

Developing a Toolkit for Airport Extreme Weather Preparedness

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1 ABSTRACT

2 Climate change poses increasing threats to airport operations and management. While airports
3 have always been susceptible to weather events and therefore generally well-prepared for
4 common significant weather types, changes in the frequency, duration, and intensity of
5 significant weather events under climate change present new and unprecedented challenges.
6 Airports recognize the need to prepare for climate change impacts but lack the information and
7 resources necessary to sufficiently understand and respond to their specific risks. Best practices
8 and management strategies for most types of significant weather events already exist at the
9 airports who experience those events on a frequent basis, yet an accessible database of these best
10 practices for airports to use as templates in their own significant weather planning does not exist.
11 Through Airport Cooperative Research Program (ACRP) project 02-49, “Addressing Significant
12 Weather Impacts on Airports,” a literature review, airport survey, and series of case studies were
13 completed to inform the development of a preparedness toolkit to address these shortcomings in
14 information accessibility. The resulting Airport Weather Advanced REadiness (AWARE) toolkit
15 is designed to help airports better understand and respond to specific significant weather risks
16 and establishes a comprehensive list of significant weather best practices utilized by other
17 airports. This paper presents how the AWARE toolkit was developed and how the toolkit
18 increases airport access to significant weather projections, access to information on the risks and
19 costs of significant weather, and preparedness for rare but plausible significant weather events.
20

1 INTRODUCTION

2 The United States is expected to experience higher average temperatures, more frequent extreme
3 temperatures, changes in precipitation patterns, sea level rise, and changes in extreme weather
4 events such as flooding, droughts, and hurricanes as a result of climate change (1). Many of these
5 changes are already occurring and are projected to worsen over time especially if the United
6 States continues on a business-as-usual track without adopting climate adaptation and mitigation
7 practices to lessen the impacts of climate change (1).

8 Transportation systems are affected by weather on a daily basis. Flooding, snow, and
9 warmer temperatures for example, all affect the reliability and longevity of transportation
10 infrastructure and operations (2). According to the National Climate Assessment, climate
11 projections indicate that significant weather-related disruptions to transportation systems will
12 increase as will the costs of responding to these weather disruptions (2).

13 Disruptions to airport operations and infrastructure are particularly harmful to
14 commercial air carriers, general aviation, military, and other users of airport facilities as well as
15 to the global economy that aviation services support (3). Airport systems recognize their
16 susceptibility to significant weather events and as a result, many airports have already developed
17 management plans for responding to locally common significant weather events (4). Few airports
18 have taken the initiative to address projected future climate changes such as hotter days, heavier
19 rainfall, increased snow and ice, and more intense storms (5). Changes in the frequency,
20 duration, and intensity of significant weather events will pose new and unprecedented challenges
21 to airport management.

22 Airports recognize the immediate need to incorporate these projected changes into their
23 management plans given that 70% of airport delays are a result of significant weather and that
24 such events can be incredibly costly (5). However, airports lack the information and resources
25 necessary to know exactly what types of weather extremes are plausible in a particular location
26 and how to best prepare for and respond to such events (4). As a result of these shortcomings,
27 identified in the Airport Cooperative Research Program (ACRP) Report, “Addressing Significant
28 Weather Impacts on Airports,” the Airport Weather Advanced REadiness (AWARE) toolkit was
29 designed to help airports better understand and respond to specific significant weather risks and
30 costs.

31 While the AWARE toolkit project was not focused explicitly on climate change, the
32 frequency, severity, and distribution of significant weather events are undoubtedly influenced by
33 changing long-term trends in climate (6). Under climate change, historically rare events may
34 occur more frequently, and if airports are not prepared for such events, operations may be greatly
35 weakened (6). Climate change risks vary widely across the globe, adding to the uncertainty of
36 future weather event projections (6). For example, while one airport may face more heavy
37 precipitation and flooding, another may face increasingly hot and dry conditions that damage the
38 aircraft tires and the tarmac (5). To help airports cope with diverse and unfamiliar significant
39 weather events, ACRP Report 160 and the AWARE toolkit also established a list of significant
40 weather best practices used by other airports to provide examples of increasing preparedness for
41 a wide variety of events.

