Airport Case Studies

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Bozeman Yellowstone International Airport

Introduction

Bozeman Yellowstone International Airport is 8 miles northwest of Bozeman, MT, nearly 4,500 feet above sea level in the heart of Gallatin Valley. The airport is the state's busiest airport, with three runways that supported more than 442,000 passenger boardings in 2013. Bozeman is the only airport serving as a year-round hub for two Yellowstone National Park entrances as well as the greater southwest Montana area.

The highest frequency significant weather events that impact Bozeman are snowstorms, extreme cold, and lightning strikes. This case study discusses how these events have affected the airport in the past and explores best practices and gaps within its planning and response protocols.

Past Weather Impacts at Bozeman

Bozeman has experienced different effects due to weather events. For instance, the airport has faced lightning storms that caused power outages throughout the airport. One particular lightning strike knocked out electricity that powered the ticket machines at the airport's paid parking lot. The airport was forced to manually open the parking lot's gate and allow customers to leave for free, leading to approximately $6,000 in lost revenue.

During the winter of 2013, temperatures dropped to –30°F, below the –25°F threshold minimum required for aircraft deicing chemical agent. Flights were therefore prevented from taking off until temperatures rose a few hours later. Because the frigid temperatures were sustained for 10 days straight, the cold temperatures penetrated deeper into the facilities. One of the airport's automatic entry doors failed to close, exposing the sprinkler line in the vestibule to cold temperatures and freezing it.

In 2004, Bozeman experienced a wet snow on one evening, which soon turned to ice as evening temperatures dropped well below freezing. The airport was not expecting temperatures to fluctuate far below freezing point and therefore did not consider applying chemicals beforehand. Bozeman had to close the runway for an hour to put down deicing chemicals and improve braking action.

Airport Overview

- IATA Designator Code: BZN
- Location: Belgrade, MT
- 442,540 enplaned passengers in 2013

Lessons Learned

- Prioritizing treatment of main runways and taxiways maintains flow of operations
- Strategically allocating other staff at access roads supports customer access to the airport
- Tenants can be valuable sources of information on impacts around the airport

Notable Weather Events/Stressors

- Snow
- Ice
- Thunderstorms and lightning
- Strong winds

Impacts to Operations and Infrastructure

- Frozen pipes
- Damaged HVAC and electrical systems
- Flight delays
- Power outages
- Lost revenues

Useful Practices

- Flexibility to apply deicing chemicals
- Surge protectors and backup generators
- Improved wiring in machinery
- Prioritization of runways and main airport functions

Improving Bozeman's Resiliency to Weather

Bozeman closely monitors the weather during a storm and sends operations staff throughout the airport afterward to assess any damage. Tenants assist by notifying operations of lost electricity or other issues within their areas. Typically, the building's power supply remains uninterrupted. Bozeman's building automation, the centralized control of a building's HVAC, lightning, and other systems, is backed up with an uninterruptible power supply (UPS) as well as backup generators. Surge protectors are expected to add to this redundancy as Bozeman upgrades its facilities.

In addition to losing parking revenue during the lightning storm, Bozeman also lost $17,000 in damage to equipment. As a result, the airport improved grounding at all ticket dispensing and payment machines and changed its copper wires to fiber, an identified fail point. Bozeman also invested nearly $10,000 to install surge protection at its control tower. Installing surge protection was relatively inexpensive and developing a robust surge protection system provides a degree of long-term protection. However, even with this added protection, there still cannot be a 100-percent guarantee that the additional measures will always provide protection from lightning strike damage.

Applying deicing chemicals to Bozeman's main runway costs $4,000 for each application and was used sparingly in preconditioning situations. Recently, though, there has been a cultural shift among decisionmakers to encourage the use of deicing chemicals whenever it is deemed necessary. Airport staff will decide to use chemicals in advance of a storm based on the weather forecast and conditions on the ground.

Bozeman's allocation of staff and prioritization of operations during winter weather has also bolstered its weather response effectiveness. During a snowstorm, the airport concentrates on keeping the main taxiway and runway open, using two brooms early and keeps them running continually to clear snow. To allow maintenance staff to focus efforts on the runway and taxiway, other staff focuses on keeping the terminal roadway and pedestrian passages clear. Bozeman does not set a limit for overtime pay (with a 12-hour maximum per day) for its maintenance staff, allowing them to work throughout a storm with fewer time restrictions in snow conditions.

Challenges in Weather Forecasting

Forecasting has been the greatest challenge for Bozeman, because its position in a valley causes it to experience unique weather patterns that differ from the greater Bozeman area. The mountains surrounding the Bozeman area prevent the airport from receiving considerable radar coverage data for areas below 10,000 feet. Furthermore, weather information published by the National Weather Service is for the greater Bozeman area and is not specific to the airport's precise location. This prevents Bozeman from receiving much localized data. Still, operations staff have found some workarounds for this problem by using observations at nearby towns to understand what weather conditions are being experienced. A longer term solution would be to obtain a radar system for the valley.

Gaps/Challenges in Response

- Lack of airport-specific weather forecasts

Toolkit Suggestions

Based on Bozeman's experiences with significant weather, more detailed checklists for assessing the condition of facilities following events could be incorporated into the AWARE Toolkit. Information on people to contact, critical systems to check, and notes on those systems could facilitate a more thorough assessment of the airport, ensuring that lingering vulnerabilities are addressed.

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Chicago O'Hare International Airport

Introduction

Chicago O'Hare International Airport is located within the City of Chicago, occupying more than 7,800 acres of land. The airport features 189 gates and eight runways that processed nearly 900,000 aircraft operations in 2013, making it the second busiest airport in the world (ACI 2014). The City of Chicago Department of Aviation operates the airport.

Chicago experiences a range of weather events each year, and O'Hare's operations staff are tasked with maintaining operations through these snow, rain, wind, and ice events. This case study discusses how these events have affected the airport in the past, how the airport responds to them, gaps in the airport's ability to respond to the events, and suggestions from the airport for the AWARE Toolkit.

Airport Overview

- IATA Designator Code: ORD
- Location: Chicago, IL
- Over 880,000 aircraft operations in 2013
- Over 67 million passengers in 2013

Lessons Learned

- Long-term investments replacing aged or damaged resources are ideally made before event.
- Tracking of equipment age and maintenance costs will provide justification when replacement is more cost-effective than repair.
- Formalized and structured communications with airlines helps improve weather response.

O'Hare's Vulnerabilities to Significant Weather

O'Hare has experienced various significant weather events that have impacted the airport's operations and infrastructure. Stressors include flooding, blizzards and heavy seasonal snowfall, ice, high winds, and lightning and thunderstorms.

A flood in September 2008 caused extensive flooding throughout the airport, which was in the middle of a runway extension and detention basin construction project. The primary detention basins contained equipment that was flooded and subsequently rendered inoperable, including a 100-ft crane. Sump pumps and ejector pumps failed, tripping out other equipment and causing power outages throughout airport facilities. The flood also affected the operations tower and base building that held radio communications, lighting, and elevator infrastructure to take people to the top of the 189-foot tower. This event was the third 100-year flood event within the span of a decade that O'Hare has experienced. Each event required elevator infrastructure to be replaced three times.

Fortunately, operations staff were planning on doing an emergency exercise the day of the flood, so the decisionmakers needed for an appropriate response were already present on site. However, the airport still experienced extensive impacts. Even with 13 pumps running, up to 30 inches of standing water was reported near terminal buildings. Some airport service vehicles were stranded and waterlogged and eventually blocked roadways. Cargo tunnels and services roadways for food services, personnel, and baggage trains were also flooded and blocked. At that point, O'Hare suspended incoming and departing flights and focused on moving passengers from aircraft into terminals.

Notable Weather Events/Stressors

- Heavy precipitation and flooding
- Heavy seasonal snow
- Blizzards
- High winds
- Lightning and thunderstorms
- Ice

Impacts to Operations and Infrastructure

- Flooded facilities and equipment
- Power outages
- Disrupted access points
- Damage to electrical systems

Useful Practices

- Teleconferences and continuous communication with air carriers and nearby airports
- Experience with numerous forecasting services
- Preparing for the worst-case scenario

Communications

In response to the September 2008 flood, O'Hare held meetings at its City Tower and conference rooms with its public relations officer, commissioner, and others. Staff reached out to the carriers and tried to keep various groups informed through teleconferences and phone calls. O'Hare has always maintained this level of communication with other airports and carriers during significant weather events, but the communication process has become more formalized. To avoid violating the U.S. DOT 3-hour tarmac rule and receiving a $22,500-per-passenger fine, air carriers and the airport have coordinated efforts to make sure that passengers are not stuck on the tarmac for more than 3 hours. Now, if there is going to be a major delay for flights, the airlines will likely cancel the flight and more clearly communicate with O'Hare about the schedule change.

