Activities

The most developed transportation sector with regard to addressing WIST is certainly the roadway sector, with FHWA as the lead federal entity. The activities that were included in the two Roadways templates (see Appendices B-1 and B-1.1) are listed in Table 4-2.

Traffic moves slowly on a snow and ice covered Interstate 235 in Des Moines, Iowa. The amount of snow was enough to cause school cancellations. Copyright AP Wide World Photos.

Table 4-2 Roadway Activity Groups

Road maintenance. This activity is generally where the requirements of the state transportation departments are compiled. It includes road surface treatment for snow and ice control in the winter, as well as road and infrastructure maintenance year-round to repair damage.

Truck operations. The primary example for this activity is commercial trucking operations, both local and long haul.

Fleet utility and transport vehicle operations. This activity includes small to medium size fleets of utility vehicles, such as those maintained by telephone or cable television companies, as well as the large, nationwide fleets of mail and parcel delivery vehicles.

Bus operations. This activity is intended to cover primarily long-haul bus operations, such as interstate travel, rather than school buses or local transit system buses, both of which are covered by the Rural and Urban Transit Operations sector.

Private vehicle operations. Private vehicle operators, daily commuters, long-distance travelers, and local drivers, as well as rental car operators, are included in this activity.

State/local emergency managers. This activity encompasses emergency managers at state and local levels.

State police. Although state police and highway patrol entities provided the input on WIST needs for this activity, the information is generally valid for law enforcement and public safety officials anywhere with roadway traffic safety responsibilities.

Forest Service. The roadway operations of the U.S. Forest Service role are limited to unimproved roads under its jurisdiction within national forests and grasslands. But the ways in which the weather affects these roads has major impact on all the uses of these areas.

SPECIAL GROUPS

NASA spacecraft and equipment transport. NASA's principal concern with roadways is in transporting spacecraft and components by land routes between its various centers and the launch facilities.

Power generating operations. The WIST needs of the power marketing administration (see Section 3.1.2) are limited to road conditions that affect the ability of repair crews in utility vehicles to reach transmission lines and facilities.

Manufactured home transport. This specialized activity has WIST needs that represent the general class of high-profile vehicles, which have special sensitivities to wind and other weather elements, such as those that affect tire traction.

Interestingly, state police organizations indicated that knowledge of the local effects and variability of weather conditions gives their troopers an advantage in performing their duties. This knowledge, coupled with accurate and timely weather forecasts, improves the ability of police agencies to refine staffing and enforce traffic control more effectively. Often, the troopers are the first on-scene weather observers, and this information can be relayed to the command center for redistribution. Some states (for example, the Minnesota Department of Transportation) even have mobile observing systems (environmental sensing systems) on board their vehicles. These systems communicate directly to the traffic control center for immediate distribution and input to traffic control decision systems. These organizations believe that monitoring the environment in a proactive manner increases personnel safety and mission accomplishment.

4.3.2 Analysis of Activity–Elements

The roadway sector has the greatest number of activity–element combinations among the sectors surveyed. This reflects both the substantial number of sector activities (Table 4-2) and the large number of relevant weather elements identified by the WIST user groups. The 52 distinct weather elements of interest to decision makers in this sector is as large as any of the sectors. (Transit sector WIST users identified needs for an equal number of weather elements. Although the transit sector had the largest representation among study participants, it was less diverse and therefore had fewer activity–element combinations.) The other sectors range from 9 distinct weather elements for airport ground operations to 25 for waterways.

Figure 4-6 shows the percentages of roadway activity–elements in each weather element group. Precipitation in various forms has the most activity–elements, accounting for 28 percent of the total for this sector. Temperature-related activity–elements are next at 23 percent, followed by thunderstorms and related phenomena (including tornadoes, lightning, and hail) at 14 percent. The miscellaneous category, with 19 percent of the total, includes many unrelated phenomena such as atmospheric transport and diffusion, fire weather, total solar insolation, forecasts of fair weather, space weather (the local and high-altitude alterations in the earth's electromagnetic field caused by waves of charged particles spewed from the sun during "solar storms"), and geophysical events such as volcanism and seismic activity.

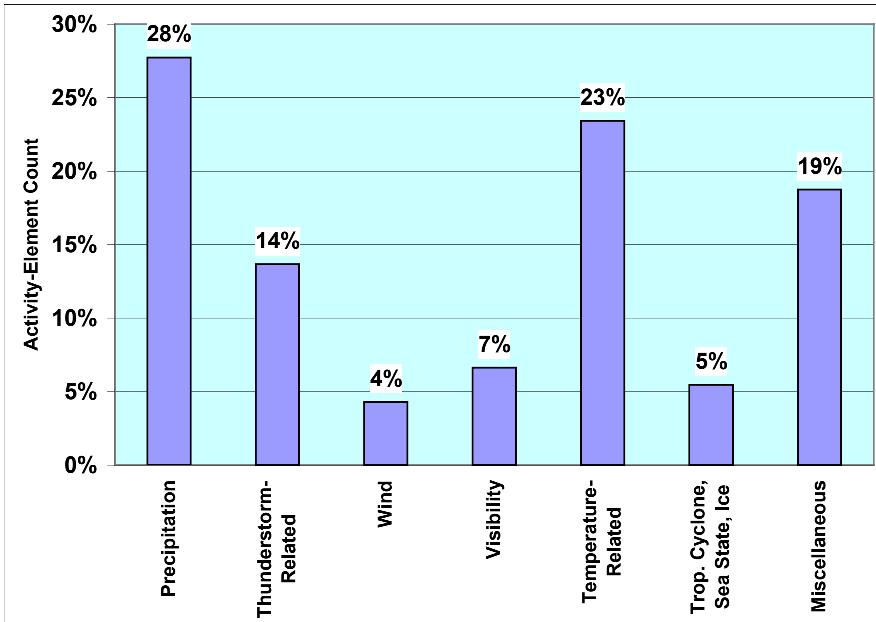


Figure 4-6 Roadway activity-elements by weather group.

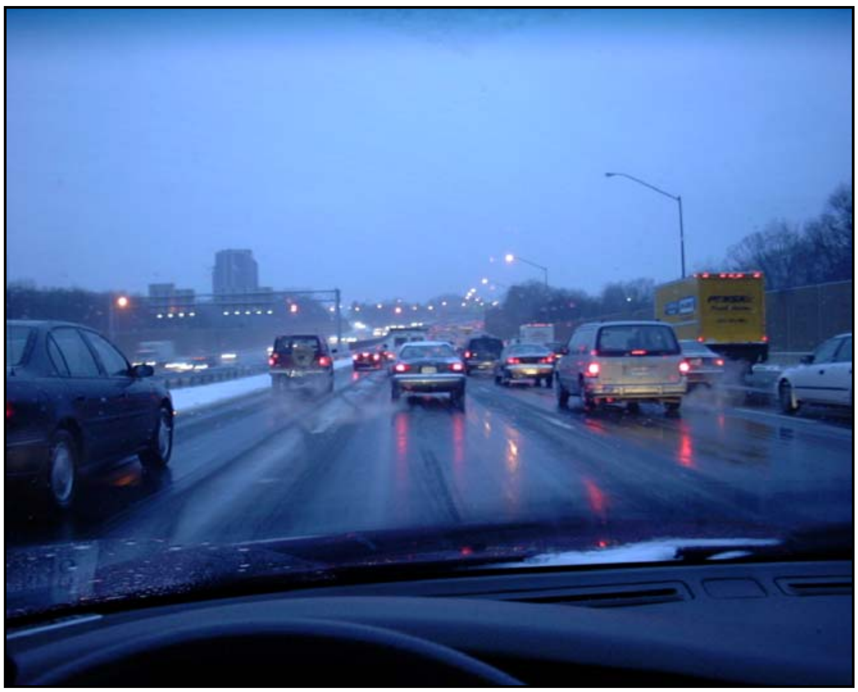
In the initial WIST survey conducted in 2000, which preceded the development of the WIST templates, precipitation was identified by nearly 88 percent of the 157 roadways sector participants as a weather element group that generated information needs. Precipitation was followed by winds, flooding, visibility, temperature-related elements, and thunderstorm-related elements; each of these weather element groups was identified by half or more of the respondents as generating information needs.

4.3.3 Impacts and Mitigation Actions, by Weather Element Group

This section discusses the effects that specific weather elements have on roadway sector operations. These effects vary widely by weather element and the affected transportation activity. As discussed in Section 4.2, weather impacts can be mitigated or obviated to varying degrees by timely action, and response decisions are affected by many factors other than weather information.

Precipitation Elements

Precipitation, especially freezing or frozen precipitation (ice or snow), causes the greatest impacts for the roadway sector. Most of the activities list safety and health risks to people and property damage risks as potential consequences of any freezing precipitation. Almost all list similar risks for frozen precipitation (snow) as well, with the risks increasing as snow depth increases. Road maintenance activities are most concerned with freezing and frozen precipitation because these conditions typically cause the greatest expenditure of resources in areas where such precipitation occurs. They have the most impact on public safety, other than perhaps a major hurricane. Ice or snow on the roadways mean loss of traction, stability and maneuverability; impaired mobility; roadway obstructions; loss of control; and increased occurrence of vehicle mishaps, with attendant injuries and risks to life and property. For almost all users, it means probable schedule and travel delays.



Precipitation increases the safety risks on crowded urban highways. Photo courtesy Blaine K. Tsugawa, OFCM staff.

State police organizations consistently report that freezing and frozen precipitation dramatically impacts their operation. When the driving public chooses to travel during adverse weather, rather than stay off the roads, the increase in accident rates shifts a larger share of police resources to vehicle accident investigation and traffic control and away from other police functions.

For road maintenance crews, accurate knowledge of the start and ending times of a winter precipitation event is crucial because the effectiveness of road surface treatments is highly dependent on timing. Treating the roadway too early or too late can substantially reduce the effectiveness of the effort to reduce the threat to life and property that freezing or frozen precipitation creates.

A front-end loader clears an avalanche from a Washington state highway. Copyright AP Wide World Photos.

The lead times these users require for information on winter precipitation events vary by activity, but two time frames stand out. The first is a longer range planning time frame, which varies by activity as follows:

- About 12 hours for vehicle drivers (enough time for them to reschedule their activities, reroute, or choose another mode of transportation)
- 12–24 hours for bus and trucking operations (allowing them to reschedule, reroute, postpone, or find safe-haven for vehicles and cargoes)
- 24–48 hours for road maintenance operations (allowing time to begin the preparation process, predict the threatened area, select a treatment strategy, and prepare and deploy treatment assets) and the U.S. Forest Service (enough time to warn campers and hikers to evacuate threatened areas, prepare to repair and reopen roads that will be made impassable, and initiate search and rescue operations if necessary).

A police officer inspects a truck that ran off the road on an icy road in Vermont while attempting to let faster traffic pass. Copyright AP Wide World Photos.

The second lead time window of major value extends roughly from 0 to 6 hours before precipitation begins. This corresponds to the execution phase of mitigation actions planned earlier. For road maintenance crews, this means final decisions and initial operations to treat and clear roads of snow, ice, and debris; deployment of treatment crews and assets; and initiating changes in traffic flow management. This phase makes use of current observations, as well as near-term forecasts and nowcasts.

Unless liquid precipitation is heavy, it affects most roadway activities less than frozen or freezing precipitation does. Two exceptions are road maintenance operations—which have concerns with traction, road submersion, drainage, and reduced visibility—and the transport (towing) of manufactured homes on the highways (many states prohibit such transport if the roadway is wet). In both cases, the critical threshold is any liquid precipitation at all. However, conditions that produce flooding are of concern to all roadway activities. The lead times that activity managers prefer to have prior to a flooding event range from 6–12 hours for local mobilization to 1–2 weeks for road maintenance preparation and detour planning activities. For most roadway activities, the principal action in response to a near-term flood warning is to avoid or escape from the areas of predicted flooding.

Temperature Related Elements

The second-highest number of activity–element combinations for the roadways sector (23 percent of the total) involve the temperature-related weather elements. Most of these come from the road maintenance community. Of the 60 activity–element combinations, 21 involve just the air temperature (including maximum and minimum; temperature relative to freezing, with rising or falling trend; temperature change rate; and heating/cooling degree days). Another 24 are related to elements combining air temperature and humidity (heat index and wind chill temperature, dew/frost point, wet bulb temperature, and relative humidity). and 12 are related to surface temperatures and moisture conditions (pavement and subsurface temperatures, pavement freeze point temperature with frost point, and pavement condition).

Crews work in the high heat produced by the weather and the asphalt treatment being done along State Route 10 near DeSoto, Kansas. Maintenance managers want advanced notice of high heat days for worker safety. Copyright AP Wide World Photos.

Road maintenance operations are highly dependent upon temperature information, particularly the combination of pavement temperature and air temperature relative to the freezing point, with rising or falling trend. Accurate and timely temperature information, coupled with precipitation information, allows operators to select the correct strategy and treatment material for treating road surfaces to minimize the effects of weather on motor vehicle operations. The Forest Service is concerned about temperatures rising above freezing during the winter months because, as frozen, snow-packed logging roads thaw, heavy logging trucks cause structural damage to the roads. If this condition can be predicted accurately, the roads can be closed to heavy trucks before damage occurs.