42 This paper presents how the AWARE toolkit was developed and how the toolkit
43 increases airport access to significant weather projections, access to information on the risks and
44 costs of significant weather, and preparedness for rare but plausible significant weather events.

45 BACKGROUND

1 Through ACRP research project 02-49, “Addressing Significant Weather Impacts on Airports,”
2 background research was conducted to identify airport needs and best practices related to
3 significant weather preparedness (7). The background research consisted of three major
4 components: a literature review, airport survey, and case studies.

6 Literature Review

7 The literature review focused on available resources to help airports define and reduce the
8 impacts of significant weather events, which are defined as those that disrupt airport operations
9 (7). The definition of what weather thresholds are “significant” varies by airport and geographic
10 location. The literature review was conducted in the summer of 2014 to inform the development
11 of the AWARE toolkit. Sources reviewed included ACRP reports, guidance and standards from
12 federal agencies such as the Federal Emergency Management Agency (FEMA) and National
13 Incident Management System (NIMS) standards, airport emergency plans, and other reports and
14 studies on significant weather and airports.

16 Survey

17 A survey of North American airports was also conducted to help understand historical weather
18 impacts on airports and significant weather event preparedness (7). The survey was distributed to
19 148 United States airports and 19 Canadian airports via a Survey Monkey email link. The 167
20 airports chosen represented a range of sizes and geographies and had shown previous
21 participation in airport sustainability-related regional and national conferences. A total of 67
22 airports across the U.S. and Canada (depicted in FIGURE 1) responded to the survey, for a 40%
23 response rate.

24 The survey consisted of 18 questions assessing the types of weather events experienced
25 by airports, the extent of damages, and how the airports prepared for, responded to, and
26 recovered from those events. The survey collected general information such as FAA airport
27 codes, airport size, and number of annual enplanements and allowed users to rate the impact
28 level of a weather stressor on a particular piece of infrastructure or operation.



30 **FIGURE 1 Distribution of 67 airport survey respondents (7).**

33 Case Studies

34 Lastly, 15 airport case studies (listed in TABLE 1) were conducted between October 17 and
35 December 17, 2014, to examine past significant weather event impacts and management

1 responses at each airport (7). Airports were selected to represent a range of sizes, weather
 2 conditions, and geographic locations, as well as their willingness to participate. Each case study
 3 consisted of hour-long phone interviews with one-to-four employees, usually in an operations
 4 management or coordination role, at each participating airport. Interview questions focused on
 5 impacts from the two or three most significant weather events experienced by the airport in the
 6 last 10-15 years. Questions about management's preparedness for, response to, and recovery
 7 from significant weather events as well as their decision-making process were also included in
 8 the interviews.

9
 10 **TABLE 1 Case Study Airports (7)**

Airport	Code	Location	Size	Type
Bozeman Yellowstone International Airport	BZN	Belgrade, MT	Small	Commercial
Chicago-O'Hare International Airport	ORD	Chicago, IL	Large	Commercial
Columbia Metropolitan Airport	CAE	Columbia, SC	Small	Commercial
Dallas/Fort Worth International Airport	DFW	Fort Worth, TX	Large	Commercial
Denver International Airport	DIA	Denver, CO	Large	Commercial
George Bush Intercontinental Airport	IAH	Houston, TX	Large	Commercial
Kahului Airport	OGG	Maui, HI	Medium	Commercial
Key West International Airport	EYW	Key West, FL	Small	Commercial, GA
Lambert-St. Louis International Airport	STL	St. Louis, MO	Medium	Commercial
Manchester-Boston Regional Airport	MHT	Manchester, NH	Medium	Commercial
Newark Liberty International Airport	EWR	Newark, NJ	Large	Commercial
Phoenix Sky Harbor International Airport	PHX	Phoenix, AZ	Large	Commercial
Seattle-Tacoma International Airport	SEA	SeaTac, WA	Large	Commercial
Ted Stevens Anchorage International Airport	ANC	Anchorage, AK	Medium	Commercial
Toronto Pearson International Airport	YYZ	Toronto, Canada	Large	Commercial

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 12
 13 **FINDINGS: AIRPORT PREPAREDNESS NEEDS**

14 The literature review revealed that airports understand historical weather impacts well and have
 15 well-developed preparedness plans in place to respond to these common significant weather
 16 events. There was little information, however, on how significant weather affects specific assets
 17 in the airport system or how to specifically prepare those assets for a given weather event.
 18 Additionally, airports did not have extensive knowledge or preparedness plans for future
 19 significant weather impacts (7).