Forecasting

O'Hare uses several sources for weather forecasts, including the National Weather Service (NWS) and a few paid vendors. Operations staff take the individual forecasts from these services and compile an average for all of them to present to executive staff, with the understanding that the airport should prepare for the worst of them and hope for the best. O'Hare also factors in its own level of confidence regarding the forecasts, which includes which one has been the most accurate recently. O'Hare's success with weather forecasting can also be attributed to its staff's experience with closely monitoring weather radar and weather models. Operations staff have noticed potentially significant weather trends on the radar prior to weather services providing notifications about the same weather phenomena.

Gaps/Challenges in Response

- Reactive and short-term spending often takes precedent over long-term resiliency investments
- Preferential-use and exclusive-use gates for airlines can limit an airport's flexibility

Challenges to Respond to Events

Spending Money

After significant weather events, O'Hare looks at what infrastructure fails and makes investments to replace or repair broken equipment to better handle future incidents. However, justifying the cost to replace still-functioning equipment can be a challenge for O'Hare operations. O'Hare management tries to keep operational costs down in order to keep prices competitive for airlines—If costs become too expensive, airlines may take their business elsewhere. Therefore, there is pressure to minimize replacement expenditures, even as equipment ages. In addition routine and immediate operational costs generally trump long-term investments to prepare for low-frequency, high-cost risks, such as 100-year events.

O'Hare operations staff track infrastructure, throughout the airport, that they want to fix or upgrade over the next 5-to-10 years and document the costs. Repair prioritization is determined according to a 10-year planning timeline. Air carriers are looking 2 months ahead rather than 1 or 2 years down the road and, therefore, often focus exclusively on what needs to be repaired or enhanced immediately rather than over the long term. For example, about one-third of snow equipment is replaced every 5 years. During winter months, O'Hare will host monthly snow and ice control meetings, when staff consistently demonstrate the value in having highly operational equipment to maintain operations. Attending airline representatives may resist additional costs they may face, even though the airport has identified it as a priority. The airports have to communicate effectively to convince the carriers of the benefits to O'Hare's snow response and the associated required equipment investments.

Musical Chairs and Terminal Gates

Many airlines at O'Hare use exclusive-use and preferential-use gates, and very few airport-owned gates exist. Therefore, airport operations staff do not have much flexibility to shift around gates in an emergency. If a particular airline cannot access its gate due to a weather (or any other) impact, other airlines do not technically have to open their gates to the stranded aircraft, limiting O'Hare's flexibility to ensure sufficient space for aircraft and threatening the airline's ability to relieve on-aircraft passengers and adhere to the U.S. DOT's 3-hour tarmac rule. However, requests from the airport to the other airlines would be made and, worst-case scenario, parking and deplaning in a hold pad is the last option.

Toolkit Suggestions

Considering O'Hare's challenges in justifying infrastructure investments, the AWARE Toolkit could be used to include information that educates personnel and decisionmakers in financial offices, marketing, and other offices to become more familiar with operational impacts and costs from significant weather. Furthermore, lease clauses for terminals may be necessary so that airports can assume control of preferential-use or exclusive-use gates during irregular operations and accommodate otherwise stranded carriers. The toolkit could include this suggestion in significant weather planning checklists.

Toolkit Suggestions

- Education information for non-operations staff
- Inclusion in checklists of airport ability to take over exclusive-use gates during significant weather events

References

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Columbia Metropolitan Airport

Introduction

Columbia Metropolitan Airport covers 2,600 acres in West Columbia, SC. Its two runways host airlines, jet freight carriers, fixed-base operators, and various charter flights that provide air passenger and cargo services. The airport on average serves more than 1.2 million passengers and processes more than 168,000 tons of air cargo each year.

Located in the southeastern United States, Columbia's main weather concerns focus on impacts from thunderstorms and occasional snow and ice events. In recent years, lightning, hail, and microbursts have affected buildings, runways, and lighting infrastructure. Hurricanes can reach the airport, though it would require a particularly strong hurricane to do so. This case study explores Columbia's experiences with lightning and microbursts, which have typically been the most frequent and damaging events, respectively.

Airport Overview

- IATA Designator Code: CAE
- West Columbia, SC
- Average 1.2 million passengers served annually
- Average 168,000 tons of air cargo processed annually

Lessons Learned

- Insurance coverage of major lightning impacts reduces the effect on maintenance budgets
- Reviewing designs of tenant's investments ensures resiliency of new investments and compliance with emergency response protocols

Impacts from Microbursts

Though infrequent, microbursts have posed the greatest impact to Columbia's infrastructure and operations. In 2007, a microburst during

Notable Weather Events/Stressors

- Thunderstorms and lightning
- Hail
- Microbursts
- Snow and ice
- Tornadoes

Impacts to Operations and Infrastructure

- Damaged hangars
- Power outages
- Damaged airfield lighting
- Damaged small aircraft

a thunderstorm hit the airport. During this time, aircraft operations were already suspended due to the thunderstorm. Planes were held at gates, and no incoming flights were accepted. However, the microburst destroyed 10 Tee hangars and one canopy hangar and damaged more than 40 small aircraft in a 1-acre corner of the airport. The event created $100,000 of damage to hangars and up to $20,000 in damage to small aircraft. Because microbursts are generally spontaneous events during thunderstorms, the airport had no warning that one would occur, even with an NWS station on site.

Since this incident, the tenant who owned the hangars has invested in more resilient structures. The damaged Tee hangars and canopy hangars, which were not completely enclosed, have been upgraded to fully enclosed hangars. Although the tenant was not instructed by Columbia to invest in more resilient buildings, the tenant was required to share the proposed hangar designs with the airport to ensure that the new buildings would not harm other airport operations and would comply with the FAA's Part 139. Additionally, Columbia representatives reported that most tenants understand that the airport's biggest weather concern is thunderstorms and therefore take stressors (e.g., hail, lightning, and occasional microbursts) into their design considerations.

Useful Practices

- Reviewing design standards of new investments of tenants
- Insurance coverage for major lightning strikes
- Backup generators as added redundancy for airfield lighting

Lightning Impacts and Response

Although microbursts generally pose the greatest impacts to airport infrastructure, lightning poses the most frequent impact to infrastructure and operations. The challenge with lightning, similar to microbursts, is the unpredictability of where it will strike. Therefore, maintenance staff try to ground all electrical infrastructure at terminals and on the airfield. Two runway precipitation approach path indicators were hit so frequently that maintenance replaced the metal washers with Teflon washers, which can help reduce impacts from all but direct lightning strikes.

If a runway or lighting is damaged, a work order is submitted for maintenance staff to repair the impacted infrastructure. Columbia has an insurance policy with a $1,000 deductible. If the cost of the repair is under the deductible, then it is put under the regular maintenance budget. If the cost exceeds $1,000, Columbia can file a claim to cover it. The airport typically spends about $10,000 through its maintenance budget per year on repairs due to lightning strikes.

As a redundancy, Columbia maintains two sets of backup generators for airside lighting, as well as a generator for its main terminal. To ensure reliability, these generators are tested once per week, given that the generators would need to be working within seconds after main power is lost.

Toolkit Suggestions

Columbia Metropolitan Airport noted that various resources could be useful in the AWARE Toolkit, such as sharing best practices. Airport representatives already attend an AAAE symposium on snow removal procedures each year, in addition to visiting other airports to see how they operate during snow removal. Given its experiences with microbursts, the airport suggested developing a method to determine the probability of microbursts occurring, given a certain forecast. Creating a range of probabilities for the occurrence of certain impacts could help airports ensure better preparation for these more spontaneous events.

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Dallas/Fort Worth International Airport

Introduction

Dallas/Fort Worth Airport (DFW) is the primary international airport serving the North Texas region, covering nearly 27 square miles with 17,207 acres of real property. The airport provides domestic and international service to approximately 166,000 passengers every day and more than 60 million passengers each year.

On December 5, 2013, a major ice storm hit North Texas, with up to a half an inch of ice covering the Dallas/Fort Worth region, including DFW. The ice, combined with below-freezing temperatures for 3 days that followed, required airlines to cancel 750 flights, about 90% of DFW's normal daily load. The ice and extreme cold caused water pipes to burst and damage to outdoor equipment.