Sufficiently high temperatures can be a concern for most roadway activities and users. Not only do high temperatures require caution for work crews and equipment, they pose a risk to vehicles and freight. High pavement temperatures increase the risk of tire blow-outs for heavy loads, such as manufactured homes being towed on the highways. State police also reported that extreme temperatures, both hot and cold, have substantial effects on their duties and workloads with respect to vehicle incidents on the roads and traffic flow management.

Thunderstorm Related Elements

The next most prevalent group of activity–elements for roadways are the 14 percent associated with thunderstorms and related phenomena. Although the impacts can be very severe and include loss of life and damage to property, thunderstorm phenomena generally affect smaller areas and for shorter durations than some of the other weather elements. When severe thunderstorms do occur, all the roadway activities recognize the potential risks to their people, vehicles, and cargoes. The protective actions are similar: most activities cease outdoor operations in the path of the threatening weather and take evasive actions as necessary.

Road maintenance activities and the Forest Service also must respond to road damage or blockage by debris. In addition to conducting search and rescue for stranded, trapped, or injured recreationists in the wake of a severe storm, the Forest Service must determine where valuable timber has been knocked down and must be salvaged.

Trucking operators and NASA (during the ground transport of spacecraft and equipment) will delay, reschedule, reroute, or seek shelter, as appropriate to protect their people and equipment. State police reported that, although lightning does not routinely affect their mission, serious difficulties do arise when lightning occasionally damages their communications towers and antennae.

Visibility

Activity–elements related to visibility represented 7 percent of the total combinations for roadways. Generally, visibility does not become a factor for roadway operations until it becomes restricted to a quarter mile or less. At that point, most activities simply slow down and exercise more caution. Some, however, take more specific actions. Manufactured home transporters stop travel; trucking operators, if hauling hazardous materials (HAZMAT), may seek a safe stopping place. NASA will try to reroute, delay movement of, or transport their cargo earlier to avoid encountering conditions of reduced visibility on the road. An element related to visibility that affects most roadway operations is sun glare. For most activities, the principal response action is to reduce speed. State police added that reduced visibility is one of the weather elements that consistently affects their operations dramatically, increasing the rate of vehicle incidents and altering traffic flow.

Winds

Although winds account for relatively few of the activity–element combinations (4 percent) for roadways, high winds are a concern to road maintenance activities and transporters of high-profile loads, including trucks, buses, manufactured homes, recreational vehicles, and NASA's road transport activities. The critical threshold for most activities is winds of 50 miles per hour and more. The exception is transporters of manufactured homes, who typically stop travel when winds exceed 25 mph.

Miscellaneous Elements

Several of the weather elements and weather-related phenomena in the miscellaneous group are worth noting for their impact on roadway activities. One of these is hurricane (tropical cyclone) storm surge, which affects all road transportation activities in the area where storm surge occurs. The response actions are to suspend travel through and vacate the affected area. Required lead time to respond effectively is 12–24 hours. Another element of interest to important roadway activities is fair weather, or more precisely, accurate forecasts of the duration of fair weather. Many activities rely on "good" weather for success or efficient operations, so an accurate forecast of good weather is just as important as an accurate forecast of adverse weather.

A third element in this category is weather information relevant to incidents of release and atmospheric dispersion of nuclear, biological or chemical hazards. Whether accidental or deliberate, these events are life-threatening, and the responses by roadway activities are either to cease operations and clear the area or participate as part of a previously trained response team. A related element, albeit less critical in potential health effects, is air quality, which typically has the greatest impact in urban areas. Many of the meteorological conditions that influence the movement of a plume from a hazardous-materials release are also of importance in forecasting air quality conditions and the areas affected.

Another element of special interest in the miscellaneous group is space weather. As the nation grows more and more dependent on electronic and wireless systems for communication, navigation, and data transfer, the need increases to monitor and manage the system components that can be temporarily disrupted or permanently damaged by space weather hazards.

4.4 Long-Haul Railway Sector

4.4.1 Sector Activities

Long-haul railway operations include inter-city freight transportation and a small volume of inter-city passenger traffic. The "light rail" systems used for metropolitan-area passenger transportation are included in the rural and urban transit sector. The long-haul railway activities identified by survey participants from this sector as sensitive to weather or weather-related conditions are described in Table 4-3 and appear in Appendix B-2, the WIST needs template for this sector.

Table 4-3 Long-Haul Railway Activities

Railway/control center operations. The control center monitors the railroad system and advises train and station operators and dispatchers. It controls system integrity.
Station and depot operations. Operations at and in the vicinity of stations, involving tracks, rolling stock, and platforms.
Hump yard operations. Includes maintenance, inspections, and local operations.
Construction. Includes scheduling, maintenance, and repair activities.
Hazardous material. Includes monitoring the transport and handling of materials, as well as mitigation, reclamation, and reporting of events or incidents.
Surveillance. Includes inspections, monitoring, and maintenance of trackage, supporting structure, and facilities.
Personnel safety. Safety of train crews, station and depot personnel, and passengers.

Since 1985, the railroad industry has grown and changed. Boxcars are being replaced by inter-modal containers and trailers. Warehousing is considered inefficient and expensive; the modern business operation plan calls for “on-time delivery” instead. Accounting for the effects of weather conditions on this time-sensitive delivery system is essential for efficient and effective operations. Decisions made with inadequate or erroneous weather information reduce efficiencies, increase operating costs, and decrease customer satisfaction. Each of the four major rail carriers either has its own weather forecast staff or contracts for weather support services.

4.4.2 Analysis of Activity–Elements

Because there are so few railroad companies, the railway sector is one of the smaller user populations in the WIST study, in terms of the number of participating entities. But this industry concentration belies the importance of the sector to the transportation industry. Responses to the WIST needs questionnaire were received from 22 separate entities, which identified 18 distinct weather elements that affect them. For the seven sector activities identified by these users, there are 129 activity–element combinations in the WIST needs template. Figure 4-7 shows the distribution of these activity–elements among the weather element groups defined in Table 2-1.

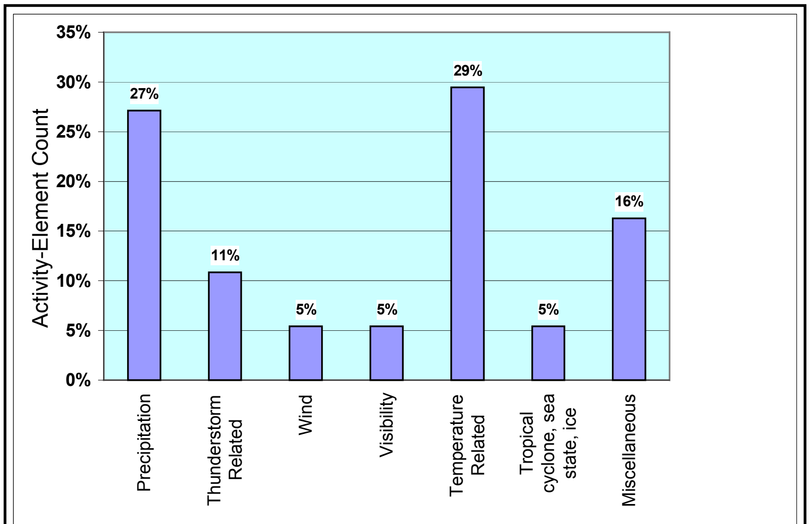


Figure 4-7 Railway activity-elements by weather group.

The initial WIST survey, which was conducted in 2000 prior to developing the WIST needs templates, showed precipitation as the weather element which drew the greatest amount of interest. Nearly 83 percent of the 47 respondents from this sector indicated a need for precipitation information. The weather elements of visibility, flooding, winds, thunderstorm-related conditions, and temperature-related elements were each identified as WIST needs by half or more of the respondents.

Among the activity–element combinations from the template, temperature-related elements account for the highest number, with 29 percent of the activity–element combinations (Figure 4-8). Activity–element combinations for precipitation elements were next at 27 percent, followed by thunderstorm-related elements at 11 percent. In the miscellaneous group, the activity–elements are split evenly between atmospheric transport and diffusion and space weather.

The emphasis on temperature-related needs reflects the larger number of temperature-related elements identified as important by the railways sector participants. Some of the nuances among the precipitation-related elements that are important for roadways, transit operations, or airport ground operations are less important for long-haul railways. However, temperatures at both the hot and cold extremes—particularly temperature changes—have substantial effects on steel rails.

4.4.3 Impacts and Mitigation Actions, by Weather Element Group

This section discusses the effects that specific weather elements have on railway operations and the response actions that the study participants identified as potentially influenced by accurate information on each element. Mitigation actions can range from simply increasing awareness to taking specific corrective actions or curtailing or suspending activities. All these actions are intended to avoid unnecessary cost, damage to property, or safety risk to people. As discussed in Section 4.2, weather impacts can be mitigated or obviated to varying degrees by timely action, and response decisions are affected by many factors other than weather information.

Freight locomotives are trapped and partially derailed in ice pushed up by rising Susquehanna River waters near Cresswell, Pennsylvania. Copyright AP Wide World Photos.

Temperature-Related Elements

Of the 38 temperature-related activity–elements identified for the long-haul railway sector, 14 are for air temperature, including daily maximum and minimum and first occurrence of a high or low for the season. Another 7 are for rail temperatures, and 7 are for soil temperature (impacts on the railbed). The remaining 10 are for wind chill temperature and heat index, which affect exposed personnel.

Expansion and contraction of the rails caused by changes in temperature or seasonal extremes are of great concern to this sector. The rail industry routinely inspects all 120,000 miles of track about twice weekly. However, the first occurrence of the fall-winter season when the air temperature drops below freezing produces rail contraction that can cause gaps and misalignment in the track. This greatly increases the number of track warning signals and the potential for derailment, malfunction of track sensors and signal sensors, and signal damage. Rail contraction continues as the temperature drops further. These conditions pose a risk to personnel (crew and passenger) safety and risks to freight and property. Mitigation actions include increased inspections of track and sensors; repair as necessary; slowing, stopping, delaying, or rerouting trains; and preparations for response to HAZMAT incidents. Similarly, increasing air temperatures produce rail expansion, which can cause "kinks" in the track beyond a certain temperature. The seasonal thresholds are the first occurrence of air temperatures in the spring at 70–75 °F, and 90 °F. When air temperatures exceed 90 °F, additional track inspections are prescribed.

More important than any single upper or lower threshold is the diurnal temperature variation. Temperature changes of 30–40 °F over 24 hours can cause inconsistent expansion and contraction, leading to track misalignment and possible rail failure. The actions taken are essentially the same as for crossing the seasonal temperature critical points. The lead time desired by the industry is 3 days for both hot and cold temperatures, followed by another notification 12 hours before the threshold temperature is reached.

Two elements closely related to air temperature are rail temperature and soil temperature. Rail temperature is of interest because of the expansion and contraction issues. The critical thresholds are the freezing point (especially if moisture is present) and 110 °F. Soil temperature is critical at the freezing point, as freezing and thawing of the soil can produce ground heaves, which may result in railbed movement, making track and railbed failures and train derailments possible. Ground heave is most prevalent during the autumn freeze and the spring thaw. Mitigation actions

Hot air rising from a rail bed near Hollywood, Florida, gives track the appearance of being distorted. Rapid temperature changes, particularly the first of a season, can buckle rails and cause accidents. Copyright AP Wide World Photos.

are essentially the same as for rail expansion and contraction. Each of these temperature elements affects all seven of the railway sector activities.

Precipitation Elements

The second highest count of activity–elements for the long-haul railway sector are those for precipitation events. The sector participants identified five precipitation elements of interest (freezing precipitation, snow, drifting snow, heavy rain, and flooding), each of which affects all seven of the sector activities.

As freezing precipitation (ice) builds up on structures and metal rails, the potential increases for failure of track switches and malfunctions of track sensors, signal sensors, and signals. Monitoring and repair requires dispatching rail and signal maintenance crews. Ice can also require reductions in train speed, causing schedule delays, even while demand for passenger service is surging because other modes of transportation are more affected or unavailable. Ice increases the difficulty for railroad employees in getting to work, impedes mobility of track inspection crews, and increases risks to personnel safety, particularly on passenger platforms at train stations. Mitigation actions include implementing traditional snow and ice control plans, modifying train operations (which may include delaying or rerouting trains), inspecting and repairing tracks as necessary, or recalling additional train and maintenance crews. The lead time desired by decision makers in this sector is 24 hours, with followup notification 6 hours before the freezing precipitation begins. These lead times are generally the same for all ice and snow events.

Frozen precipitation (snow) of less than 6 inches generally does not pose a problem for operation of long-haul trains. Perhaps the best mitigation action is to keep the trains running, which keeps the rails clear and holds accumulations at a manageable level. Snow accumulation greater than 6 inches, however, brings much the same impacts as are associated with ice, with the same range of potential mitigation responses.