20 The survey additionally revealed that rare significant weather events are the most
 21 disruptive to airport systems. Because these events occur infrequently, airports have historically
 22 devoted fewer resources to preparing for and responding to these types of events.

23 The case studies echoed the surveys by similarly identifying rare weather events as the
 24 most difficult type of event to prepare for, but also indicated that previous impacts can help
 25 justify new investments to better prepare for the next event occurrence. The case studies also
 26 revealed that prioritizing core operations during a significant weather event are important for
 27 maintaining the airport's main functions, customer services, and passenger satisfaction.

28 This background research led to the following key findings regarding airport
 29 preparedness:

30 1) Airports have a strong understanding of historical weather conditions and frequent
 31 significant weather events, but lack understanding about unexpected significant weather events

1 from climate change. This disconnect is further complicated by the fact that significance
2 thresholds vary by location.

3 2) Many airports have best practices in place for various significant weather events
4 that would serve as useful models to other airports, but this information is not easily accessible.

5 3) Most airports lack general management practices to collect data to quantify and/or
6 monetize the vulnerability of airports to unexpected significant weather events.

7 While airports recognize the need for significant weather preparedness and are well-
8 prepared for common events, there is a clear knowledge gap in understanding and preparedness
9 for unexpected events. The first challenge to address therefore is helping airports identify those
10 events that, while rare, may be plausible in their location. The second challenge is accessibility to
11 the best practices of other airports who experience similar significant weather types. If this
12 information were readily available to airport managers, other airports could serve as models of
13 how to manage certain significant weather types especially for airports seeking guidance on an
14 event type rarely experienced in their location. The third challenge is then to establish general
15 management practices for significant weather data collection and vulnerability assessments so
16 that airports can collect and access this information to inform investments and other decision-
17 making over time.

18 **THE AWARE TOOLKIT**

19 **Purpose**

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21 The AWARE toolkit was developed to meet these identified needs and help airports reduce
22 significant weather event impacts. The toolkit utilizes Microsoft Excel 2007 versions or later to
23 provide significant weather planning, response, and recovery guidance for airports of all sizes.
24 The toolkit identifies opportunities to increase weather event preparedness within existing airport
25 responsibilities and strategies while also facilitating coordination across staff and departments.
26 The toolkit is intended for use prior to a significant event and can be useful to planning,
27 operations, emergency management, or risk management personnel.
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29

30 **Toolkit Components**

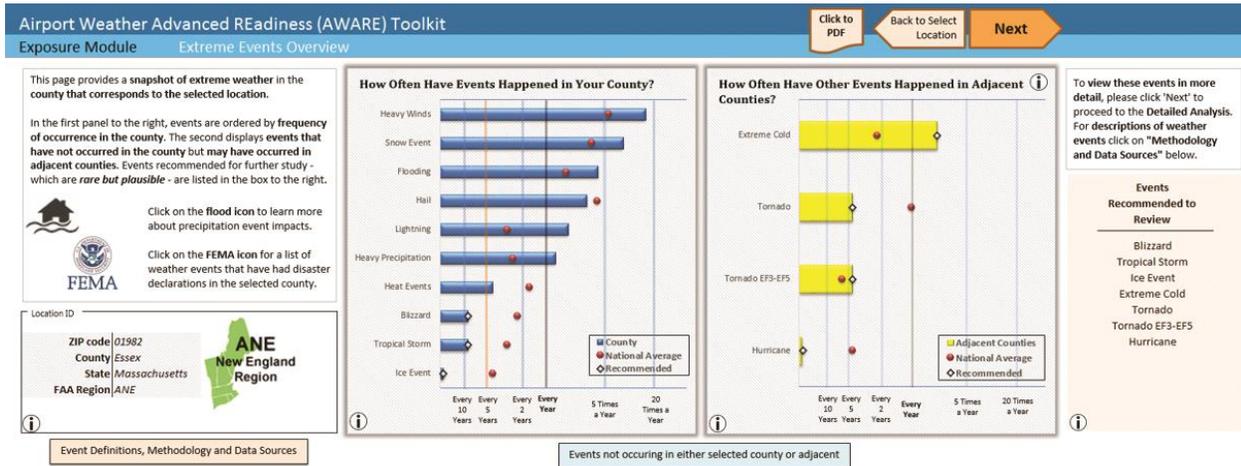
31 The toolkit consists of three “modules” to address each of the three respective knowledge gaps.
32