In addition to ice storms, DFW experiences a range of severe weather types. This case study explores how these events have affected the airport, how the airport responds to them, gaps in the airport's ability to respond to the events, and suggestions from the airport for the AWARE Toolkit.

Airport Overview

- IATA Designator Code: DFW
- Location: Northern Texas
- Average 1,850 airline operations per day
- Average 166,000 daily passengers

Lessons Learned

- Strong relationships and communication with partners and airlines helps build capacity during planning, response, and recovery
- Contracted staff that are available to assist outside of regularly scheduled shifts help prevent extra stress or damage to facilities

Weather Stress on DFW Assets and Operations

DFW has experienced various significant weather events over the past 10 years, including heat waves and severe storms that produce lightning, hail, tornadoes, ice, and snow.

- On December 24th, 2009, snow and westerly winds limited the airport to only using the diagonal runways for more than 10 hours, which reduced the aircraft arrival rate to 20 flights per hour as opposed to 90 when both diagonal and parallel runways are operational.
- In 2010, DFW experienced 70 straight days with 100+ degree temperatures, which posed a major impact on maintenance, infrastructure, personnel, fuel consumption, and utilities.
- Drought that occasionally plagues the Dallas/Fort Worth area limits the ability to use water for facility maintenance purposes.
- One particular hailstorm damaged 40 airport-owned vehicles, 63 aircraft, and various parts of its 1.5 million square feet of roofs. It took nearly a week for some airlines to fully recover.
- On May 24th, 2011, DFW experienced more than 205 cancellations and various diversions when their central terminal ramp was closed due to a severe thunderstorm warning. While tornadoes touched down south of the airport, DFW had over 6,200 passengers stuck at the terminal due to cancelled flights.

Notable Weather Events/Stressors

- Thunderstorms
- Ice storms
- Heat waves
- Snow
- Hail
- Tornadoes

Impacts to Operations and Infrastructure

- Reduced flight traffic
- Stress on fuel consumption, facilities, and personnel
- Damaged roofing and aircraft

Because of the variety of these weather events, DFW's operations and infrastructure must be prepared to handle different stressors throughout the year.

Useful Practices

- Shifts for response workers
- Using lessons learned to inform new investments and decisions
- Communication with airlines to understand their needs and planned operations
- Using communication tools and hotlines

Effective Responses by Dallas/Fort Worth

Following major events, DFW studies elements of its response and their effectiveness to understand how to improve. Following the December 2013 ice storm, DFW enhanced its staffing plans for different weather events, acknowledging that preparing for snow and ice events may differ from planning for thunderstorms. For example, planning for snow and ice events requires establishing two separate shifts of 10 or 12 hours for groups of personnel in preparation for those impacts. In addition, from lessons learned, DFW is considering how to find space in the airport for staff to shower, eat, and sleep so that they reduce trips to and from home during difficult weather conditions.

DFW also recently enhanced snow and ice clearing procedures. Part of the targeted improvements from the 2013 ice storm was to acquire more equipment for runway and apron maintenance, including the purchase of two additional snow blowers to deal with the resulting snow piles that plows generate. In 2014 DFW also created a model that takes into account the intensity of precipitation (including rate per hour and density), the amount of downtime needed to maintain equipment, and the resources that go into that maintenance so that operations managers can incorporate that into the maintenance and operations scheduling.

A significant component of DFW's planning involves understanding how partners are planning for certain events. The airport has an established plan that outlines planning priorities, which is dynamic to accommodate information from airlines, the FAA, the NWS, and others so that DFW staff understand what the potential conditions are and how airlines and other partners will be responding. Under this plan, for example, when significant weather events occur, DFW communicates with airlines to see what their expected operations are going to be in order to determine how many runways need to be maintained. If an airline expects to operate at 75% capacity, DFW can then determine ahead of time what materials and equipment are needed in order to support fewer flights under harsher weather. Communicating with airlines and other partners following events also benefits DFW's investments in preparing for weather events. The findings from conversations about what airliners and other partners need to operate in more extreme weather provide DFW with a strong justification for requesting funds for specific purchases following an event.

Improved forecasting can also improve preparation and response. Two weeks prior to the December ice storm, the Northern Texas region was forecasted to experience icy weather. While the weather system stayed north of DFW, it allowed the airport to see what happened to airports in Oklahoma. DFW had time to understand the impacts near them and get an advanced start on preparation activities.

In events where dozens of flights are grounded and thousands of passengers can be stranded at the airport, communicating with passengers is critical. DFW uses a paging system that allows them to quickly broadcast messages directly to the terminals, as well as a tool they use to communicate the status of operations, the "DFW C3 Portal," through an online webpage and email notifications. The DFW C3 Portal can push weather and operations notifications to tenants and other internal/external stakeholders who need to be informed so they can provide appropriate information to customers. A representative from DFW's public relations department is also present in the emergency operations center when it is activated in order to handle media attention.

DFW also monitors a hotline run by FAA, called the Texas Hotline, which brings together FAA controllers, airports, and airline representatives to discuss airspace routing, areas that are shut down, workarounds and diversions, and other pertinent pieces of information. Furthermore, DFW strives to ensure that it knows the right points of contact for each player in its emergency response efforts. Establishing relationships with airlines and government agencies through table-top exercises and active dialog throughout the year helps DFW ensure its response to weather is as effective as possible. From DFW's perspective, whether airports have one or one thousand flights going out, they must have regular in-person meetings with aviation partners and develop and maintain strong relationships.

Gaps

The December ice storm and other weather events have provided lessons to learn from. First, recovering from snow and ice events requires time. Equipment needs to be repaired, cleaned, and placed back on line for operation. Pipes cracked from freezing water need to be replaced, and sand used to treat icy surfaces needs to be removed from airport pavement. This recovery process can last weeks after winter weather events.

Gaps/Challenges in Response

- Lengthy recovery times after ice storms
- Managing influx of passengers at airport during and after weather events

Furthermore, following events where aircraft may be diverted to other airports, such as ice storms and thunderstorms, the airport is focused on tracking those flights until they return to DFW. During this time there is much activity in the terminals, and DFW needs to communicate with tenants that they need to stay open later in order to accommodate passenger needs, such as food, coffee, and other goods and services. The biggest challenge has been bringing in additional custodial staff to handle this influx of passengers. During the May 24th, 2011, thunderstorm that left 6,200 people in DFW's terminal, an insufficient number of contracted custodial workers were present at the airport. Lack of custodial workers contributed to terminal public spaces aesthetic concerns related to cleaning and emptying waste collection bins.

Toolkit Suggestions

Considering their gaps, DFW suggests that airports look at their contracts with custodial staff and other key contracted service providers. What is included in the contract? Who is responsible for custodial services during emergency events? Should there be a custodial contract provision requiring extra custodial service staff for more extreme weather events? These elements can also be applied to other contracted airport staff that may be critical to response and recovery operations, such as engineers, electricians, and plumbers.

Toolkit Suggestions

- Considerations for using contracted staff during significant weather events

References

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Denver International Airport

Introduction

With more than 53 million passengers traveling through it each year, Denver International Airport is the 5th busiest airport in the United States and

Airport Overview

- IATA Designator Code: DEN
- Location: Denver, CO
- Number of runways: 6
- More than 1,550 daily flights on average in 2013
- More than 52.5 million passengers in 2013

15th busiest airport in the world. The airport is owned by the City and County of Denver Department of Aviation and serves as a hub for Frontier Airlines, Great Lakes Airlines, Southwest Airlines, and United Airlines. The airport has experienced various weather events, most notably blizzards and thunderstorms that produce flooding and tornadoes.

This case study focuses on Denver's lessons learned from a blizzard in 2006 that left the airport closed for nearly 2 days. In addition, this case study discusses the development of an airport-specific tornado warning system between Denver International Airport and the NWS.

2006 Blizzard Highlights

By trying to operate at full capacity during the blizzard, Denver's maintenance operations slowly began to fall apart.

Its balanced throughput approach allows the airport to maintain what it can manage without causing significant backlogs of departing flights.

December 2006 Blizzard

In December 2006, a blizzard dumped more than 2 feet of snow on Denver airport, shutting it down for 45 hours. The airport's problems began with a poor forecast. A day before the storm, Denver was expecting a typical 2- to 4-inch storm. As the storm approached, that forecast quickly changed to over 24 inches of snow in a day-and-a-half period. At that time, Denver's snow removal plan required an all-or-nothing approach, trying to keep all operations functioning normally instead of keeping only what they could manage. This approach slowly broke down as the blizzard continued. Since the 2006 blizzard, Denver has changed its operations approach to focus on snow clearance from priority runways at the airport and temporarily closing some areas of the airfield in order to maintain primary operations.