Liquid precipitation (rain) is only a problem when it is intense enough to reduce visibility, which may cause a train crew to miss a signal unless train speed is sharply reduced (creating schedule

After the storm surge and heavy rain from a hurricane, obstacles lie across a flooded section of track in Alabama.

delays). However, flooding—a byproduct of rain—can have much more serious impacts. It can wash out portions of the railbed; damage railbed support structures, switches, sensors and signals; or cause mudslides or high water over the tracks, which pose risks to train operations. The rail industry operates under a “fail safe” rule: if there is a reported problem with or on the tracks, a track inspection is required prior to resuming operations. In general, the first reaction to reports of flooding is “when” and “where.” This approach isolates the potentially affected region, limits suspension of operations to just the affected areas, and initiates rail inspections.

Thunderstorm-Related Elements

Tornadoes are of course the most severe threat in the thunderstorm-related group, but they are infrequent and normally confined to a relatively small area. A much more widespread and frequent threat is lightning strikes within 5 miles, which brings many exposed or outdoor operations, such as refueling, to a halt. Lightning can also produce track sensor and signal malfunctions, resulting in train delays and stops. Knowing where lightning has occurred allows the signal repair crews to isolate more quickly the locations of signal and sensor problems. Another problem can be the high winds associated with thunderstorms, which are addressed below in the section on winds.

In 1998, heavy rains from Hurricane Georges washed out 350 feet of track near Crestview, Florida.

Winds, Visibility, and Tropical Cyclones

Each of these weather elements or weather-related phenomena affects all of the railway activities.

Wind speeds in excess of 50 mph, no matter what the source, are likely to blow some types of rail cars over, which makes it prudent for those trains to be stopped or otherwise protected. Decreased visibility makes it more difficult to see train signals and obstructions on the track, which increases the possibility of collisions and derailments.

Visibility thresholds are based on the stopping distance, which is a factor of speed, topography, and weight. For example, a 10,000-ton train moving at 60 mph on level ground requires 1.25 miles to stop. As a rule, visibility is not a significant factor until it drops below 1 mile. As the visibility drops, the mitigation response is to reduce train speed.

Tropical cyclones combine the effects of storm-force winds, the cumulative effects of tides and storm surge, and inland flooding. These phenomena can scour, bury, damage, or destroy the railbed; damage rail from line stretch and debris impact; damage structures; and cause rail sensor and signal failures. Railbed and track failures are likely, and derailments are possible. Winds, seas, and tides may restrict or suspend coastal rail traffic. Mitigation actions include relocating rail assets before a storm to preclude damage or stranding, suspending rail operations in the affected area, and cleaning up and repairing as necessary afterward. Particular attention must be focused on rail surveillance and inspections of bridges, trestles, and railbed for structural integrity.

4.5 The U.S. Marine Transportation System

The MTS is a key component of our national transportation system. In 1998, about 2.4 billion tons of cargo moved on U.S. waterways and through U.S. ports. By 2020, trade is conservatively projected to double, with the largest increase expected in container shipping. The length, width, and draft of commercial vessels have grown dramatically over the last 50 years, pushing the limits of many ports and posing significant safety concerns (NOAA 2001). Environmental risks have also increased with increasing vessel size because nearly half of all goods transported are oil or other hazardous materials. Growth in ferry, cruise line, and recreational boating also contributes to increased congestion on our waterways. Ensuring safe and efficient port operations is vital to maintaining the competitiveness of the U.S. port industry and U.S. exports (DOT 1999). The WIST needs study identified the impacts on this system of weather and related elements. Characteristics of information about these elements that could help in mitigating these consequences were identified and validated by participants from the MTS user communities, as well as the federal agencies with responsibility for the MTS.

In 1998, Congress directed these federal agencies to assess the state of the MTS and develop a vision for modernizing the system. This was a first step toward developing a transportation system for the twenty-first century—a system that addresses the future of marine transportation safety, security, competitiveness, infrastructure shortages, and environmental health. Federal entities—in particular the U.S. Coast Guard, Maritime Administration, and NOAA—and the private sector have partnered to support the MTS initiative by raising awareness of MTS issues.

4.5.1 Sector Activities

The sector activities of the MTS include the full spectrum of waterborne transportation on freshwater and estuarine waterways, coastal routes, and the open sea. These activities range from recreational boating and commercial barge traffic on inland waterways to movement of large commercial vessels in harbors and on the open ocean. The first 10 activities in Table 4-4 constitute the waterborne component of the nation's MTS. A closely allied activity that WIST users in this sector wished to include is marine modeling. All 11 of these activities are covered in the WIST Needs Template in Appendix B-3.

Table 4-4 MTS Sector Activities

Inland water activities
Ferries.
Commerce; includes barge traffic on major rivers.
Recreational boating; includes fresh water lakes, rivers and streams.
Open water activities
Cargo/freight; includes large ocean-going vessels, including U.S. Navy ships.
Cruise lines.
Commercial fishing; primarily includes near-shore and off-shore salt water operations.
Recreational boating and salt-water operations.
Port operations. Operations include keeping port facilities open and safe movement of vessels in and out.
St. Lawrence Seaway operation. Operation of locks and canals, control of navigation and movement of vessels.
NASA movement of launch vehicle/payload elements via barge. Primarily external fuel tank and solid rocket boosters moving to and from the launch facility.

4.5.2 Analysis of Activity–Elements

Participants from the MTS sector constituted the third largest population in the WIST needs study, after roadways and transit. Responses were received from 28 separate agencies or entities (Appendix A). These participants identified 25 distinct weather elements that affect them. When these weather elements are combined with the sector activities affected by each element, the total count of activity–element combinations is 188, the second highest count among the six sectors studied.

In the distribution of these activity–elements by weather element group (Figure 4-8), the precipitation group accounts for 20 percent. Temperature-related elements account for 19 percent. Elements in the category of tropical cyclones, sea state, and ice account for another 14 percent of the total.

In the initial WIST survey conducted in 2000, prior to developing the WIST needs templates, “precipitation elements” was the group most frequently cited by the respondents. Of the 32

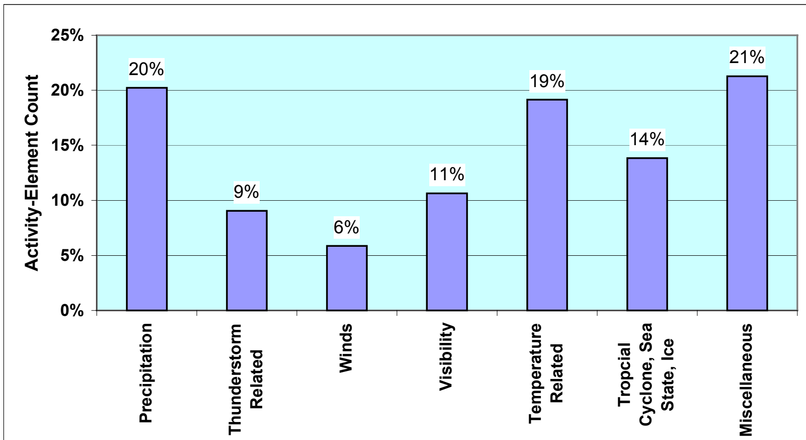


Figure 4-8 MTS activity-elements by weather group.

respondents for this sector, 75 percent indicated a need for precipitation information. Visibility, winds, and flooding were identified by half or more of the respondents. The groups for thunderstorm-related elements and tropical cyclones were cited by between 30 and 50 percent of this initial set of WIST respondents.

4.5.3 Impacts and Mitigation Actions, by Weather Element Group

This section discusses the effects that specific weather elements have on MTS operations and the response actions that the WIST study participants identified as potentially influenced by accurate information on each element. Mitigation actions can range from simply increasing awareness to taking specific corrective actions or curtailing or suspending activities. All these actions are intended to avoid unnecessary cost, damage to property, or safety risk to people. As discussed in Section 4.2, weather impacts can be mitigated or obviated to varying degrees by timely action, and response decisions are affected by many factors other than weather information.

Precipitation Elements

Precipitation, especially freezing and frozen (ice and snow) precipitation, causes the greatest impact for this transportation sector. With any amount of freezing precipitation, all the activities show impacts to safety of personnel, impaired operations, and risk to cargo and equipment. Almost all of the sector activities show corresponding risks and impacts with frozen precipitation (snow) as well. Intense rain impairs operations, primarily because it reduces visibility and creates a danger to personnel and equipment due to flooding.

Vessel operators, whether on large commercial or small recreational vessels, mitigate the risk posed by freezing precipitation and the buildup of ice on decks and structures by limiting or terminating on-deck activities, covering equipment, or avoiding operating in areas of, or during periods of, freezing precipitation. When NASA moves spacecraft components by barge, all equipment and cargo are covered, and the operator considers delaying barge movement until the weather event has passed. Snow does not necessarily terminate operations, but it requires operators to clear the snow from decks and consider curtailing on-deck activities. The reduced visibility brought on by heavy rain requires extra vigilance and reduced speeds for vessels.

Representatives from the U.S. Coast Guard, in discussing operation of small and medium size cutters on the Great Lakes, reported that no matter what the form, precipitation reduces visibility and clutters the radar of cutters that are underway. Snowfall accumulating on a cutter affects the cutter’s stability and the crew’s movement onboard. Snowfall on top of ice-covered waters slows a cutter’s movements through the ice. Flooding caused by ice jams may require icebreaking operations to alleviate the flooding.

Port operations are affected somewhat differently than are vessels underway. This sector activity involves not only water-borne operations but also the ground-based operations of the terminal and the surface transportation systems that service the port facilities. Thus, ports have snow and ice removal responsibilities similar to those of other roadway and rail system operations. Heavy rain can hamper port operations by producing local or widespread flooding, which can also endanger inland waterway activities, including lock operations, as well as damaging equipment and cargo.

Inland waterways of the U.S. Marine Transportation System play a critical role in the nation's commerce. Photo courtesy NOAA Photo Library.

Required lead times for information on these weather elements vary by activity, but two time frames are clearly of most value. The first is the medium range planning time frame, which for most water-borne activities is 12 hours for freezing and frozen precipitation and 6 hours for rain. For port operations, 12 hours is the preferred lead time as well, except for heavier snowfall (greater than 4 inches), when 24 hours is desired. The second lead time period of great value is 0–6 hours. Information requested in this time frame includes current observations (or current nowcasts) of weather conditions that are affecting operations, as well as forecasts of weather conditions in the next six hours.

Temperature-Related Elements

Temperature-related activity–elements account for 19 percent of the total for MTS operations. Of the 36 activity–elements, 11 are for air temperature. Another 20 are for heat index and wind chill temperature, and 8 are for water temperature and freezing spray. (Freezing spray is actually a weather-related consequence of winds, seas, and temperature.)

Air and water temperatures have the greatest effect on water-borne operations as they fall to and below the freezing point. Air temperatures of 32 °F or less cause water that splashes or sprays on a vessel to freeze. The resulting accumulation of ice on decks, superstructure, and rigging of a vessel can make it top-heavy and seriously decrease its stability. This condition occurs with a combination of freezing temperatures, heavy seas (relative to the vessel), and wind, which together produce large amounts of spray inundating the vessel and accumulating as ice. Operators of Coast Guard cutters on the Great Lakes cited this as a particular concern. Mitigating actions include changing direction and speed to reduce the amount of spray, removing ice from the vessel, and seeking shelter until the conditions abate. Cold temperatures are also a health and safety risk for personnel and affect the operation of some equipment, requiring that personnel are properly clothed and equipped and that sensitive equipment is protected.

Decreasing water temperatures and formation of ice, particularly on inland freshwater bodies, affects all vessels from small recreational boats to large ferries and barges. On the Great Lakes, for example, the Coast Guard removes its small boats from the water and Coast Guard cutters become the primary search and rescue resource. Coast Guard icebreaking operations then commence for emergency operations, flood control, and facilitating navigation.

Hot temperatures also affect the safety and effectiveness of personnel. In almost all cases, the lead time desired is 12 hours for the onset of either cold or hot conditions that affect operations or safety, whether it be for a cruise liner or recreational boaters. Port operations are the exception, where the desired lead time is 24 hours to prepare for cold temperatures.

Tropical Cyclones, Sea State, and Ice

This category includes wave height (which has already been discussed as a factor in freezing spray), storm surge (including abnormally high or low tides), and ice (inland bodies, rivers, and open seas). Other than the U.S. Navy, none of the users specified tropical cyclones, per se, as an item of required information. Instead, they specified elements that can occur with tropical cyclones, such as wave height, high winds, heavy precipitation, thunderstorms, and storm surge.

For the U.S. Navy and operators of other ocean-going vessels, tropical cyclones and even severe winter storms provide planning and operational challenges, as ships cannot generally ride out storms in port without sustaining damage. Once they are underway (or "sortie"), ships must steer well clear of the highest winds and seas to avoid personnel injuries and damage and to ensure their stability limits are not exceeded. Storms that remain well out to sea are of little consequence to the general public but of great concern to the Navy. Because of the need to sortie ahead of tropical cyclones, the Navy must make decisions 3 to 5 days in advance of potentially dangerous weather. Sortie decisions are significant because of their high cost and impact on personnel and operations. In making these decisions, Navy fleet commanders must strike a balance between the risk of staying in port and the cost and potential for damage at sea. Within the continental United States and adjacent ocean areas, tropical cyclone forecasts in particular are closely coordinated between Navy forecasters and the NWS.