33 *Exposure Information Module*

34 The Exposure Information Module (shown in FIGURE 2) addresses the question, “What weather
35 events am I exposed to?” by identifying rare, but plausible significant weather events and
36 providing information on the expected frequency of different weather events at a given airport
37 location. The tool provides information and data on 15 different weather event types for each
38 airport. The 15 weather event types include floods, heavy rains, tropical cyclones (e.g.,
39 hurricanes, tropical storms), tornadoes, lightning, hail, heavy winds, extreme heat, extreme cold,
40 snow, blizzards, ice, dense fog, dense smoke, and dust storms.

41 Using the geographic location of the airport as the input value, the module produces
42 figures and tables summarizing the frequency of each weather event type in the airport’s county,
43 adjacent counties, and region; the number of FEMA disasters for each respective weather event
44 by county and adjacent county; potential changes in the respective weather event type over the
45 next century; maps of event frequency nationwide; and, finally, a list of “rare but plausible”
46 significant weather event types in the geographic location. Rare but plausible events are defined

1 as those “occurring fewer than once every five years in the airport’s county or occurring in
 2 adjacent counties without occurring in the airport’s county during the available time period.”
 3 These types of events are recommended for further review though the user has the option to
 4 select or delete any event for further review in the remaining modules. The Exposure
 5 Information Module addresses the first knowledge gap by providing airports with detailed
 6 information about future and unexpected weather events.
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 9 **FIGURE 2 Screenshot of the Exposure Information Readiness Module (7).**

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The Exposure Information Module presents data from the National Oceanic and Atmospheric Administration (NOAA) Storm Events Database (8). This database was selected after extensive review of available datasets for temporal and geographic extent of data, range of weather events covered, ability to analyze frequency of locally defined extremes (e.g., the threshold for significant snowfall is different in Fulton County, GA than in Suffolk County, MA), and ability to derive “rare but plausible” events. The NOAA Storm Events Database provides data by county for the entire United States for a wide range of weather event types. Data are available from 1996 to 2013 and include events that are defined as “extreme” based on local definitions (7). An example of flooding event data per county from 1996 to 2013 is shown in FIGURE 3.

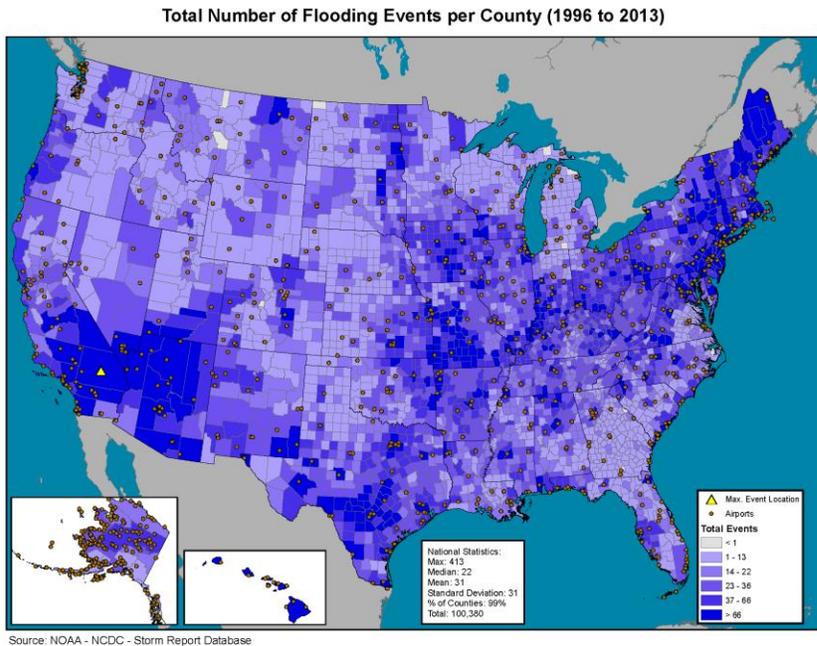


FIGURE 3 Total Number of Flooding Events per County (1996-2013) (8).