The prioritized approach proved to be effective in providing adequate landing capacity for incoming flights. Ground crews deicing aircraft could not match the volume of the flights still able to land in snowstorm conditions. Prior to the 2006 blizzard, the FAA's operating procedures specified maintaining a full load of 96 incoming flights per hour during a snowstorm. Although the planes could arrive, ground crews had a difficult time trying to get planes through the de-icing pad so as to depart on time. Denver operations identified an innovative solution they named "the balanced throughput" concept to address the imbalance between incoming and departing flights. Denver worked with the FAA and carriers to create a system which intentionally slows arrivals to balance the reduced departure rate. For example, if weather conditions reduce Denver's departing rate of flights to 64 per hour, the FAA, in cooperation with the airport and airlines, will implement Ground Delay Programs to slow the arrival rate to 64 arrivals per hour. The carriers appreciate this, because it reduces both their need to cancel flights and their likelihood of breaking the 3-hour tarmac rule.

The balanced-throughput approach requires cooperation among different agencies. The airlines during the 2006 blizzard hesitated to delay or cancel flights, since that would open up more space at the airport for other airlines to come in. However, some carriers that brought in as many planes as possible during the blizzard could not get those aircraft back into service until the airport was reopened and the recovery effort began, significantly impacting their business. This experience encouraged carriers to buy into the balanced throughput approach.

Prior to the onset of forecasted events, Denver will hold a conference call with airlines and FAA Air Traffic Control Tower (ATCT), Denver Terminal Radar Approach Control Facility (TRACON), and Denver Center (ZDV) to discuss the event and forecasted precipitation rates. The FAA can use their tools to slow arrival rates, allowing Denver and its carriers to work with predictable delays. Denver can manage its reduced operations, and airlines provide passengers advanced notice that their flights are delayed or cancelled.

Weather Forecasting

Denver uses several forecasting services since the 2006 blizzard, including the NWS, contracted weather providers, airline weather services, and online weather tools. The airport also uses forecasts from the National Center for Atmospheric Research (NCAR), which measures surface temperatures at the airport and builds a forecast to understand how much snow will actually accumulate on the pavement. Denver gathers reports and compares them to determine the probability of a forecast. The forecasted precipitation amount corresponds to certain snow alert levels that, in turn, determine staffing numbers, avoiding bringing in more staff than needed and burning them out.

Forecasting Highlights

Measuring and monitoring the accuracy of weather forecasts help develop seasonal understandings of which forecasts to trust.

Operations staff looks at weather forecasts during each shift and will start a collection and comparison of data. This comparison builds confidence in certain forecasts over others before a season begins. Denver will also compare the accuracy of forecasts against what actually happened following significant events. The accuracy of forecasts changes from year to year, so this is an ongoing activity for Denver staff.

Weather forecasting has also played a large role in response to tornadoes at Denver. Tornadoes in the Denver area are generally small, though frequently appear during thunderstorms. When they appear at the airport, the NWS issues a tornado warning instructing all staff, tenants, and passengers to seek shelter. However, because the airport covers 53 square miles, it can have tornadoes in different parts of the airfield without impacting the most populated, at-risk area, around the terminal and concourses. Therefore, Denver has worked with NWS to develop a tornado warning specific to the airport terminal and concourses. Depending on where the tornado is located, people in affected areas seek shelter while operations elsewhere can continue.

Large Airport Highlight

Airports with large footprints may experience weather events in particular areas that do not affect the main operations of the airport. Denver's tornado warning system helps the airport know when a tornado may impact critical or non-critical areas.

Advocating for Airport Needs

Denver International Airport has rigorously incorporated lessons learned from weather events into planning, response, and recovery protocols. However, much of Denver's success with improving the weather response and forecasting approaches discussed in this case study was achieved through significant lobbying from airport operations staff. Although the balanced throughput approach and the tornado warning system have been effective elements, they originally received pushback from Denver's partners. By a continued push to show how these services had value, Denver was able to generate support and eventual buy-in from its partners.

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George Bush Intercontinental Airport

Introduction

George Bush Intercontinental Airport (IAH) serves as a transportation hub in the southern United States. The airport covers more than 11,000 acres and boasts five runways serving more

Airport Overview

- IATA Designator Code: IAH
- Location: Houston, TX
- More than 40 million passengers in 2013

Lessons Learned

- Determining different types of shifts for staff in response to different weather events improves response effectiveness
- Providing amenities for staff working in irregular conditions improves worker morale and safety
- Performing "ramp hygiene" prior to the onset of an event reduces the number of airborne, damaged, or lost objects during significant weather events
- Coordinating responses to weather with airlines and tenants improves passenger safety

Notable Weather Events/Stressors

- Ice storms
- Snow
- Tropical storms and hurricanes
- Heavy winds
- Heavy rain
- Tornadoes

Impacts to Operations and Infrastructure

- Delayed inter-terminal transportation
- Reduced flight traffic
- Extensive cleanup in facilities and runway
- Damaged roofing and terminals

than 650 daily departures and 40 million passengers in 2013. The Houston Airport System runs IAH and other airports near Houston.

The Houston area experiences a variety of weather events, including tropical storms and hurricanes, thunderstorms and lightning, high winds, tornadoes, heavy rain, and occasionally ice and snow. This case study explores elements of IAH's planning and response practices for ice storms, tropical storms, and tornadoes. The gaps, best practices, and lessons learned from these preparation and response elements have been incorporated into the AWARE Toolkit.

Ice Events

During ice events, airlines do not cause many problems for IAH, in part since airlines have become proactive in cancelling and delaying flights in order to comply with the 3-hour tarmac rule. Airlines at IAH often cancel regional carriers and decrease the number of flights per hour to a manageable number. The most prominent issue for IAH during ice events is the impact of ice on the elevated train, Terminal Link, which transports passengers across terminals. Terminal Link's tracks, which are outside, freeze, ice over, and are rendered unserviceable until the ice melts.

This forces IAH to move to a bussing operation across five terminals, a logistically demanding and time-consuming alternative process that cannot match the train's efficiency. While the train system can normally carry about two thousand passengers per hour, the buses can transport at most 600 passengers. Other airports have enclosed rail systems that are more protected from weather stressors. Though enclosure would help avoid future ice impacts, the cost to enclose the tracks is too high for the low frequency that these events occur. However, IAH has learned that—except on the most severe occasions—continuing to run the train will keep the tracks warm and resistant to ice buildup.

Because of the relatively infrequent occurrence of ice events in the region, IAH does not usually hold significant stockpiles of de-icing resources. The airport has only a quarter of the number of de-icing trucks that typical "snowy" similarly sized airports have. United Airlines, a major carrier at the airport, can provide additional de-icing trucks for its aircraft during icy conditions. However, keeping all necessary resources at the airport can be difficult. If the airport is considering purchasing a 5,000 gallon tanker truck for de-icing fluid, it also must consider purchasing and storing a storage tank large enough to refill the truck. Because IAH does not have sufficient resources to cover all of its needs, it is limited in responding to severe ice and freezing temperature events.

Tropical Storms

The paths of tropical storms can be anticipated days in advance and IAH has time to prepare for the anticipated impacts. The airport conducts a pre-impact meeting with all response-related partners at the airport to discuss the response. Airlines cancel flights and communicate with passengers when the final flights will be departing, reducing the number of people at the airport by the time the storm hits. At that point, the airport starts securing movable

items, tying down outside equipment, ensuring generators are safe and operational, and sending out final flights.

Hurricanes and tropical storms generally last for less than 24 hours, so the amount of time required to recover depends on what infrastructure is impacted. Airside equipment does not have enough storage space, so much of it is tied down on aprons to ensure it is not blown or swept away by wind or rain. Airport staff protect other potentially airborne equipment like loose carts and airstairs by barricading them in with large and heavy materials (e.g., tugs or K-loaders) and situating them away from buildings or infrastructure that could be damaged. Airside and landside vehicles are generally not parked in parking garages or underground areas in case of structural damage to the building or flooding, so the vehicles are moved to secluded areas near where they are needed.

Gaps/Challenges in Response

- Encouraging passengers to seek safety during significant weather events
- Maintaining stockpiles of materials for events that rarely happen
- Outdoor terminal train system is open to the elements

Following the storm, the airside portion of the airport is closed, allowing workers to go through the taxiways and runways to comprehensively assess the condition of infrastructure. The airport's role as a major hub however requires the consideration of opening at least one runway. Fortunately, with five runways, IAH can make this happen relatively quickly.