Storm surge and abnormally high or low tides are of greatest concern to recreational boaters, ferries, and port operations. The danger is primarily to port and mooring facilities and to vessels that are moored. For ferries, there is an increased risk of grounding and impaired passenger accessibility, especially for those with disabilities. The WIST participants generally requested lead times of 24 hours for response to these weather elements.

Ice poses a threat to all MTS activities due to the risk of hull damage to vessels and damage to port facilities. Mitigation actions include avoiding areas of ice, navigating ice-bound areas at speeds and with equipment that permit safe passage, requesting ice breaking services, or ceasing operations. Lead times requested by participants were generally 12 hours for vessels and 24 hours for port operations. Tailored ice forecasts and analyses are provided by the National Ice Center, located in Suitland, Maryland. The Navy (through the Naval Ice Center), NOAA, and the United States Coast Guard jointly operate the National Ice Center, which provides ice analyses and forecasts to civilian as well as military activities for the Arctic and Antarctic regions, coastal United States waters, and the Great Lakes.

Ice on the Delaware River floats in the shipping lanes near Philadelphia, in January 2001. Copyright AP Wide World photos.

Winds

High wind by itself accounts for only 11 of the activity–element combinations identified for this sector. However, if the wave height element is included with wind (since wave height is a wind-driven phenomenon), the activity count doubles to 21 (11 percent of the total count for this sector). Wind and waves may be the weather elements that most frequently affect a wide range of waterborne and port operations.

High winds are a concern for all sector activities including marine modeling (which seeks to take wind effects into account in the models). Small boat handling becomes difficult at about 20 knots and operators are advised to exercise caution. At about 30 knots and greater, suspension of all small boat operations is strongly recommended. Ferry and barge operations begin experiencing difficulty at 20 knots, and by 30 knots operators may find it appropriate to cease operations until conditions improve. At 45 knots, these operators are likely to experience extreme difficulty with handling and maintaining control of their vessels. Larger ocean-going vessels are not as affected by wind speeds less than 30 knots, but when winds are above that speed they, too, begin to modify their operations to reduce risks to their cargo, passengers, and vessels. Port operations, which are also affected by high winds, begin to implement mitigation actions when wind speeds exceed 25 knots. Wind damage is possible to port facilities at speeds above 25 knots and likely at speeds above 45 knots.

The greatest wind-related effect is increased wave height. Wave heights of 2 to 4 feet affect passenger comfort and pose some risk to small boats, both inland and on open water. At 4 to 6 feet, there are safety risks for passengers and crew, and small boats should curtail or cease operations. Ferries and barges are likewise affected and may need to reduce speed or suspend operations. Waves of this height can also damage port facilities. Coast Guard cutter operations on the Great Lakes are greatly affected by the combination of wind and waves. Indeed, the Coast Guard reports that each class of cutter reacts differently to different wind speeds, and each Coast Guard operation is affected differently by winds at a given speed. When wave height reaches 6 to 12 feet, there is risk to passengers, crew, and cargo for medium to small vessels, which should adjust course and speed to minimize the impact of the seas on the vessel. At this sea state, damage is likely to port facilities, and ports therefore implement procedures to minimize the damage where possible. At heights of 10 or 12 feet and greater, there is safety risk to personnel and risk of structural damage to larger vessels and their cargo. NASA, for example, will consider delaying movement of its cargo until conditions improve.

Although the Great Lakes do not experience gravitational tides, they do have wind-driven tides (referred to as "seiching") that can affect MTS operations. Under the influence of a steady wind, water is pushed from one end of a lake to the other, leaving behind low water levels that can prevent vessels from transiting shallows that are normally passable. In addition waves on the Great Lakes typically have a shorter period than ocean waves do. They can come from various directions and build rapidly.

For both winds and wave height, the WIST participants reported that they generally require 12 hours lead time for the more moderate conditions that require only increased caution. They require 24 hours lead time for more serious conditions that hinder or preclude safe vessel operations.

Visibility

Each sector activity except marine modeling has an activity–element for reduced visibility in general and another for sun glare, resulting in a total count of 20. The principal impact is decreased ability to navigate and maintain safe clearance from obstacles and other vessels. Generally, visibility does not become a factor for MTS operations until it decreases to 3 miles or less. At that point, most activities simply slow down and exercise more caution. Some take more specific actions. NASA, for example, does not allow movement of cargo when visibility drops below one-eighth of a mile. Most of the users require only 6 hours lead time for reduced visibility conditions; however, NASA needs 24 hours.

Thunderstorm-Related Elements

Thunderstorms and related weather phenomena account for 17 of the activity–elements for the MTS sector. Although these phenomena can be very severe and cause loss of life and property, they generally affect smaller areas for shorter periods of time than do some other weather elements. When severe thunderstorms do occur in the vicinity of MTS operations, all the sector activities recognize the potential risks to people, vessels, and cargo. The range of mitigation actions is similar; most activities cease outdoor operations in the vicinity of the threatening weather. Vessels underway take evasive actions as necessary.

Lightning is the most common risk. When lightning is present, small boats will generally cease operations and most users will cease hazardous activities such as refueling. Hail may damage cargo or equipment and injure personnel. Heavy rain and wind reduce visibility, requiring extra caution and reduced vessel speeds. Protective actions include keeping vessels and people out of the severe weather as much as feasible and curtailing outside activities when possible. For example, NASA will delay, reschedule, or reroute water-borne transport of spacecraft, vehicles, and equipment as appropriate to protect people from injury and prevent damage to very sensitive, high-value space program equipment.

The most severe risk is from tornadoes (primarily to inland waterway operations) and some extreme waterspouts. Although this risk is far less frequent than thunderstorms with lightning, tornadoes pose a severe threat to life and property. The preferred mitigation action is to adjust course and speed to avoid the severe storm. In almost all cases for thunderstorm-related weather, the desired lead time is 3 hours, with real-time updates when storms are actually occurring and affecting operations.

Miscellaneous Elements

The miscellaneous group contains several weather elements of particular interest to WIST users in the MTS sector. One is the element for atmospheric dispersion from release of a nuclear, biological, or chemical hazard. Such events are health and environmental risks, as well as being potentially life threatening. The mitigating action in almost all cases is to cease operations and clear (or avoid) the area. A related element is air quality. Poor air quality can pose a health risk to personnel. Both of these elements were designated as relevant to ten sector activities (all except marine modeling).

Every day, the Port of Baltimore handles tons of coal, hundreds of foreign-built cars, and thousands of boxcar-sized containers. Hazardous material incidents, including deliberate releases of nuclear, biological, or chemical hazards, are among the emergencies for which managers of this complex intermodal transportation node must prepare. Copyright AP Wide World Photos.

Space weather is a third element in this group that was designated as relevant to the ten sector activities except marine modeling. As the MTS becomes increasingly dependent on modern communications, navigation, and data transfer systems, there is a corresponding need to monitor and manage these electronics-dependent systems for any adverse effects of heightened solar weather activity.

The fourth miscellaneous element designated as important to ten of the sector activities is volcanic ash. Volcanic ash can damage equipment, present a health risk, and reduce visibility. Mitigating actions include protecting equipment, clearing the ash, providing breathing equipment for personnel, and curtailing operations in the vicinity of an ash plume.

Finally, although not explicitly designated by the participants from this sector, the element of "correctly forecasting fair weather" is also important to the MTS. Many sector activities rely on good weather for efficiency and, in some cases such as recreational boating, safety and feasibility. Therefore, accurate forecasts of good weather can be as valuable to activities in this transportation sector as a forecast for adverse weather.

4.6 Pipeline Systems Sector

Pipelines are essentially product "highways."

Pipeline operations can be divided into two distinct areas of responsibility: the pipeline industry itself and the users of pipeline delivery services. The pipeline industry can be viewed as the "highway system" for commodities transported through long-distance pipelines. These pipelines control the transport of immense quantities of fluids (gases and liquids) across the United States to support our economic system's requirements for on-time delivery of supply to meet demand. This critical function is maintained and managed at control centers operated by the individual pipeline companies. A control center is the focal point for all gathering and distribution of information relevant to a pipeline's operation and status. The control center monitors and controls the complete length of pipeline. It receives measurement data on flows, pressures, and temperatures and remotely controls valves and limited holding tanks. Relative to the volumes being transported in a unit of time, pipeline companies have little or no holding capacity for the transported fluids at either end of the line. Thus the product providers, for example an oil refiner or a natural gas supplier, are responsible for most storage, usually in the form of tank farms. The product providers are also responsible for well-head operations, tank farm pipeline distribution, local pumping stations, and maritime tanker distribution operations.

The Trans Alaska Pipeline carries crude oil from Northern Slope oilfields 800 miles to the ice-free port of Valdez, Alaska. Photo courtesy Office of Pipeline Safety, U.S. Department of Transportation.

4.6.1 Sector Activities

Weather-sensitive activities or operations related to pipeline system operations generally fall into one of more of the categories shown in Table 4-5. These nine activities are used in the WIST needs template for this sector (Appendix B-4) to define activity–element combinations.

Table 4-5 Sector Activities for Pipeline Systems Sector

Control center operations. Operations to monitor the pipeline system, advise system operators, and control system integrity.
Pumping station operations. Responsible for fuel movement, allocation, storage, and distribution.
Well head/drill site operations. Includes operations for fuel pumping, storage, and distribution near source wells.
Tank farm operations. Includes fuel storage, distribution, and maintenance at tank farms.
Construction. Operations include construction, maintenance, and repair, as well as the scheduling of these operations.
Hazardous material. Includes monitoring storage and transport of hazardous materials and any mitigation, reclamation, and reporting operations associated with their accidental release while within the pipeline system.
Surveillance. Includes inspections, monitoring, and maintenance.
Personnel safety. Any operation where safety and health risks to workers or others may be present.
Fuel barge operations. Includes barge docking, fuel movement by barge, and transfer to/from fuel barges.

4.6.2 Analysis of Activity–Elements

The pipeline system sector of transportation had the smallest participant population in the WIST needs study, with inputs received from 15 separate agencies or entities. These participants identified 19 distinct weather elements that affect their activities and for which weather information could aid in mitigation actions. Figure 4-9 shows the distribution of the 128 activity–element combinations in the Pipeline Systems template among the weather element groups. Of these groups, precipitation had the highest count of activity–elements, followed by the tropical cyclone–sea state–ice group and the temperature-related group.

Even though a pipeline system, including the well heads, valves, tanks, etc., as well as the pipeline itself, completely encloses the material that is moving (the product flowing through the pipe), weather does affect the system's safe, economical, and efficient operation. Weather affects the complete spectrum of pipeline operations; including all of the sector activities listed above. However, for the weather element groups with the highest counts of activity–elements in the template, it is the secondary phenomena caused by precipitation, temperature extremes, or high winds that are of direct concern. Specific conditions cited by the WIST participants as major threats to sector activities include flooding, seabed scouring, landslides, and frost heave. These and other consequences of weather and environmental phenomena comprise the second largest contributor to pipeline damage or failure.

In the initial WIST survey conducted in 2000, prior to preparation of the WIST needs templates, precipitation elements were of interest to 80 percent of the respondents for this sector. Flooding, visibility, and winds were weather elements of interest to half or more of the respondents.

4.6.3 Impacts and Mitigation Actions, by Weather Element Group

This section discusses the effects that specific weather elements have on pipeline system operations and the response actions that the WIST study participants identified as potentially influenced by accurate information on each element. Mitigation actions can range from simply increasing awareness to taking specific corrective actions or curtailing or suspending activities. All these actions are intended to avoid unnecessary cost, damage to property, or safety risk to people. As discussed in Section 4.2, weather impacts can be mitigated or obviated to varying degrees by timely action, and response decisions are affected by many factors other than weather information.

Precipitation Elements

Precipitation in its several forms, including freezing or frozen (ice and snow) and liquid precipitation (heavy rain, flooding), is the weather element group with the highest count of activity–elements (36, or 28 percent of the total) in the WIST needs template for pipeline system

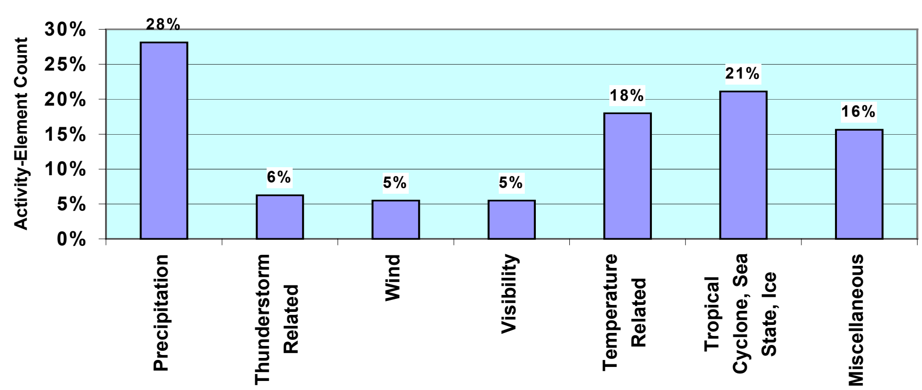


Figure 4-9 Pipeline systems activity-elements by weather group.

operations. Accumulations of ice and snow can freeze valves, rendering them inoperative. Ice and snow removal may damage valves and gauges, and pipeline sensors are more likely to fail. Consequent disruptions of product delivery may require emergency fuel management procedures; re-allocation, transfer delays, re-routing, or unscheduled storage. Disruption of construction or maintenance cycles may result. Leaks or other pipeline failures are possible, which may require implementing procedures for HAZMAT incident response. Safety of personnel and equipment is critical, requiring proper clothing and increased monitoring of crews and equipment because accidents are more likely in icy conditions. Inspections of buried pipeline by digging an inspection trench or bore hole may be complicated by ice, snow, and frozen soil. Delays in scheduled construction and inspections are likely. During ice and snow storms, telephone communications by satellite, radio, or cellular wireless networks may be disrupted, and data collection from pipeline sensors may fail. Any of these physical consequences may also impact public relations of the pipeline operator, the product provider, and any regulatory or oversight agencies involved with them.