To supplement the data from the NOAA Storm Events Database, the module also includes data from FEMA’s Declaration of Disaster Records (9), NOAA Atlas 14 Precipitation Frequency Estimates Report (10), and the ACRP Report 147 ACROS Tool (11).

Readiness Modules

The Readiness Modules address the question, “How can I increase my readiness?” The modules provide users access to best practices for reducing impacts from weather events. The modules are divided into six functional area topics including administration and finance, planning and environment, airfield operations, terminal operations, ground transportation and parking, safety and security (see TABLE 2). The AWARE Toolkit also provides a “small airports” module as an alternative to these six that provides a consolidated version. This module may be more applicable for airports with smaller staffs.

TABLE 2 Toolkit Modules and Topics Covered (7)

Module	Topics Covered
Administration & Finance	Human Resources (HR) functions Airport leadership Insurance coordination Tenant contracting Budgeting for capital and operating expenses Social media Public relations / press relations Reviewing financial impacts of increased weather-related maintenance Contracted services including provisions for existing on-call trades in place before events and post-event processes for major repair projects
Planning & Environment	Airport "Master Plan"

	Airport sustainability and energy management Strategic planning Planning documents (e.g., Irregular Operations (IROPS) plan, Continuity of Operations (COOP) Plan) Engineering design standards Engineering planned improvements (e.g., change in materials, runway length/position) Environmental compliance (including noise, groundwater, and hazardous materials) NEPA documentation
Airfield Operations	Runways (operations and maintenance) Taxiways (operations and maintenance) Aprons Jetways/boarding bridges Flight logistics Air Traffic Control Fuel tanks Documenting impacts to airside pavement, runway lighting, and related areas Deicing Runway maintenance On-airport communication systems (internal PA system, radios, etc.)
Terminal Operations	Check-In/Ticketing Retail Gate areas, terminal space beyond TSA checkpoints HVAC system upkeep and maintenance Terminal facility maintenance Janitorial/custodial services Waste removal Gates Baggage Lighting and signage Utilities (including electricity, phone lines, and water/wastewater) Information Technology (IT) infrastructure Operational areas aside from those that support aircraft. Pre-security areas. Documenting impacts to terminal buildings (interior and exterior) On-airport communication systems (internal PA system, radios, etc.)
Ground Transportation & Parking	Parking lots Transit stations Access roads Recirculation road Curbside facilities On-airport rental car facilities Taxi/limo stands Road and parking maintenance Documenting impacts to airport roads, transit connections, and parking
Safety & Security	TSA checkpoints Terminal space beyond TSA checkpoints Badging and identification systems Airport-wide Emergency Operations Center

Fire-fighting operations
 On-airport communication systems (internal PA system, radios, etc.)

These modules provide best practices for the 15 weather events used in the exposure module, assess airport preparedness for each weather event, and generate customized checklists for preparing for and recovering from these weather events such as the checklist shown in FIGURE 4. Users may select weather event types or use the recommendations from the Exposure Module for further review.