Staffing for a hurricane differs from snow or ice events, during which two teams of staff switch back and forth on 12-hour shifts. Hurricanes require a strike team and a post-event cleanup team. Staff are notified of which group they are in ahead of time to give them time to handle any needs at home before coming into work. Additionally, the airport provides food, fuel, showers, and places to sleep for staff providing their services during events. Staff are encouraged to bring other amenities they might need to be comfortable to ensure that they can be ready and able to work when their shift begins.

Tornadoes

Unlike hurricanes, tornadoes occur with little advance notice. IAH relies on NWS for weather notices, which will issue tornado watches and warnings. For a "watch" designation, a tornado might occur. For a "warning" designation, a tornado is occurring. However, these notices from NWS are not legally binding for passengers and tenants, so the airport cannot force people to move to safety. Another challenge is that adjacent counties might experience a tornado and even though there might be secondary impacts to IAH, the airport might not receive all the information because forecasts do not indicate direct exposure to the event.

With only a handful of police officers and five airside and five landside operations staff on any given shift, IAH must rely on assistance from airlines and concessions. IAH has found this necessitates significant coordination among airlines and tenants in order to get them to assist with moving large groups of people to shelters and sending the right messages to passengers. The airport has therefore worked with airlines and concessions in tabletop exercises and planning to help them understand their major role at the airport. The airport has also worked on developing effective messaging in their public announcements on terminal speakers and information screens.

Lessons Learned

Considering these experiences with weather, IAH works to strategically assess each aspect of its weather response planning. The airport studies when and how airside and landside resources are used to maintain operations and also considers the best ways to engage airlines, tenants, and passengers to ensure human safety during potentially high-risk weather events.

References

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Airport Overview

- IATA Designator Code: OGG
- Location: Maui, HI
- Average 350 aircraft operations per day
- Average 7,000 passengers per day

Lessons Learned

- Strong relationships with partners creates more fluid communication during emergency events
- Having an airport representative present at major emergency operations centers improves the airport's access to information
- Ensuring in advance that terminals can accommodate an influx of passengers improves passenger safety and reduces damage to facilities

Notable Weather Events/Stressors

- Tropical storms
- Tsunamis
- High winds

Impacts to Operations and Infrastructure

- Overcrowded terminal and strain on facilities
- Minor damage to fencing and loose materials on property
- Loosened roofing and doors on buildings
- Lack of access to resources due to disrupted access points

Kahului Airport

Introduction

Kahului Airport is on the northern edge of the island of Maui, occupying 1,391 acres of land at an average elevation of 54 feet above sea level. It has two intersecting runways and provides full air carrier facilities for domestic, overseas, and interisland commercial service as well as commuter/air taxi and general aviation operations. The airport, along with all other airports on Maui, is run by the State of Hawaii. Staff who work at Kahului also support operations and management at other airports on Maui, Molokai, and Lanai.

Kahului is exposed to tsunamis[1] and severe storms. This case study discusses how these events have affected the airport in the past, how the airport responds to them, gaps in the airport's ability to respond to the events, and suggestions from the airport for the AWARE Toolkit.

Stress from Tsunamis and Severe Storms in Maui

Maui has experienced various effects of tsunamis and hurricanes throughout the operation of airports on the island. The earthquake near Japan in 2011 created an 8-foot tsunami that caused minor damage to fences near the airport; water came within 50 feet of Kahului's runways. Because the runways at Kahului Airport are about 45 feet above sea level, it would take an approximately 12-foot storm surge or tsunami to reach them.

The terminal building has been designated as an evacuation facility for people seeking shelter from earthquakes and tropical storms. During these events, up to 7,000 people may seek shelter in the airport's main terminal, which has a regular capacity of 5,000 people. This influx of people puts significant stress on the terminal's facilities, including its two bathrooms. The airport's parking lot facilities also cannot handle this surge in occupants, causing cars to park along the streets to the airport and potentially block emergency vehicles' access to the airport.

Effective Responses by the Airport

In anticipation of storm surge and tsunami events, the County of Maui will shut off water and power in order to protect electrical equipment in inundation zones, thus causing no running water or electricity to be available in the terminal. The airport therefore tries to bring in extra mobile bathrooms in anticipation of these types of events. Kahului also works with the local police

[1] Although tsunamis are triggered by earthquakes, rather than a weather event, they provide valuable insight into weather-related events like storm surge.

to ensure that either police or airport staff are present at airport roadblocks to manage the movement of vehicles and passengers following incidents.

In the event of a tsunami, hurricane, or other significant event, Kahului Airport follows an emergency plan, which is required by the FAA. Depending on the event, which could include tropical storms, structure fires, tsunamis, hazardous materials releases, power failures, and crowd control issues, the airport uses appropriate checklists in the Airport Emergency Plan. These checklists, initially developed by the FAA, include actions such as setting up an emergency operations center (EOC), notifying tenants, ensuring that loose materials are tied down, and fueling vehicles. These general actions are then supplemented with information specific to Kahului's operations.

Useful Practices

- Maintaining access to and established relationships with external partners
- Following detailed checklists
- Maintaining contact lists

For example, before the onset of a weather event, Kahului Airport will send out notifications to relevant groups and stakeholders within the airport to take precautions such as fueling vehicles and moving them to higher ground. The airport has limited space for aircraft fuel storage on its grounds and therefore loses access to excess fuel in the case of a storm or tsunami that disrupts access points at the airport. Staff also ensure that they have extra water for staff and guests. If the nearby harbor, which has a potable water source, or water pumps are damaged, the airport may not have water for several days.

One of the most effective elements of these checklists comes from the relationships that Kahului has established with partners throughout Maui and Hawaii. The airport's emergency management operators have developed relationships with these partners and therefore know who is responsible for certain activities and how to contact them. For all of their emergency plans, Kahului has contact information for each person responsible for potential activities. Emergency checklists also include a contact list of who is in each incident command post throughout the island. Furthermore, when given sufficient advance notice of an event, emergency teams meet with external partners face to face before the event occurs to confirm each organization's emergency response role. By not only knowing who to talk to but also establishing a strong relationship with them, Kahului Airport can improve coordination and trust between responders during an event.

Coordinating with private, local, state, and federal organizations has been a valuable resource in planning for and responding to weather events. Maui County's civil defense center houses architects, engineers, and representatives from organizations such as the State of Hawaii, Coast Guard, private water companies, and fueling companies. During significant weather events, a representative from Kahului Airport is also present at the civil defense center, providing the airport with rapid access to relevant decisionmakers and resources in case a particular need arises.

Gaps in Resources for Responding to Events

While Kahului's emergency management system has several effective components, some gaps in resources, staffing, and communications can compromise its response before, during, and after significant weather events. An EOC is located at Kahului, which is supposed to be the main EOC for the Maui airports. However, the EOC contains few resources for partners, so the airport normally uses its main office as the EOC. The office does not have wireless internet or cable for airlines and other partners who would need to use the space, putting them at a disadvantage in communicating with outside contacts.

Gaps/Challenges in Response

- Lack of time and staff availability to conduct training
- Lack of resources (internet, computers, cable, and printers) available for external partners

Having additional training and contingency staffing for significant weather planning would be valuable to Kahului. While the airport does plan, host, and participate in tri-annual exercises and post-event trainings with partner agencies and staff, many staff members are too busy to be involved in these types of trainings on a day-to-day basis. During emergency events, there are only enough people to have one group organize and plan the airport's response throughout the entirety of the event. Ideally, Kahului would have enough emergency management staff to have two management teams available so that staff can take shifts.

Communications during events can also be very challenging. Incident Commanders typically work with three or four radios at a time and also communicate with other partners in the room with them at the EOC. Commanders are therefore challenged with understanding who should know what information across the several communications lines they run, potentially leading to confusion during busy events.

Toolkit Suggestions

- Detailed checklists
- Education measures for staff

Toolkit Suggestions

Kahului provided two suggestions for features to be included in the AWARE Toolkit. The airport noted the importance of checklists in its planning efforts and suggested that the toolkit include checklists that remind operations managers to consider various components of their planning, response, and recovery functions. Additionally, educating staff members who are not familiar with emergency procedures on the terminology used would provide value to the airport.