In addition to the impacts listed for freezing or frozen precipitation, heavy rain and flooding may scour pipeline roadbeds and unearth buried pipelines. The pipeline can also be damaged by line stretch and impacts of foreign objects and debris. Direct inspection of buried pipeline sections may be complicated by standing water.

Mitigation actions for precipitation above threshold values for the type of precipitation include increased visual inspections and remote monitoring. Control centers will issue advisories and/or warnings to other pipeline activities (see Table 4-5). Fuel management contingency plans (re-route, store, cancel transfers, etc.) may be initiated. Control centers may issue communication advisories, all operations report communication failures and monitor outages, and alternative modes of communication may be implemented, such as backup plans for collecting and distributing pipeline sensor data.

Crews dig around a buried portion of the Trans Alaska Pipeline in search of an underground leak. Although pipelines are often underground, weather–related conditions are the second-most frequent contributor to pipeline damage or failure. Copyright AP Wide World Photos.

The integrity of pipelines, tanks, and valves is checked, the liquid level in tanks is checked, and tank contents may need to be sampled and analyzed for homogeneity and purity. Inspections of floating tank roofs, sumps, and water impounds may be needed, and these structures may need to be drained or pumped out if heavy rain or snow melt is anticipated. Additional crews or crew assignments may be required. The pipeline scheduler can make arrangements with product providers and terminals or customers to accommodate a schedule disruption. For longer lasting or more severe conditions, any work that can wait until the weather clears is postponed and alternate construction and maintenance schedules are developed. Aerial and vehicle pipeline inspections are rescheduled, restricted, or suspended based on weather safety.

For freezing or frozen precipitation, de-icing, anti-icing, or snow removal programs may be initiated for roads, walkways, valves, gauges, etc. Crews are required to wear proper clothing and footwear for icy or slick conditions. If a pipeline is breached or other leakage occurs, HAZMAT spill reaction and mitigation plans must be implemented and proper authorities notified. If flooding is forecast or observed, additional inspections of bridges, trestles, and pipeline roadbed for structural integrity may be included in the pipeline inspection procedure.

Tropical Cyclones, Sea State, and Ice

This weather group accounted for 21 percent of the total activity–element count for the pipelines sector. The impacts on pipeline systems are, like those associated with flooding, primarily risks of physical damage to the infrastructure, with potential secondary consequences such as HAZMAT incidents and personnel safety.

Pipeline roadbed may be scoured by flooding, and buried pipeline may be unearthed and damaged or destroyed. Seafloor pipeline may be damaged or destroyed. These conditions increase the risks of pipeline damage from line stretch, foreign debris impact, and corrosion from damaged coating. Pumping may be restricted or suspended. Pipeline sensor failure is more likely. High winds, seas, and tides restrict or suspend movement of barge traffic between offshore drill sites and coastal pumping facilities. Disruption of fuel delivery may require emergency fuel management procedures, including re-allocation, transfer delays, re-routing, or unscheduled storage. Construction and maintenance cycles may be disrupted. Leaks or other containment failures may require HAZMAT procedures.

Mitigation actions begin with increased pipeline and infrastructure surveillance, including visual inspections and remote monitoring. Additional inspections of bridges, trestles, and pipeline roadbed for structural integrity may be included in the pipeline inspection procedure. The integrity of pipelines, tanks, and valves is checked, the liquid level in tanks is checked, and tank contents may need to be sampled and analyzed for homogeneity and purity. Additional crews or crew assignments may be required. Any work that can wait until the weather clears is postponed, and alternate construction and maintenance schedules are developed.

Control centers need hurricane advisories and warnings prior to and during barge operations, tank construction, maintenance, or repair. They will issue advisories or warnings to other pipeline system activities and product providers. If conditions become unsafe at the control center, controllers evacuate the building and go to a strategic backup site. This site is already set up to allow the controllers to monitor and operate the pipelines. The pipeline scheduler will make arrangements with product providers and terminals or customers to accommodate schedule disruptions. Pipelines may be drained or filled, as appropriate to decrease damage susceptibility.

If high winds and heavy precipitation are involved, aerial and vehicle pipeline inspections are rescheduled, restricted, or suspended, based on safety, as are fueling operations. If a pipeline is breached or other leakage occurs, HAZMAT spill reaction/mitigation plans must be implemented and proper authorities notified.

Temperature-Related Elements

Temperature-related activity–elements constitute 18 percent of the total for the pipeline sector. Soil temperature affects eight of the sector activities. Air temperature (four activity–elements) and heating/cooling degree days are also important for potential impacts on the pipeline infrastructure (five and four activity–elements, respectively). Wind chill and heat index are important primarily for health and safety risks to personnel working outside.

For soil temperature, the principal concern is temperatures below freezing or oscillating around the freezing point. These conditions can produce ground heave, resulting in pipeline motion or movement. Ground heave is most prevalent during the autumn freeze and the spring thaw. Inspections of buried pipelines by digging out an inspection trench or boring may be complicated or delayed by frozen soil. Construction and maintenance delays may also occur.

When the air temperature drops to freezing and below, especially if moisture is present from precipitation, many of the same impacts can occur as are discussed above for freezing precipitation. When the air temperature drops below -20 °F or increases above 100 °F, there are sanctions and prohibitions against the use of plastic pipe.

Mitigation actions for the soil and air temperature elements include most of the non–weather-specific actions listed above for precipitation. Control centers will issue advisories and/or warnings to other sector activities and may schedule additional system inspections and monitoring. Fuel management contingency plans (re-route, store, cancel transfers, etc.) may be initiated. Additional crews or crew assignments may be required. The integrity of pipelines, tanks, and valves may need additional checking, as may the liquid level in tanks. Tank contents may need to be sampled and analyzed for homogeneity and purity. If a pipeline is breached or other leakage occurs, HAZMAT spill reaction/mitigation plans must be implemented and proper authorities notified.

Fuel demand can vary dramatically, depending on the heating or cooling degree days. Thus, this weather element can have major impact on regional and national fuels distribution by pipelines. Accurate forecasts help pipeline operators prepare for changes in demand and help product preparers in readying appropriate quantities of fuels formulated for different regions.

Wind and Visibility

Taken together, wind and visibility elements make up about 10 percent of the total count of activity–elements for the pipeline sector. Visibility of less than one-fourth of a mile restricts or suspends movement of barges and tankers to and from offshore drilling sites and coastal pumping facilities. Reduced visibility also restricts or suspends the safe surveillance of the pipeline by air or truck, disrupts construction and maintenance operations, may cause pumping to be restricted or suspended, and affects the safety of personnel and equipment.

Wind speeds above 60 mph, particularly in coastal areas, restrict barge and tanker operations, may disrupt fuel deliveries, may cause pumping to be suspended, and may disrupt construction and maintenance schedules. In addition, high winds may cause physical damage to the pipeline system, especially if the wind is associated with heavy seas or inland flooding and severe storms.

Damage can result from debris impact or from scouring or erosion of the pipeline roadbed by water and wave action, particularly for underwater pipelines.

The pipeline system operators generally want 12 hours lead-time for these weather events. Mitigation actions, which are similar to those for flooding or high seas, include increased inspections for integrity of pipelines, tanks, and valves, as well as for bridges, trestles, and pipeline roadbed. Maintenance and construction may be rescheduled, and fueling operations may be suspended. If deliveries are disrupted, fuel management contingency plans may have to be implemented.

Thunderstorm-Related Elements

This weather element group includes only 6 percent of the activity–elements. The count may be misleading because three separate weather elements—tornadoes, hail, and lightning—were reported together with thunderstorms as a single weather element. Nevertheless, all of the pipeline system activities are impacted by one or more of these severe weather elements, with tornadoes and lightning being the most significant. Both can result in injury to personnel and damage to equipment. In addition, lightning can damage or destroy pipeline sensors and disrupt data flow and communications from both sensors and control facilities. Pipeline operators desire forecasts and warnings of these conditions 6 hours in advance.

Mitigation actions primarily involve delaying or terminating outdoor activities such as fueling and construction. In the vicinity of severe storms, there may be additional inspections of the pipeline system required, after the storm has passed. Contingency plans may need to be implemented for loss of sensor data, physical damage, or disruption of the flow, as well as response to any HAZMAT incident that may occur.

Miscellaneous Elements

For pipeline systems, the two largest counts of activity–elements from the miscellaneous group are for earthquakes and space weather, with 8 sector activities potentially impacted by each. The importance of these elements reflects the susceptibility of buried pipelines to ground movement and the dependence of pipeline system operations on communications linkages that may be susceptible to the electromagnetic disturbances resulting from solar storms.

The impacts of seismic activity are much the same as those related to flooding or tropical cyclones (hurricanes). Primary impacts include roadbed scouring; buried pipe being unearthed, damaged or destroyed; disruption of fuel delivery; pipeline sensor failure; leaks or other pipeline failures; and, of course, the safety of personnel and equipment. The mitigation actions are similar to those cited above for flooding or tropical cyclone conditions.

Forest fires are a potential threat to above-ground pipelines. Copyright AP Wide World Photos.

Space weather affects all pipeline activities because of the impact it can have on communications (especially satellite, radio and cell phones) and data distribution from pipeline sensors. Remote sensors may detect a leak or pipeline failure, but the communications link to relay the information to the pumping station, tank farm, or control center may be temporarily lost or physically damaged. The control centers monitor communications outages, make use of alternative modes of communication, and execute backup plans for sensor data distribution.

Two other elements, air quality and atmospheric transport and diffusion of hazardous substances, are issues of concern to control centers and personnel at any operation (the "personnel safety" sector activity). In the event of a leak or pipeline failure, vapors and toxins are released to the environment with possible catastrophic results. The control centers ensure the proper authorities are notified and advisories and warnings are issued, work schedules are revised, the HAZMAT spill reaction and mitigation plan is implemented as necessary, and relevant inspections are conducted to ensure the integrity of the pipeline system.

4.7 Rural and Urban Transit Sector

Weather impacts on transit operations are often significant. When a weather event is extreme, it can be the most important factor in satisfying or not satisfying the transit mission. Transit systems often experience increased ridership when snowstorms or other severe weather induce mode shift. Thus, even as weather conditions are complicating operations, transit systems must be prepared to meet these surges in demand through increased staffing and deployment of standby equipment (buses, railcars, vans.).

One of the principal goals of transit officials is to provide early and understandable weather information products and services to transit customers, as well as to surface transportation professionals. A key aspect of the WIST problem identified by the transit officials in this study is the current limitations on acquiring reasonable, physically consistent weather data at small scales. This user issue underscores the importance of mesoscale and misoscale variations that

Transit passengers wait for their bus to arrive. The safety of passengers waiting at stops is a major concern of transit system managers. Copyright AP Wide World Photos.

greatly impact the transit sector. Transit authorities need WIST suppliers to provide tailored, detailed, and ***accurate*** forecasts with lead times of 12 to 24 hours.

4.7.1 Sector Activities

Table 4-6 defines the operations and transportation activities used in the WIST needs template for rural and urban transit operations (Appendix B-5). The weather sensitivities of transit systems generally parallel those for buses and roadway maintenance operations in the roadway sector and for station and depot operations, railway/control center operations, and personnel safety in the long-haul railway sector. However, in this sector the railway activity is primarily aimed at passenger transport, with commuter schedules (e.g., dealing with morning and evening peak loads) being a major concern. Another sector activity with some unique sensitivities is school transportation.

Table 4-6 Sector Activities for Rural and Urban Transit Operations

Roadway maintenance. This activity includes roadway surface treatment for snow and ice control in the winter, as well as maintenance to repair damage to roads and infrastructure.

Bus operations. In addition to bus driving, this activity includes road supervision and maintenance of the bus fleet, terminals and other facilities, and bus stops.

Trolley bus. This activity refers primarily to electric trolleys with overhead wires.

School transportation. This activity includes transportation of students by bus and commuting to school by young, inexperienced drivers.

Rail operations. This activity includes passenger rail operations above and below ground, and station and platform areas. Trains are predominantly electric, using a power rail ("third rail") or overhead wires.