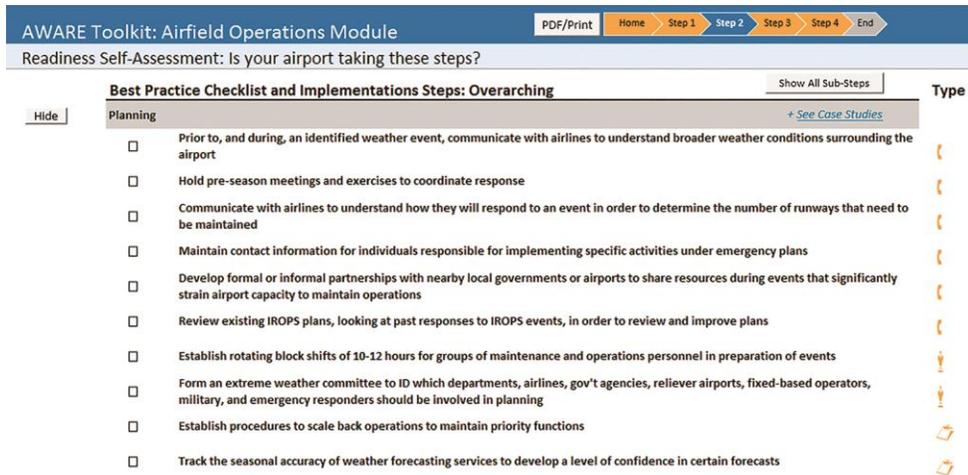


FIGURE 4 Example Best Practices Checklist and Implementation Steps for Airfield Operations (7).

The core of these readiness modules is a compiled set of 730 best practices, organized by functional area and weather event type. These best practices were collected through the literature review, airport case study interviews, and interviews with airport operations experts. The list includes best practices for nearly all significant weather events. A small selection of best practices representing a range of significant weather events, event stages, and functional areas are displayed in TABLE 3.

TABLE 3 AWARE Toolkit Example Best Practices (7)

Weather Event Type	Event Stage	Functional Area	Best Practices
Flood	Planning	Personnel	Identify dedicated airside-focused teams for significant weather response
Heavy Rain	Mitigation	Infrastructure	Ensure drains are clear of debris through regular maintenance
Tornadoes	Response	Communications	Document Foreign Object Damage (FOD) occurrence via electronic database
Tropical Cyclone	Recovery	Equipment	Coordinate with the local military or heavy equipment company to remove debris from the airfield

Many airports directly influenced the diverse list of best practices through their case study interviews. This includes Manchester-Boston Regional Airport’s strategy to always prepare for the worst (7). After a three-day power outage, the airport invested in additional

1 backup supplies and a generator capable of running for at least three days to better prepare for
2 the next power outage. The airport also learned to maintain a season's worth of chemicals, sand,
3 and other supplies at all times to insure preparedness for worst-case scenarios of most types of
4 weather events. Other airports choose to focus their attention on maintaining core operations
5 during significant weather events. Bozeman Yellowstone International Airport's airside ground
6 operations reportedly focuses all attention and resources on maintaining the main runway and
7 taxiway during major snow events so that the airport can continue to operate even in a reduced
8 capacity (7). Some airports see benefit in closing entirely prior to a major weather event that will
9 surely shut-down operations. Newark Liberty International Airport chose to shut down well in
10 advance of Hurricane Sandy in order to properly organize staff, aircraft, equipment, passengers,
11 and emergency response resources and partners to properly prepare and minimize losses and
12 damages (7).

13 Other best practices in the list that apply to all types of weather preparedness include
14 holding pre-season meetings and exercises with staff and emergency response personnel to
15 coordinate and update weather event responses, assigning staff specific roles or shifts well in
16 advance of significant weather event conditions, or establishing relationships with airlines and
17 emergency response personnel prior to working together during a weather event.

18 The list also contains best practices for specific significant weather events grouped by
19 functional area such as personnel or infrastructure and also by the stage (planning, mitigation,
20 response, recovery) of a weather event. Preparing for a blizzard, for example, may include
21 creating a list of priority areas to keep clear of snow and ice (planning), storing equipment
22 indoors and in heated environments whenever possible (equipment), monitoring pavement and
23 friction conditions regularly throughout the storm (infrastructure), or in the case of ice, using a
24 layer of snow on the runways to act as a buffer between ice and runway pavement (mitigation).

25 The Readiness Modules help to resolve the second knowledge gap by providing access to
26 other airport's best practices and providing customizable checklists for preparing and responding
27 to weather impacts. This tool allows airports to more easily respond to weather event challenges
28 by having access to the best practices successfully implemented at other airports as well as
29 checklists for ensuring the airport has taken all appropriate steps to prepare for, respond to, and
30 recover from a significant weather event.