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Airport Overview

- IATA Designator Code: EYW
- Location: Key West, FL
- 738,000 total passengers in 2014

Lessons Learned

- Having redundancies built into all operations improves airport resiliency
- Understanding disaster recovery funding opportunities maximizes the speed and amount of access to funds
- Maintaining clear and constant communication with emergency response partners improves operations

Key West International Airport

Introduction

Key West International Airport (EYW), the southernmost airport in the continental United States, is on the northeast end of the island of Key West in Monroe County, FL. The airport has one 4,800-foot-long runway that supported nearly 738,000 passenger arrivals and departures in 2014. Operations contain a mix of transient and local general aviation, commercial, air taxi, and military services.

Because EYW is along the coast and only 3 feet above sea level, it is exposed to the effects of hurricanes and tropical storms annually. In the past decade, numerous storms have caused the airport to mobilize for major impacts, particularly due to its role as an access point for emergency response resources. This case study explores EYW's experiences with these storms, including the gaps, best practices, and lessons learned in its preparation, response, and recovery practices.

Vulnerabilities to Hurricanes

The Key West area experienced hits by Hurricane Andrew in 1992 and Hurricane George in 1998, and EYW experienced minor wind damage and airfield debris. Hurricane Wilma in 2005, a Category 5 hurricane, occurred during a season when at least one event happened per month that caused Key West to mobilize for each. Wilma created a 5-foot storm surge that covered the airport in 3 feet of water on the airfield and in its lower terminal, damaging facilities, lighting, and undercarriage infrastructure of planes left outside. Nearly 10 hours later, maintenance staff were clearing debris and fish from its runway and taxiway so they could bring in emergency operations as quickly as possible. Although EYW was able to use generators to deliver electricity to its control tower and runway and taxiway lighting, the airport's phone banks that provided internet services were flooded on the ground floor. It took another week for the phone company to replace the system, locating it 12 feet above sea level to prevent repeated failure.

Impacts to Operations and Infrastructure

- Damage to aircraft
- Flooded terminals, runways, and low-lying infrastructure
- Debris from airport and ocean on airfield
- Wind damage to hangars, fencing, and other airport property
- Power outages

Useful Resources

Due to Key West's extensive experience with hurricanes, EYW has developed numerous best practices to maintain operations. Redundancy has been built into everything. EYW maintains a large inventory of spare parts and employs specialized personnel such as plumbers and master electricians to fix any immediate issues. The airport's bag belt is wide enough to run a cart down it in case the belt fails. Any operations that require electricity have dedicated generators that run on both diesel and jet fuel. The airport also keeps at least 3 days' worth of diesel and 30,000 gallons of jet fuel at all times. Generators on older buildings have been moved to at least 12 feet above sea level, and generators on new terminals are housed on the roof in an enclosed generator building.

In the case of a hurricane that has major impacts on events, the airport serves as a major access point for relief supplies and personnel. Therefore, returning the runway and taxiway to an operational state is the EYW's priority following a hurricane. The airport has tractors, powered brooms, and street sweepers to treat the runway, all of which are parked above sea level along with their fire equipment. Once the runway and taxiway are cleared, daytime emergency operations can begin.

Before, during, and after hurricanes, EYW coordinates with the county administration, NWS, hospitals, police and fire departments, utilities, and any other organization needed to run the airport. Clear and continuous communication during these times is necessary for Key West. For example, the airport emergency plan requires that a functioning hospital must be available for EYW to allow commercial service to operate. When the hospital closes down, Key West must close down airline operations. Therefore, EYW needs to know when the county calls for an evacuation. With the closure of hospitals, Key West is also on high alert to keep its staff safe, since injuries requiring hospital care may be especially harmful.

Useful Practices

- Redundancy of operations
- Maintaining storage of spare parts, generators, and excess fuel
- Building weather-resistant infrastructure
- Understanding of funding mechanisms for disaster assistance

Funding Key West's Recovery

Key West has benefitted from financial assistance from the federal government following hurricanes and has come to understand how to work with different agencies to maximize its funding to recover from events. After Hurricane Ivan in 2004, EYW experienced about

$50,000 worth of damage. FEMA offered financial assistance to the airport, though later requested the funds be paid back since the costs could be funded through the FAA. FEMA, on the other hand, would only cover for losses that EYW actually has. EYW therefore sees FEMA as a way to expedite access to funds but not as a source of permanent grants, especially for smaller financial impacts.

On the other hand, EYW experienced approximately $600,000 of damage during Hurricane Wilma. It collected money from the FAA, FEMA, and its insurance company. Although the airport eventually paid FEMA back its funds, EYW ended up receiving more money than its assessed cost of damage. This in part was due to Monroe County hiring professional adjustors who worked to maximize coverage payments from insurance and found additional funds for EYW.

Conclusion

The level of redundancy built into EYW's operations is a testament to the number of times it has had to prepare for significant exposure to hurricanes and tropical storms. This comprehensive redundancy can be incorporated into the AWARE Toolkit, either through checklists or examples of best practices. Key West's ability to navigate the financial side of recovering from events can also serve as a valuable example for other airports considering ways to soundly recover from significant events.

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Airport Overview

- IATA Designator Code: STL
- Location: St. Louis, MO
- 12,400,000 passengers and 183,920 aircraft operations handled in 2014

Lessons Learned

- Expand authority to less senior staff to designate an emergency event and take action.
- Work with airlines and tenants to enlist their help in maximizing passengers' personal safety
- Keeping detailed building designs handy increases the time and financial efficiency of the rebuilding process after events
- Insurance reimbursement may limit an airport's ability to finance premium costs to make infrastructure more resilient (e.g., window replacement)

Lambert–St. Louis International Airport

Introduction

On the night of April 22, 2011, an EF4 tornado packing 200 mph winds struck the St. Louis area. The tornado traveled eastward parallel to Interstate 70. At 8:10pm the storm's path took the tornado straight through Terminal 1 and Concourse C at Lambert–St. Louis International Airport. Nearly all windows in Terminal 1 were broken and debris from the airport could be found up to 1.5 miles away. The Concourse C roof was pulled up by the tornado and slammed back down onto the building, creating gaps in roofing that allowed rainwater to enter the building. Damage to parking facilities and outlying buildings was extensive. Total damage costs to the airport and airlines ranged in the tens of millions and cost for business disruption added to the price. Despite the severity of the storm, only five people required treatment at area hospitals due to injuries, with another two dozen people treated at the scene. It was fortunate there were no fatalities.

Despite the immense destruction on its property, Lambert–St. Louis only ceased operations for 24 hours. With the tornado occurring Friday evening, the airport managed to operate at 70% capacity on Sunday, 90% capacity on Monday, and 100% on Tuesday. This case study examines how Lambert–

St. Louis was able to minimize injuries of the passengers, staff, and tenants and return to normal operations within 4 days.

Pre-Impact: Forecasting the Storm and Warning Passengers

The tornado was on the ground 20 minutes prior to hitting the airport. At 7:50pm, regional tornado warnings had been issued. At 8:02, the airport was advised that a tornado was on the ground, but not tracking toward the airport.

The assessment was in error and, just before 8:10pm, the Airport Police Watch Commander observed the tornado. Recognizing the danger, an immediate order was issued to evacuate the public to lower terminal levels, into concourse restrooms, and into stairwells. The vast majority of the public was able to take shelter, but many were still exposed as the tornado hit.

EF Number	Three Second Gust (mph)
0	65-85
1	86-110
2	111-135
3	136-165
4	166-200
5	Over 200

Enhanced-Fujita Scale

Given the late hour on a Friday night, airport staffing was nominal and management staff was not present. The appropriate decision to move people into shelter was made unilaterally by the Police supervisor. Thereafter, an audio warning was made over the public address system—the warning was of short duration because electricity and communications were cut by the tornado. There was no information or visual cue provided on information display boards or at gate monitors. Word of mouth was passed by police, airline, and TSA personnel who physically ran the hallways to announce the tornado was imminent.

Surprisingly, even though passengers received warnings to seek shelter, many were curious to see the tornado and stood by the terminal windows to observe or take videos. Because airport staff do not have the authority to order at-risk individuals to take shelter, little could be done for such individuals other than communicating the danger.

For future events, the authority to initiate evacuation procedures or send the public to shelter has been expanded. Visual messaging on gate monitors and information displays will alert the public to the potential for severe weather. Regional tornado warnings will preempt all messaging throughout the airport terminals and concourses.

The airport adopted a more extensive approach to monitor and assess weather patterns and provide warnings to people with more advance notification. For example, less senior employees, especially operations personnel, can decide what emergency notifications should be disseminated and when.