Traffic management. Activity consists primarily of managing traffic signals and traffic routing to enhance safety and efficiency.

4.7.2 Analysis of Activity–Elements

The transit sector was represented by the largest population of study participants (60). With 141 activity–elements identified by its study participants, the transit sector has the third highest activity–element count of the study. (The roadways sector has the same number of distinct weather elements, 52, and the MTS sector has only 35, but both have a greater number of sector activities affected, resulting in more activity–element combinations.)

Figure 4-10 shows the percentages of Transit activity–elements from the WIST needs template in each weather element group, as defined in Table 2-1. The precipitation group, with 45 activity–elements, has the largest fraction (32 percent). Temperature-related activity–elements constitute the next highest group, with 30 activity–element combinations (21 percent). For comparison, the roadway and long-haul rail sectors had only 28 percent and 27 percent, respectively, of their activity–elements in the precipitation group, but higher percentages than transit in the temperature-related group (23 percent and 29 percent, respectively).

In the initial WIST survey in 2000, which preceded the needs templates, precipitation was the general weather condition most frequently cited by transit sector participants as one for which they needed information. Nearly 90 percent of the 78 respondents from this sector indicated a need for precipitation information. Winds, flooding, visibility, temperatures, and thunderstorms were identified by half or more of these respondents as weather conditions on which they needed information.

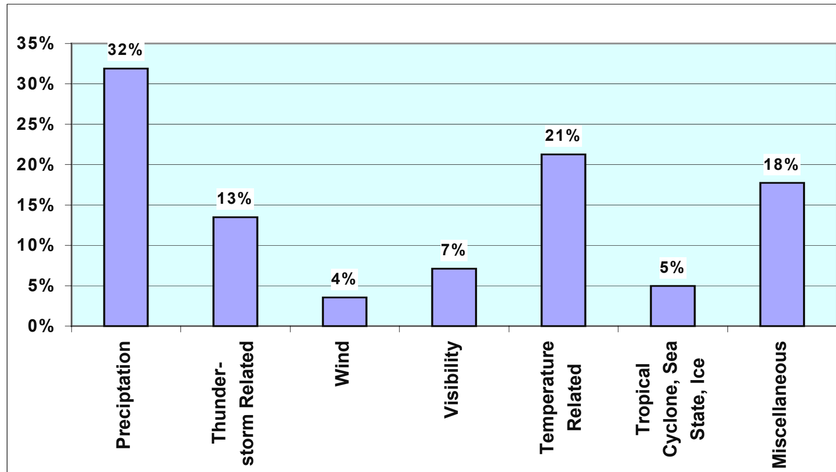


Figure 4-10 Transit activity-elements by weather group.

4.7.3 Impacts and Mitigation Actions, by Weather Element Group

This section discusses the effects that specific weather elements have on transit operations and the response actions that the study participants identified as potentially influenced by accurate information on each element. Mitigation actions can range from simply increasing awareness to taking specific corrective actions or curtailing or suspending activities. All these actions are intended to avoid unnecessary cost, damage to property, or safety risk to people. As discussed in Section 4.2, weather impacts can be mitigated or obviated to varying degrees by timely action, and response decisions are affected by many factors other than weather information.

Decisions not within the control of transit system managers can undo a transportation decision reasonably based on an accurate weather forecast. For example, businesses or agencies sometimes release their employees in mid-day when snow begins to fall, without regard to the regularly scheduled public transportation slow-down between the morning and afternoon rush hours. This action creates a tremendous surge in demand for public transit services just when the system's capability is at a minimum, resulting in delays and overcrowding.

As noted in the discussion of the roadway sector, state police organizations that participated in the WIST survey indicated that knowledge of the local effects and variability of weather conditions gives their troopers an advantage in performing their duties. This knowledge, coupled with accurate and timely weather forecasts, improves the ability of all police agencies to refine staffing and enforce traffic control more effectively. Often, the police are the first on-scene weather observers, and this information can be relayed to transit command centers for redistribution. Some states (for example, the Minnesota Department of Transportation) even have observing systems on board their vehicles. These systems communicate directly to a traffic control center for immediate distribution and input to traffic control decision systems. Monitoring the environment in a proactive manner can increase public safety and help both the police and transit activities achieve their transportation missions despite adverse conditions.

Precipitation Elements

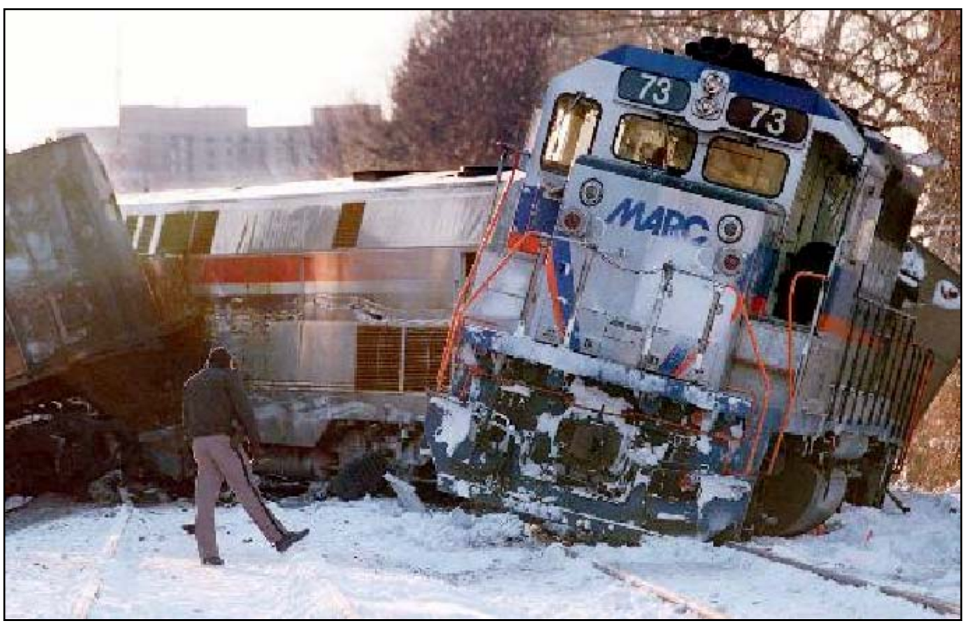
Precipitation, especially freezing or frozen precipitation (ice and snow), causes the greatest impacts for the roadway sector. Most of the activities list safety and health risks to people and property damage risks as potential consequences of any freezing precipitation. Almost all list similar risks for frozen precipitation (snow) as well, with the risks increasing as snow depth increases. Road maintenance activities are most concerned with freezing and frozen precipitation because these conditions typically cause the greatest expenditure of resources in areas where such precipitation occurs. They have the most impact on public safety, other than perhaps a major hurricane. Ice or snow on the roadways mean loss of traction, stability and maneuverability; impaired mobility; roadway obstructions; loss of control; and increased occurrence of vehicle mishaps, with attendant injuries and risks to life and property. For almost all users, it means probable schedule and travel delays.

The first snowstorm of the season slows the morning school bus commute on I-35W near Minneapolis. School superintendents rely on timely and accurate weather information to make the right decisions regarding school closing or delayed opening. Copyright AP Wide World Photos.

In addition to impediments to safe travel resulting directly from ice or snow, bus operations are hampered by traffic congestion and accidents, delays of operations, and routes that require detours. The risk of damage to buses increases, and inclement weather causes delays in maintenance of facilities, the bus fleet, and bus stops. Operators are advised to drive with extreme caution. Operations are modified, restricted, or suspended as necessary, especially on hills. Trolley buses face the additional complication of ice on overhead electric wires, which can cause malfunctions that disrupt operations. At the onset of precipitation, they can be equipped with ice cutters to keep the wires clear of ice.

School systems are concerned not only with large numbers of school buses but also with large numbers of young, inexperienced drivers who may have never driven before in adverse weather conditions. The mitigation options include deciding to close schools prior to opening for the day, delaying opening of schools in the morning, or dismissing early if school is already in session. School officials who participated in the WIST study underscored the critical importance for this decision process of accurate local weather forecasts with sufficient lead times.

Rail operations face similar difficulties. Ice buildup on the third rail or catenary lines (overhead wires) causes power outages for trains. The risk of mishaps increases when ice builds up on the rails, affecting braking action, and on the platforms where personnel safety is the issue. Delays occur as trains operate at slower speeds for safety reasons. Mitigation actions include inspecting and clearing ice buildup from rails and overhead wires, using ice scrapers and snow brakes on the trains, running service vehicles or snow trains to keep the tracks and overhead wires clear, activating heaters in the third rail and switches, removing ice from platforms and parking lots, and, as a last resort, restricting or suspending operations as necessary.



Winter storms increase the risks of track signal malfunctions. Here, a passenger transit train has collided with an inter-city passenger train using the same rail line during a winter storm in Maryland. Copyright AP Wide World Photos.

The lead times these users require for information on winter precipitation events vary by activity, but two time frames stand out. The first is a longer range planning time frame, which varies by activity as follows:

- 12 hours for school administrations (allowing them to make decisions and disseminate the information to the public and employees)
- 12–24 hours for bus operations
- 24 hours for train operations
- 24–48 hours for road maintenance operations (allowing preparations to begin, prediction of the threatened area, selection of treatment strategy, and preparation and deployment of treatment assets).

The second lead time window of major value extends roughly from 0 to 6 hours before precipitation begins. This corresponds to the execution phase of mitigation actions planned earlier. For road maintenance crews, this means final decisions and initial operations to treat and clear roads of snow, ice and debris; deployment of treatment crews and assets; and initiating changes in traffic flow management. This phase makes use of current observations, as well as near-term forecasts and nowcasts.

Liquid precipitation affects most transit sector activities less than frozen or freezing precipitation does, unless it is heavy precipitation. Road maintenance operations are an exception because of concerns with traction, road submersion, drainage, and reduced visibility. The impact threshold for this activity is any liquid precipitation at all.

Conditions that produce flooding of any sort are of concern to all transit activities. Local knowledge of flooding is critical to transit operations, especially where low-lying underpasses are affected. The local transit authorities know where flooding tends to occur; but they also need to know when a weather event will generate sufficient precipitation (intensity and duration) to produce flooding. For most activities, the lead times desired by decision makers for forecast of flood conditions range from 12 to 24 hours. The lead time and format of information must be adequate to convey the information to the traveling public efficiently and effectively.

Mitigation actions for flooding vary by sector activity. Buses may be rerouted, diverted, taken out of service, or used to help evacuate people from flood-prone areas. If not in use, they may need to be moved to high ground. Rail transit operators may need to suspend or reroute service through areas that are likely to flood or are already flooded. After the flooding has receded, they must clear rails and wires and inspect and repair track, roadbed, bridges, and culverts.

Temperature-Related Elements

Most of the temperature-related activity–elements in the transit sector come from the road maintenance community. Of the 30 activity–elements in this group, 11 are for air temperature (including maximum and minimum temperature, temperature relative to freezing with rising or falling trend, temperature change rate, and degree cooling/heating days). Another 8 are for heat index and wind chill temperature. Six are for pavement, subsurface, and rail temperatures.

Road maintenance operations for this sector, as for the roadway sector, depend on temperature information, particularly the combination of pavement temperature and air temperature with rising or falling trend. Accurate temperature information, coupled with precipitation information, allows maintenance managers to select the correct strategy and material to treat road surfaces to minimize the effects of winter weather on vehicle traction and traffic flow.

In most cases, the mitigation actions in response to temperature extremes include advising operators, transit customers, and the driving public, as well as modifying or restricting non-essential operations as necessary. Transit bus operators normally do not curtail operations during extremes of temperature because of concern for passengers waiting at bus stops and the need to minimize their exposure time. During extreme cold temperatures, public transit buses may be used to transport homeless persons to shelters.

High temperatures, as well as low extremes, are a weather concern for transit operators, private vehicle drivers, and transit passengers. High temperatures require that work crews take precautions for their own safety and to prevent damage to equipment. They also pose risks for vehicles. High pavement temperatures increase the risk of tire blow-outs for heavy loads. Rail operations are particularly affected by air temperatures above 85 °F, as rails will then expand enough to kink and older catenary wires will sag. Rail operators must increase the frequency of rail inspections and reduce train speeds under these conditions.

Thunderstorm-Related Elements

Although the impacts of some of the phenomena associated with thunderstorms can be very severe, including loss of life and damage to property, they generally affect smaller areas and for shorter durations than do some other weather elements. When severe thunderstorms do occur, all the transit activities recognize the potential risks to their personnel, passengers, students, vehicles and vehicle drivers, and equipment, as well as indirect consequences from loss of power or communications, impeded mobility, and increased traffic congestion. The protective actions are similar: most activities cease outdoor operations (particularly such things as refueling and maintenance) in the path of the threatening weather and take evasive actions as necessary. Road maintenance activities try to predict where the threatened areas will be, prepare to implement warning and evacuation plans, then respond to roads blocked or damaged by debris. Transit bus operations normally are not suspended because of concern for passengers waiting at exposed bus stops. School transportation officials may implement schedule changes to prevent exposure of students who are in transit between school and home.