31 32 *Impacts Tracking Module*

33 The Impacts Tracking Module addresses the question, "What are the costs of these events?" by
34 allowing airports to track the direct costs and other event impacts as a weather event occurs. The
35 inputs for this tool include data on costs such as labor, equipment, or material costs, and other
36 impacts such as flight delays and the number of passengers affected. The tool includes a template
37 for tracking costs, and calculators with integrated default values and calculations to help airports
38 quantify their impacts. There are calculation tools for airport labor costs, equipment and material
39 costs, passenger delay costs, carrier delay costs, and aircraft damage costs. The output results in
40 a dashboard display highlighting total costs by event type, by specific event, and a timeline of
41 costs over time by cost type and event type. The data collected from users serves as a database to
42 inform future weather preparedness investment decisions. The Impacts Tracking Module
43 addresses the third knowledge gap by providing a system to track and quantify the costs of
44 significant weather events that can be utilized across airports.

45 46 **Applications**

1 To ensure its applicability and utility for airports, the AWARE Toolkit was developed, revised,
2 and refined through a series of feedback gathering exercises, including repeated review and
3 testing by a “core team” of reviewers from six airports, hands-on toolkit testing at two national
4 airport conferences, and review and testing by ACRP 02-49 Panel members. In total, throughout
5 its development, the AWARE Toolkit was reviewed and tested by over two dozen individuals
6 representing 17 airports.

7 The AWARE toolkit is intended to increase accessibility to pertinent information about
8 significant weather event impacts and costs, preparedness assessments and ratings, and access to
9 best practices and effective management strategies. First, the toolkit identifies rare weather event
10 types in a specific location that could plausibly occur. This is particularly important as most
11 airports have little knowledge about rare events and as noted earlier, rare events are the most
12 disruptive type of weather event. Second, the toolkit assesses airport preparedness for different
13 weather events and assigns preparedness ratings. This helps airports to evaluate and make
14 improvements to their weather preparedness, response, and recovery plans to increase their
15 preparedness. Third, and foremost, the toolkit identifies and provides access to 730 best practices
16 from peer airports. This can be a valuable resource for all airports, particularly those facing
17 changing weather patterns and weather events the airport has not experienced within institutional
18 memory. The list provides easy access to best practices from peers around the country, filterable
19 by event type, applicable functional area, and other factors to make best practices easy to locate.

20 Finally, the toolkit provides a method for airports to track weather event costs and
21 impacts over time, and to quantify the costs of those events including direct costs to the airports,
22 but also costs to airlines and passengers. As airports use this toolkit, the database generated will
23 provide useful information and opportunities for vulnerability analyses and further evaluation of
24 the costs of significant weather and implemented strategies to address them.

25 While each module addresses one of the three major knowledge gaps identified in the ACRP
26 report, collectively the AWARE toolkit makes information more readily accessible to airports
27 and ultimately helps airports make better and more informed decisions regarding significant
28 weather.

30 **Areas for Future Research and Development**

31 The process of developing the AWARE Toolkit uncovered additional potential needs likely to
32 arise over time. For example, the toolkit does not directly quantify how climate change might
33 affect the likelihood of the different weather events at a given airport. Some information on this
34 is available through the ACROS toolkit (11), and the AWARE Toolkit incorporate those
35 projections alongside the historical data on weather event frequency. But the data are not
36 available, nor was it within the scope of the ACRP 02-49 project, to estimate specific potential
37 future frequency of different weather events by location. As the science on this front evolves,
38 airports will need to consider climate change in how they prepare for extreme weather.

39 In addition, the best practices compiled throughout this project are surely not—and can
40 never be—comprehensive. However, maintaining a community of practice to share best practices
41 over time will be important for the airport industry to continue to address challenges from
42 significant weather over time.

44 **CONCLUSION**

45 The ACRP Report identified gaps in airport knowledge and preparedness for significant weather
46 events and also revealed that best practices do exist for most significant weather events at other

1 airports. This research clearly indicates that airports should first look to other airports who
2 experience a particular weather event more frequently and/or to others who experience similar
3 event frequency but are more prepared, for guidance on how to prepare for, respond to, and
4 recover from a significant weather event. The AWARE toolkit directly addresses the challenges
5 of understanding significant weather exposure in a specific location, accessibility to other airport
6 significant event best practice information, and quantifying and tracking the cost of significant
7 event impacts.

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