Post-Tornado Emergency Response

Lambert–St. Louis had never practiced for a tornado. However, the response post tornado was essentially an emergency response drill from the Airport Certification Manual. By 9:00pm, the following actions were well under way:

- Medical Triage and Transport
- Damage Assessments
- Assessment of Crisis Communications
- Handling of Security Issues—Airfield Perimeter
- Passenger Plane Evacuations
- Re-establishment of Electricity

At 10:00pm, the Airport Director gave the first of many local and national news conferences. The remainder of the night until daybreak was given to boarding up windows and debris removal performed by Airport and city

Useful Emergency Response Elements

- Dedicated airside-, landside-, and terminal-focused teams
- Post-event asset assessments
- Communications-dedicated personnel with an understanding of airport operations
- Using vacant gates to support enplanements and using apron bussing services when gates are out of commission
- Allowing less senior staff to disseminate weather warnings

crews and on-call contractors. Response was split among three teams: airside, airport buildings, and landside of the terminal.

The morning of Saturday, April 23, the full extent of damage was realized. Early in the recovery process, the airport assessed assets to see how well operations could return to normal. Auspiciously, a recent withdrawal of the American Airlines hub had resulted in excess gate capacity. This extra capacity allowed the airport to relocate four airlines immediately to other concourses. Had gate space not been available, provisions were in place for ramp boarding using hold pads with bus services between airplane and terminal.

A significant element of Lambert–St. Louis emergency response was its overall crisis communication with employees, passengers, tenants, and especially the media. The Airport Director served as the single voice for the airport. When not giving information to the media, the Director was seen throughout the damaged areas providing command presence and visibility among staff and tenants.

By the evening of Saturday, April 23, the airport was in full cleanup mode. Maintenance crews were clearing roads and electricity had been restored. Specialists would still be needed for other essential repairs and on-call contractors for these services were brought in, as well as externally based airlines personnel for airline-specific cleanup. Later on, after a full assessment of damage was conducted, additional non-critical services would be contracted out. However, at 5:00pm, April 23, the runways were re-opened and commercial airline landings resumed—all less than 24 hours after the tornado event.

Rebuilding

Rebuilding the airport's terminal, concourse, and other facilities cost $26,000,000. Airlines and other tenants likewise suffered tens of millions in losses for facilities, equipment, and business disruption.

The airport's damage was covered by insurance and the rebuilding process was complete by April 2012. However, in some instances, the insurance company would only replace materials of the same standard, rather than funding materials of increased resiliency. For instance, other than changes required by code, the rebuilding changed few elements of the terminal and the window strength was not increased. That said, concourse ceiling tiles were removed and the building interior overhead-space altered to "industrial" style. Lack of acoustic tiles has not created noise issues and the visual appearance is improved.

After staff assessed damage, it was also realized that glass panes in the terminal window walls were largely separate cut with few duplicate panes. Fortunately, the company that had provided glass in 1956 was still in business and had original design drawings. The airport has since implemented a long-term solution to keep this type of information accessible.

Lessons Learned

Once normalcy was achieved, a comprehensive review of the event was initiated. Unlike an aircraft incident, the tornado affected every airport department. Thoughts were solicited from all quarters and the inputs addressed policy, procedures, and individual actions. Key findings were

- Plan, train, learn—internalize emergency procedures and expand the "what if" scenarios
- Team effort—set expectations throughout the organization for full response
- Develop and nurture relationships that pay off in crisis

- Rely on core leaders (at any level) to make difficult decisions quickly and in the best interest of the organization
- Communicate the facts, honestly and frequently, with the public

The Pay Off

In May 2013, an EF3 tornado cut through Lambert–St Louis International Airport. This storm was less intense than the one in 2011 and it did not directly hit the terminal or concourses. Outlying buildings, maintenance facilities, and hangars were damaged.

Protocols were initiated throughout the airport upon receipt of tornado warnings. Employees in the damaged areas received abundant warning issued by Operations staff and the public had ample time to take shelter on site.

The airport was shut down; however, normal operations resumed after just a few hours to remove debris and assess critical components. Lambert–St. Louis International Airport was able to use the lessons learned and practices developed since the 2011 tornado to ensure that repeated challenges were not encountered.

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Manchester–Boston Regional Airport

Introduction

Manchester–Boston Regional Airport is less than 50 miles north of Boston, MA, and 3 miles south of Manchester, NH. The airport serves as an access point to the region's popular ski areas, resorts, and beaches. In 2012, the airport saw nearly 2.5 million passengers go through the airport and it is one of the busiest cargo airports in the New England region. These services are supported by the airports two asphalt runways.

Manchester experiences several significant weather events throughout the year and has therefore developed several best practices to ensure its preparedness. This case study discusses these best practices, in addition to particular vulnerabilities and challenges the airport has undergone in recent years.

Vulnerabilities to Weather Events

The Manchester–Boston region experiences a number of weather events, including blizzards, ice storms, lightning strikes, heavy winds, thunderstorms, and occasionally tropical storms and hurricanes. Lightning strikes have damaged airfield lighting, creating lost revenue from shutting down the runway until lighting is fixed and additional costs to replace infrastructure. While recovering to compliancy can take only a couple hours, the entire recovery process can eventually cost tens of thousands to hundreds of thousands of dollars, depending on the intensity of the lightning strike.

Airport Overview

- IATA Designator Code: MHT
- Location: Manchester, NH
- Nearly 2.5 million passengers in 2012

Lessons Learned

- Keeping an excess of supplies ensures a sufficient response regardless of needs
- Maintaining worker safety and preparedness helps strengthen staff responses to weather
- Taking advantage of emergency FEMA funds reduces operating costs
- Using paid forecasting services can provide airport-specific weather information
- Holding seasonal meetings with tenants and airlines ensures all needs are met during an emergency

Notable Weather Events/Stressors

- Snow
- Ice
- Thunderstorms and lightning
- Strong winds
- Hurricanes and tropical storms

Impacts to Operations and Infrastructure

- Damaged airfield lighting infrastructure
- Closed runways
- Flight delays
- Wear and tear on maintenance equipment

Useful Practices

- Maintaining an excess of additional supplies
- Using paid weather forecasting service
- Prioritizing worker safety
- Streamlining FEMA reimbursements
- Meetings with partners to discuss seasonal weather response

In February 2013, Blizzard Nemo left 32 inches of snow in the Manchester area. While the airport's crew was able to keep the airport in operation, the amount and drifting of snow taxed removal equipment. During this type of event, Manchester tries to keep both of its runways open, although at times staff will let one go in order to concentrate on one runway and continue to bring in planes. However, because of its geographical location in the northeast, the airport tends to experience multiple wind directions throughout a storm. Winds that start in the northeast may end up blowing south. Therefore, keeping a secondary runway open helps ensure that aircraft can continue to land.

Useful Resources

Manchester Airport experiences up to 35 weather events and at least one weather emergency each year. As a result, the airport has developed several best practices. Below are some that the airport has highlighted.

Maintaining Supplies

Handling significant weather events is typical work for the airport, so staff prepare for the worst and store additional supplies. Manchester keeps thousands of feet of extra wire and extra circuits, bulbs, and other resources so that its lighting infrastructure can get back on line after a severe lightning strike. While normally it is suggested to keep 40 tons of sand to handle snow at any given time, Manchester keeps 1,000 tons. It keeps 80,000 gallons of liquid deicing chemical in anticipation of winter storms. While the airport generally needs between 8,000 and 16,000 gallons of chemical, it has experienced events where iced-over roads prevented the delivery of additional chemical. Therefore, the airport now keeps at least an average season's worth of chemical, sand, and other supplies on hand because there have been weather events that have required that amount. For example, the airport's worst power outage lasted 3 days. When it plans for new generators, the airport ensures that it has a direct feed that allows the generators to run for at least 3 days. Procuring and storing this enormous quantity of supplies is expensive, but the upfront cost allows great flexibility in Manchester's ability to respond to and recover from weather events.

Forecasting

Manchester uses several sources of weather forecasts, including NWS, free internet services, and a paid forecasting service. The paid service, which costs between $5,000 and $7,000 per year, has proven to be particularly useful for the airport. Because the service understands how the airport prepares for storms and how weather impacts the airport, it can provide daily reports targeted to Manchester's needs. For example, the service understands that the airport's surface temperatures will likely differ from other areas due to pavement thickness and ground temperatures specific to the airport. Manchester has an airfield system that relays runway and underground temperatures, which it shares with its paid service. The paid service also communicates with Manchester throughout the day on current and expected conditions.