Visibility

Visibility and sun glare are the two elements in this group, with five activity–elements apiece. Reduced visibility from air-borne obscurants (e.g., fog, smoke, precipitation, dust) is not a concern until visibility decreases to a quarter-mile or less. At that point, safety is affected and road vehicles simply slow down and exercise more caution. These mitigation actions introduce schedule delays and increase congestion. Visibility thresholds for rail operations vary, depending on factors such as the length of a train, the degree of cab control, and operator difficulty in monitoring signals and switch alignments. Thus, visibility thresholds for transit rail operations vary from a quarter-mile up to 3 miles. For sun glare, the standard mitigation action for transit activities is to reduce speed.

The Staten Island Ferry moves through New York Harbor in the fog. On February 21, 1996, one of the ferries collided with the pier while docking in heavy fog. Copyright AP Wide World Photos.

Winds

High winds are a concern to all transit activities. The critical thresholds for most activities are 30 mph for moderate risk and 50 mph for severe risk and significant impact to safety and transit operations. High winds produce roadway debris, flying debris, downed live electric lines and poles, traffic slowdowns and congestion, operational delays, and drifting snow in winter. Maintenance of vehicles, facilities, and bus stops may be suspended or postponed. Mitigation actions include prepositioning barriers to debris or snow (such as snow fences in the winter); advising transit operators, passengers, and the driving public; and implementing detours where necessary. Operations and traffic patterns may be modified, particularly to allow for removal of debris or drifted snow. Rail operators slow their trains and, when winds reach 70 mph, suspend service over bridges.

Miscellaneous Elements

Several of the weather elements and weather-related phenomena in the miscellaneous group are worth noting for their impact on transit activities. Among these are tropical cyclones and the associated storm surge. A number of weather conditions associated with a tropical cyclone (wind, rain, reduced visibility, and tornadoes) affect all surface transportation activities in the area where a storm occurs. Storm surge may affect the coastal area where a storm makes landfall. The mitigation action includes suspending travel or vacating the area. Road maintenance activities mobilize maintenance forces for disaster response and damage repair. Transit bus systems prepare to assist in evacuations and other emergency preparedness actions. The lead-time required for adequate preparation and implementation of these actions can be up to 72 hours.

Another element in this category is weather information relevant to incidents of release and atmospheric dispersion of nuclear, biological or chemical hazards. These events are life-threatening, and the responses by transit activities are either to cease operations and clear the area or participate as part of a previously trained response team. A related element, albeit less critical in potential health effects, is air quality, which typically has the greatest impact in urban areas. Many of the meteorological conditions that influence the movement of a plume from a hazardous-materials release are also of importance in forecasting air quality conditions and the areas affected.

A third element of special interest in the miscellaneous group is space weather. As transit systems become increasingly dependent on electronic and wireless systems for communication, navigation, and data transfer, the need increases to monitor and manage system components that can be temporarily disrupted or permanently damaged by space weather hazards.

4.8 Airport Ground Operations

The assessment of weather information needs for airport ground operations is a small but critical piece of an overall assessment of how weather elements affect surface transportation and what information can be useful in improving actions to deal with these weather impacts. Airport ground operations constitute the interface between other surface transportation modes and the airborne movement of people and cargo. Weather information support for the multimodal operations that occur at or near this interface is critical because the effectiveness, efficiency, and safety of these airport ground operations bear directly and substantially on the overall throughput of aircraft, passengers, and cargo (the capacity of the air transportation system). This support is also critical to the timeliness of air transport of both goods and travelers. The weather impacts and the general types of mitigation responses available to sector operations are more like those of other surface transportation modes (for example, urban transit operations or port operations of the MTS) than the weather concerns of aircraft in flight. It is therefore reasonable to include consideration of airport ground operations as a distinct transportation sector in a WIST study.

Airport ground operations include wing de-icing prior to takeoff, as well as all ramp operations and passenger ground traffic. Copyright AP Wide World Photos.

4.8.1 Sector Activities

This transportation sector includes airport operations on the ground but not flight operations, since the latter are relevant to aviation weather support rather than weather information for surface transportation. The sector does include factors that affect the ability of people to get to and from the airport, as well as ground traffic on the airfield, between aircraft and airport facilities. The sector activities used in the WIST needs template for airport ground operations (Appendix B-6) are listed and defined in Table 4-7.

4.8.2 Analysis of Activity–Elements

The airport ground operations sector had the second smallest population of participants in the WIST study; responses were received from 27 agencies or entities. These participants identified nine weather elements as affecting the sector activities listed in Table 4-7.

Table 4-7 Sector Activities for Airport Ground Operations

Aircraft movement. Includes all ground movement of aircraft and safety of flight considerations that affect aircraft ground movement.
Vehicle movement. Vehicle movement and traffic flow on the airfield and on approaches to the airfield
Gate accessibility. Includes operations for the transfer of baggage and cargo and general aircraft servicing (cleaning, catering, minor maintenance) while an aircraft is parked at a gate.
Aircraft maintenance. All ground maintenance conducted away from the gate.
Refueling aircraft. Includes transportation of fuels from at-airport storage to aircraft and the operations during transfer from fuel truck to aircraft fuel tanks.
Foot traffic. All pedestrian movement on the airfield.
Construction and maintenance projects. All vehicular movement and operations related to construction or structural maintenance of airport and airfield facilities, while the airport continues to operate.

Development of the WIST needs template for this sector, like the efforts for the other sectors, involved identifying the weather elements of concern to participants, the threshold(s) at which each element becomes significant to sector activities, and the activities most affected by each element. For each activity–element combination, the template includes impacts when an element occurs and the mitigation actions available, if accurate weather information with sufficient lead time is in the hands of activity decision makers. The participants were also asked to specify the lead times desired, if a weather warning or weather advisory for a specific weather element were to be most useful and effective for the impacted activities.

More than 20 civilian airports, 4 major airlines, and 2 military airfields were contacted; each provided a response useful in developing the sector's WIST template. In addition, the Federal Aviation Administration (FAA) identified five key weather-related areas that affect airport ground operations:

- Snow removal
- Aircraft de-icing operations
- Aircraft refueling operations
- Equipment protection

- Ground support personnel effectiveness.

Figure 4-11 shows the distribution among weather element groups of the 38 activity–element combinations in the WIST needs template for airport ground operations. The precipitation group has 15 activity–elements, providing 39 percent of the total. The temperature-related and thunderstorm-related groups account for 8 activity–elements apiece (21 percent). There are four activity–elements for wind and three for visibility. Conspicuously absent are any activity–elements for tropical cyclone (i.e., hurricane) information. None of the airports that participated were located in coastal regions where storm surge might be an issue, and other phenomena associated with tropical cyclones are accounted for by the precipitation, wind, thunderstorm-related, or visibility activity–elements. Nor did any of the participants report a need for information on weather elements in the miscellaneous category. If the survey were repeated now, homeland defense issues that have grown since September 11, 2001, would very likely lead to an interest in air transport and dispersion information in the event of release of a nuclear, chemical, or biological hazard.

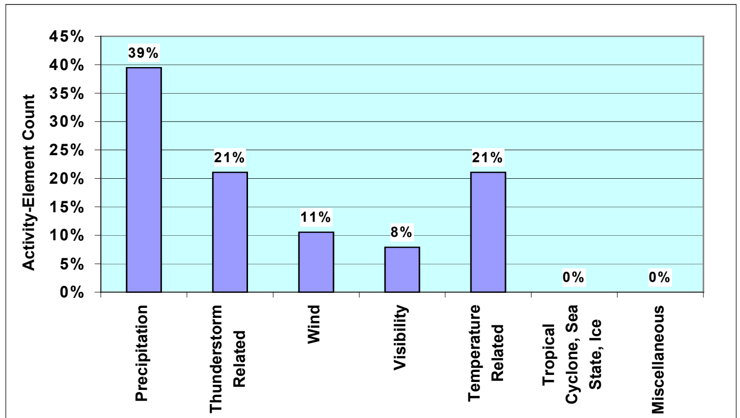


Figure 4-11 Airport ground operations activity-elements by weather group.

4.8.3 Impacts and Mitigation Actions, by Weather Element Group

This section discusses the effects that specific weather elements have on airport ground operations and the response actions that the WIST study participants identified as potentially influenced by accurate information on each element. Mitigation actions can range from simply increasing awareness to taking specific corrective actions or curtailing or suspending activities. All these actions are intended to avoid unnecessary cost, damage to property, or safety risk to people. As discussed in Section 4.2, weather impacts can be mitigated or obviated to varying degrees by timely action, and response decisions are affected by many factors other than weather information.

Precipitation Elements

With any amount of freezing or frozen precipitation (ice or snow), the sector activities experience impacts to safety of personnel, impaired operations, and risk to aircraft and equipment. Heavy liquid precipitation (rain) impairs operations primarily because it reduces visibility and creates flooding risks to personnel and equipment.

> Aircraft icing is a critical condition that affects safety of flight. Thus, the effective and assured de-icing of aircraft on the ground before take-off is essential.

Safety of flight is paramount, and it begins on the ground. Aircraft icing is a critical condition that affects safety of flight. Ice on aircraft caused by freezing or frozen precipitation of any kind, along with frost and rime icing picked up on descent, all affect the aerodynamic performance of aircraft. Lift is dramatically affected, most often during the critical take-off and landing phases of flight. Thus, the effective and assured de-icing of aircraft on the ground before take-off is essential. When conditions conducive to icing are forecast to occur, airport and airline operations managers are advised of the threat. They plan for the availability and readiness of equipment, supplies, and manpower. Airport tenants are alerted, and de-icing pads are prepared for use. The airport continues to issue advisories to tenants on type of precipitation expected, expected accumulation and duration, temperature, and wind. Airlines may implement personnel recall to cover the additional function of de-icing airplanes.

The acceptable "hold-over-time"—the time between the beginning of de-icing and take-off—varies with weather conditions and the type of de-icing fluid used. Based on the forecast and observation of the type and rate of precipitation, wind speed, and temperature, a fluid is selected that will be most effective. When feasible, operators begin applying de-icing fluid before precipitation begins, using an agent that prevents precipitation from bonding (freezing) to the wing surface. Then, on take-off roll, the accumulated precipitation will slide off the wing. Other agents can be applied to remove frozen precipitation from aircraft surfaces. Frost and "cold wing" icing are routinely dealt with, even when freezing precipitation is not present. Efficient and well-planned de-icing operations can minimize schedule impacts.

Aircraft icing is by no means the only threat from freezing or frozen precipitation. Accumulation of ice and snow affects all aspects of airport operations. It increases risks to personnel safety and equipment and causes operational delays and cancellations. It may close runways, limit airport parking, and generally inhibit all activities that require surface movement about the airfield and airport grounds. To mitigate these effects, airport operators rely on early planning to ensure availability and readiness of equipment and supplies (stockpile of salt/sand for roadways and parking areas and of other materials for runways and taxiways). They plan manpower availability and implement personnel recall plans (some airlines use a 24–30 hour forecast for a preliminary staffing estimate); advise carriers, the fixed base operator, and all tenants; and prepare de-icing pads for use. As an anticipated event occurs, they decide on choice of surface treatments (anti-ice, sand, etc.); execute snow and ice control plan(s); begin treating runways, taxiways, roads, parking areas, and walkways; and monitor pavement subsurface and surface temperatures for continued snow removal strategy. Airlines may begin de-icing aircraft at the gate with activation of the snow plan; they may also implement schedule changes and plan for reconstitution of normal operations.

In general, if freezing precipitation is observed to be moderate or greater, and ice is accumulating on surfaces and structures, airport flight operations will likely cease. Heavy snow coupled with high winds will cause blizzard conditions and “white outs,” in which case snow removal ceases until visibility improves.

Intense liquid precipitation (rain) also impairs airport ground operations. It impedes construction projects, reduces visibility, slows down all vehicular movement on the airfield (both on the ramp and on access roads and parking areas), impedes foot traffic, and presents a safety risk for employees and passengers. These direct effects, as well as some of the mitigating responses, can cause schedule delays. Mitigating actions for heavy rain include issuing advisories to all airlines and all other airfield tenants, planning for vehicular traffic flow to bypass known trouble areas, coordinating with other agencies in the vicinity for opening drainage control points, preparing equipment for sweeping or pushing standing water, and ensuring that adequate equipment and trained personnel are available.

Thunderstorm-Related Elements

Thunderstorms and their related phenomena can be very severe, causing loss of life and property, but they generally affect smaller areas for shorter periods of time than do some other weather elements. When severe thunderstorms do occur in the immediate vicinity of an airport or are forecast to move over it, all sector activities respond to the potential risks to people, aircraft, and other equipment. The range of protective actions is similar, with most activities ceasing outdoor operations in the vicinity of the threatening weather and personnel required to take shelter as necessary.

Lightning is the most common thunderstorm-related threat. Most activities begin halting noncritical activities when lightning is observed at or near the outer boundaries of their lightning detection grid. When lightning is observed within 3 nautical miles of the airfield, all refueling operations are halted and personnel are moved inside or under cover. (Some operators reported that they take their people off the line when lightning is observed at or within 10 nautical miles of the airfield.)

A passenger maneuvers her luggage cart through rain at the Atlanta airport. A forecast of snow and ice for this day led Delta Airlines to cancel many of its Atlanta flights, causing delays throughout the nation. Copyright AP Wide World Photos.

Hail can damage cargo, equipment, and vehicles, as well as injuring personnel. Hail greater than 1 inch in diameter can severely damage aircraft sitting exposed on the ramp. Hail also affects aircraft servicing (refueling and maintenance) and causes operational delays and cancellations. It impedes construction and airfield maintenance projects. Protective actions include curtailing outside activities where possible and moving personnel inside or under cover.

In almost all cases, the desired lead times for forecasts of thunderstorm-related weather begin with a “heads up” advisory 12 to 24 hours in advance, followed by a warning 4 to 6 six hours before onset. This is followed by a “take cover” type of warning an hour or less from the actual occurrence of the severe weather, with real-time updates when a storm is actually occurring and affecting operations.

Temperature-Related Elements

Temperature-related activity–elements, specifically air temperatures less than zero °F and wind chill temperatures below -20 °F, account for 21 percent of the total for this sector. These cold temperatures primarily affect personnel working outside, including aircraft maintenance, refueling and servicing, baggage and cargo handling, and construction projects. The primary risks are hypothermia and frost bite for personnel and, to a lesser extent, risks from water freezing on aircraft as they are being serviced. In addition, cold temperatures can result in delays because ground crew personnel are limited in the amount of time they can work outdoors under these harsh conditions.

To mitigate the effects of cold weather, personnel are equipped with proper cold weather protective clothing, exposure time outdoors is limited to periods of 12–15 minutes, ground crews are provided with warm fluids to help them warm up and avoid dehydration, and extra personnel are scheduled as necessary. Outdoor construction and maintenance projects are rescheduled or adjusted as necessary.

Winds

Sustained high winds primarily affect aircraft movement, aircraft servicing and maintenance, and construction projects. Short-lived wind events, such as microbursts and gust fronts can also affect airport ground operations, primarily through their effects on takeoffs, approaches, and landings. Large changes in wind speed or direction affect the choice of runways, and the need to change runways in use at busy times contributes to schedule delays. Likewise, maintenance on large aircraft, especially work on areas high above the ground, is impeded or prevented altogether. Servicing of aircraft is slowed, and more wind-blown foreign objects are present in aircraft movement areas. All of these impacts contribute to delays in aircraft departures. Snow removal and de-icing operations are also affected, as snow blower and aircraft de-icing operations must respond to wind direction and speed. Construction materials are more prone to blow away in high winds, and blowing dust from construction sites can become a hazard.

Mitigating actions include advising air traffic control and all airfield tenants and planning for more frequent ramp, taxiway, and runway inspections (to reduce or eliminate damage from wind-blown foreign objects). Operators will ensure that motorized carts not in use are braked and chocked for the duration of high winds. Equipment or objects not in immediate use or being handled (e.g., igloo containers, baggage) are stored in protected areas. If de-icing of aircraft or snow removal operations are required, operators will decide where and how these activities will be conducted to control blowing spray and snow. Construction contractors and maintenance personnel are advised of impending high winds, and they may adjust their work and project schedules.

Visibility

Visibility of less than a quarter-mile affects aircraft ground movement, flight operations, vehicle movement (including aircraft servicing and maintenance vehicles), and construction projects. It increases the probability of runway incursion incidents. Because all aircraft and vehicular movement is slowed, reduced visibility can delay schedules significantly. Construction and repair projects may also be delayed.

Mitigating actions include coordinating with air traffic control and ensuring that "follow me" guidance vehicles are available for aircraft on request. At some airports, when the runway visual range drops to 600 feet, no take-offs or landings are allowed. If necessary, airport operations will also coordinate with construction contractors on project schedules.

An American Airlines jet at LaGuardia airport in New York is delayed in thick fog. Visibility of less than one-quarter mile restricts airport ground operations. Copyright AP Wide World Photos.

4.9 Overarching Themes from the WIST Needs Identification and Validation Activity

This section highlights four themes that emerged from the WIST needs analysis in this chapter and from participants' comments during the two WIST symposia, other meetings, and interviews conducted during the study.

Theme 1. The WIST study provides a validated baseline of user needs for moving forward with a coordinated WIST initiative.

Representatives from user communities throughout six surface transportation sectors participated in the WIST study. These participants, representing federal, state, and local governmental agencies and commercial interests in each sector, provided the initial responses compiled in the WIST needs templates and validated the templates. The templates thus provide a validated baseline of user-defined weather information needs for these six surface transportation sectors.

Users' needs for weather information, identified and coordinated through the WIST study process described in Chapter 3, are compiled in Appendix B of this report. The templates have been reviewed and validated by the federal, state, and local government agencies with oversight and operational missions in these transportation sectors, as well as by representatives of commercial firms operating in the sectors. This coordination process revealed an unequivocal need among the various user communities for weather information that is more accurate, timely, and relevant.

Theme 2. The benefits from improving WIST data sources, infrastructure, and applications will be substantial.

The nation can benefit significantly from improved weather information for surface transportation. The safety benefits will include reductions in injuries and loss of life. The economic benefits will include reduced economic losses and increased productivity. The challenge is to gather the necessary data, turn it into relevant and accurate weather information, and put it into the hands of people who must make decisions about various activities.

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Reduction in Injuries and Loss of Life

As noted in Chapter 1, precise numbers for injuries and deaths attributable directly or indirectly to weather conditions and their impacts on surface transportation systems are difficult to establish, even for the nation's highway system. The WIST Needs Templates support abundant anecdotal evidence that snow, rain, ice, fog, freezing or rapidly changing temperatures, and numerous other weather elements, as defined in Table 2-1, increase the safety risks to personnel and travelers in all of the surface transportation sectors. Table 4-8 shows that users identified risks to safety as an impact of more than three-fourths of the activity–element combinations in every sector.

Table 4-8 Activity–Elements with Safety Impacts, by Sector

	Activity-Elements with Safety Impact	
Transportation Sector	**Activity–Element Count**	**Percent of All Sector Activity–Elements**
Roadway	223	87%
Long-Haul Rail	98	76%
MTS operations	156	83%
Pipelines	98	77%
Transit	110	78%
Airport ground operations.	33	87%

Reliable information on surface transportation elements—what conditions are now or are forecast to be—allows transportation system managers and operators, as well as travelers, to make choices that reduce these safety risks. A study, cited in Chapter 1, of one stretch of Idaho highway reported an 83 percent decrease in accidents after forecast-activated pavement anti-icing was implemented (Breene 2001). Surveys of travelers' attitudes, such as those conducted for the ATWIS in the Midwest (Owens 2000) or the Gallup survey of information desired for "511" travel advisory service (ITSA 2002b), show that travelers value reliable surface transportation weather information. Finally, the "Actions" listed in the WIST Needs Templates for weather elements with a safety impact show that transportation decision makers in every sector have a range of options available to them to lessen safety risks—***provided they get accurate information with the lead time needed to inform their decision processes***.

Reduced Economic Losses

> The "Actions" entries in the WIST Templates detail mitigating actions that can be taken in every transportation sector to lessen the economic impacts of weather events or weather-related conditions.

NHTSA has estimated that the economic costs just from weather-related crashes on U.S. highways amounts to nearly $42 billion annually (Lombardo 2000). Fog, snow, and icy conditions on highway capacity caused an estimated 544 million vehicle-hours of delay on the nation's freeways and principal highway arteries in a single year (Chin et al. 2002). Snow and ice treatment costs state and local highway maintenance departments about $2.1 billion annually (FHWA 1998). Chapter 1 cited examples of how the intermodal system for freight and cargo that links surface transportation sectors can be impacted by weather conditions, with ripple effects across the economy, as well as across transportation sectors. The "Actions" entries in the WIST Needs Templates detail mitigating actions that can be taken in every sector activity to lessen the economic impacts of a weather event or weather-related condition.

However, the importance of accurate, timely information, at the needed spatial and temporal scales, becomes critical in ensuring that the ***net value*** of preparing for and responding to an adverse weather event or condition is an economic benefit rather than a loss. Most of the actions listed in the templates have an economic cost associated with them. If the weather information received is timely and accurate, the cost of acting is often less than the cost of failing to act. If a predicted event does not occur, however, the cost of the unnecessary preemptive action remains. Users' perceptions of the reliability of the transportation weather information they receive determine how much they rely on that information in making difficult economic choices.

Forecasts that correctly predict that an adverse event or condition will not occur are also of economic value. As an example, for a local government a single correct weather forecast that prevents the unnecessary deployment of snow and ice crews can mean the difference between operating within budget and becoming seriously overextended, requiring the cancellation or deferment of other critical highway maintenance projects.

Increase in Productivity

Weather affects the efficiency and effectiveness of each of the major modes of surface transportation. A good example is the freight community, with its concept of multimodal just-in-time delivery. In moving goods across the country, freight companies must plan for, or cope with, weather of all types and severity. The efficiency of the system depends on a high level of coordination among producers and shippers. All the transportation modes used in the supply chain rely on weather information to sustain this tight coordination. To the extent that disruptive weather conditions can be anticipated and communicated, mitigating actions can be taken to maintain the overall coordination of a just-in-time delivery system. Throughout the economy, as well as within transportation systems, efficiency and effectiveness can be improved.

Across all the sectors studied, two lead-time periods for weather information to be useful to surface transportation activities stand out. There is a planning window at 12–24 hours and a response-implementation window at 0–3 hours (extending to 6 hours in some sectors).

Theme 3. Substantial near-term benefits can be reaped just by increasing the utility of currently available data and products to WIST users.

Many of the weather information needs specified in the WIST templates (and discussed at the general level of activity–elements in this chapter) can be met to some degree today, simply by distributing existing weather data and products more quickly and widely through open systems. The utility to WIST users of available weather-related data and information products can be increased in the near term simply by:

- Making more information more accessible to more users through open information systems
- Tailoring the format and content of information products to be readily understood by potential users and easily incorporated into their decision procedures or decision support systems.

> "The mechanism for providing the (weather) information is not nearly as important as the accuracy of the information…. For K-12 education systems such as Fairfax County Public Schools, the specific timing of weather events is critical to effective decision making."
>
> Dean Tistadt, Assistant Superintendent, Fairfax County Public Schools, Virginia

The ability of a WIST user to incorporate weather information into decisions often depends on how quickly and easily the information can be assimilated into that user's planning window or operational decision time frame. There are roles for both the public and private sectors in meeting these needs. The disparities among various users with respect to their knowledge of the sources and availability of weather information present opportunities for commercial providers. They can meet many of the validated WIST needs by tailoring generic data and products from the public sector, then delivering the results with existing and emerging information technologies. Some of the many issues involved in expanding this public–private partnership in meeting WIST needs will be addressed in Chapter 5, as part of suggested next steps for a coordinated WIST initiative.

Theme 4. Over the next decade, additional and substantial benefits to the nation, in terms of safety, reduced economic losses, and increased productivity, are possible with (1) better spatial and temporal resolution in both forecasts and observations and (2) better forecast accuracy.

Almost all participants in the WIST needs validation stressed the critical importance of ***accurate*** weather information. Across sector activities, weather elements, and thresholds, increased accuracy is essential for meeting user needs. Most WIST users desire weather information that is more precisely specified in terms of spatial and temporal resolution than what is now available.

They want weather information that matches the geographic and temporal scales of the sector activity they conduct and the mitigation actions they have available for responding to threatening weather. These needs include weather information that is valid both at the current time and at some specified time in the future.

As accuracy and consistency increase, user confidence in weather information products increases, which leads to increased reliance upon it in the users' decision-making processes. Thus, improved accuracy is a requirement for improving the safety, efficiency, and effectiveness in surface transportation systems by making more use of weather information.

Uncertainty and risk in weather predictions need to be addressed by both the research and operations communities. Probabilistic forecast products may help to convey the full range of uncertainty present in a prediction. However, either the user needs to be skilled in interpreting probabilistic information or a decision support tool is needed that interprets the probability information in terms the user can comprehend and use.

4.10 Summary: Meeting the Needs and Addressing the Concerns of WIST User Communities

The WIST needs collection and validation effort provides ample evidence that the nation can benefit greatly by improving the weather information provided to the activities responsible for surface transportation systems and services. The benefits will accrue not only to the traveling public but also to the various levels of government and to the commercial enterprises that rely on transportation to accomplish their missions or to satisfy their customers' demands.

Many of these benefits could be achieved now, by improving the delivery of currently available weather data and forecast products through open systems and integrating them into formats and information products tailored to the needs of decision support processes throughout the spectrum of surface transportation activities. These near-term results will substantially improve the value of WIST to surface transportation in all sectors. Beyond this near-term "low-hanging fruit," additional benefits will require observations and forecasts at higher spatial and temporal resolution than the current state of practice. It will also require improved forecast accuracy across the range of spatial and temporal scales needed by WIST users.

Some progress has been made in improving weather information for surface transportation decision makers. Still, this WIST study process gathered many concerns from participants who are either WIST users themselves or are well acquainted with users' needs. The deficiencies and gaps identified through this process require attention if WIST users' needs are to be met. Chapter 5 suggests next steps toward addressing these concerns.