Crew Safety

Manchester provides weather forecasts to its operations and maintenance crews, in advance when possible. This transparency helps staff take care of their lives at home before their shifts start. If an event appears to be particularly significant, Manchester will bring in extra crew to make sure people are on duty before impacts are felt. During events, Manchester is concerned with not only keeping runways cleared and operational but also ensuring that worker conditions are safe. Manchester worked with manufacturers of snow melters to install a wireless control so that workers can operate them from within their machinery. The airport has also installed fall protection throughout facilities to reduce injury from falling.

FEMA Reimbursements

When a declaration of emergency is called in the Manchester–Boston region, the airport can use funding from FEMA to cover response and recovery functions by staff or contractors. For snow events, FEMA covers the act of removing snow at the airport and nearby access roads or downed power lines, including the equipment hours and overtime hours for individuals actively operating the equipment. For hurricanes, FEMA may only reimburse for debris cleanup or to rebuild damaged infrastructure, depending on how the declaration of emergency is made. In order to receive any reimbursement, Manchester must keep very clear payroll records that match their historic record of equipment hours of operation for the specific operator.

Communication

Manchester meets with representatives from the FAA and airport tenants at least once per year to discuss its winter weather response. In these conversations, the airport covers in detail what it expects to do in response to snowstorms and how it is going to do it, as well as requests it will likely make and why. In addition, Manchester meets with airlines separately to discuss winter weather planning and to understand what the airlines need. These conversations clarify each group's role and what requests and requirements need to be met in winter storms.

Challenges in Winter Weather Planning

Forecasting the relationship between near freezing temperatures and precipitation is a challenge for many airports, including Manchester. The airport needs specific temperatures, and many forecasting services provide a range of temperatures. Temperatures hovering between 30 and 35 degrees Fahrenheit increase the possibility of rain quickly turning to ice.

The media coverage of a potential storm before it strikes can also be a challenge for Manchester. While it is helpful to understand potential impacts several days in advance, the naming of storms can produce unnecessary buildup among passengers, tenants, and media when these events result in minimal impact to the area. For example, the polar vortex event in early 2014 that received widespread media attention left 1 inch of snow at the airport.

Best Practices

Manchester's best practices can apply to many other airports. The airport's paid weather service provides local, airport-specific weather information to inform weather response. Keeping additional supplies at the airport, in addition to ensuring ample storage space for supplies,

provides Manchester with great flexibility in responding to weather events. Taking advantage of access to FEMA funds during emergency declarations helps reduce labor and equipment costs. Throughout these activities, ensuring that staff are working under safe conditions ensures that Manchester's preparation, response, and recovery are successful.

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Airport Overview

- IATA Designator Code: EWR
- Location: Newark, NJ
- Operated by the Port Authority of New York and New Jersey
- 35.6 million passengers in 2014

Lessons Learned

- Closing the airport well in advance of the storm provides time for staff, airplanes, and equipment to be moved to safety
- Having representatives from federal agencies and utility companies present at the airport's emergency operations center improves access to key decisionmakers and supporting operations
- Keeping constant and clear communication with partners improves response times

Notable Weather Events/Stressors

- Heavy winds
- Heavy rain
- Thunderstorms and lightning
- Tropical storms and hurricanes
- Snow
- Ice

Impacts to Operations and Infrastructure

- Flooded runways
- Debris on airfield
- Power outages
- Broken windows and glass doors
- Damaged electrical systems

Newark Liberty International Airport

Introduction

Opened in 1928, Newark Liberty International Airport is the nation's oldest continuously operating commercial airfield. In 2014, it employed about 20,000 people and contributed about $22.9 billion in economic activity to the New York-New Jersey metropolitan region, making it a major economic player in the region. In 2014, the airport handled 35.6 million passengers and 666,198 tons of cargo through nearly 369,119 plane movements. Newark Liberty is operated and maintained by the Port Authority of New York and New Jersey, which also operates and maintains infrastructure related to the New York/New Jersey region's trade and transportation network.

In 2012, Hurricane Sandy struck the east coast of the United States, affecting millions of people from the Mid-Atlantic through New England. Newark Liberty along with other airports in the region stopped providing service before and during the storm and experienced damage from the hurricane throughout its airfield, landside infrastructure, and terminals. This case study examines Newark Liberty and the Port Authority's planning, response, and recovery measures, largely focused on its coordination and relationships with regional, national, and airport partners.

Impacts of Hurricane Sandy

Sandy hit Newark Liberty with 70 mph winds that shattered terminal windows and knocked down light poles. Storm surge in Newark Bay washed over the New Jersey Turnpike and into the eastern part of the airport, creating debris and impacting electrical equipment. As a result, Newark Liberty had to repair more than 30 damaged buildings, including broken glass doors, heating systems, and electrical systems. This was a major drain on airport resources, costing significant time, money, and effort to return operations to normal.

Impacts outside the airport fenceline also created secondary effects at EWR. Although the airport managed to restore aircraft landing and take-off operations only 24 hours following the storm, very few passengers and staff were able to access the airport due to gasoline shortages, other transportation limitations, or issues at home.

Useful Resources in Preparation, Response, and Recovery

Forecasting and Early Closure

Weather forecasting during Hurricane Sandy was very effective. The forecast was more severe than what was eventually experienced at Newark Liberty, so the airport was prepared for a higher magnitude of impact than what actually occurred. For example, the airport closed operations nearly 24 hours before hurricane-strength winds hit the airport. This provided lead time for staff to secure equipment out on the airfield, which in some cases could take up to 12 hours. Although the airport could have remained open for several extra hours and closed with enough lead time to secure equipment and ensure the safe passage of staff, the Port Authority chose to maximize safety and shut down the airport 12 hours in advance of the storm to provide adequate time to prepare for Sandy's impacts. The Port Authority learned that they could mobilize faster than expected and might not need as much operations closure time for a future storm of similar magnitude.

Useful Practices

- Closing the airport early in anticipation of major impacts
- Frequent communication with local, regional, and national partners
- Representatives from federal government agencies present at airport EOC
- Providing free gasoline to airport staff to help them get to and from work
- Thorough facility assessments immediately following storm

Communication with Partners

Well-coordinated and well-communicated decision making was an important element of the response to Hurricane Sandy. The Port Authority's Office of Emergency Management hosted group calls with various regional players involved with the Port Authority, including the New Jersey State Police and local Fire Departments, the Department of Transportation, the Metropolitan Transportation Authority, New Jersey Transit, political leaders, and other regional organizations. These conversations discussed regional planning and what needed to be done in preparation for and response to the hurricane. In addition, the airport's emergency operations center (EOC) hosted representatives from the police, fire department, department of transportation, utility companies, FAA, TSA, and FEMA. Because Sandy was likely going to affect various operations and infrastructure, the Port Authority ensured that representatives from any relevant organizations were present at the EOC.

The FAA representative came to the airport ahead of time so that he could serve as a direct communication link to the federal government, which provided great value to Newark Liberty's response and recovery. Representatives from the utility company, Public Service Electricity and Gas (PSE&G), also proved to be very useful in Port Authority's emergency response. The representatives were in constant communication with their headquarters to learn when PSE&G was getting certain areas back onto the electrical grid. Newark Liberty provided specific priority areas to regain electricity, such as major facilities and the control tower, and PSE&G worked well with them to determine which feeders and grids they were on and prioritize fixing those areas, when possible. Together these entities greatly helped restore power and reopen Newark Liberty in less than 48 hours.

In addition to broader communications about regional responses to Sandy, Newark Liberty communicated with Port Authority groups frequently about its own hurricane response and recovery. During and in the days following the event, Newark Liberty participated in Port Authority-hosted teleconferences every 6 hours with every Port Authority facility, including the George Washington Bridge, the Port Authority Bus Terminal, airports, and others. These conversations sought to understand each party's immediate needs to move them to the next step toward normal operations. While some requests included siphoning water out from basements, Newark Liberty needed portable emergency generators. As needs changed and recovery

Forecasting

While it was effective for Hurricane Sandy, weather forecasting can be a challenge for Newark Liberty, particularly for snow events. The speed at which precipitation accumulates and the time of day during which the snow falls creates different types of snow on the ground and determines Newark Liberty's response method. Because forecasting these types of events can be difficult, Newark Liberty uses multiple forecasting services, including NWS, free online services, and paid services. Staff go through the different forecasts and consider the timing, amount of precipitation, rate per hour, and other characteristics of each forecast. Upon reviewing this information, Newark Liberty can determine the appropriate staffing levels to take. Generally, the airport prepares for the worst-case scenario. If all forecasts are predicting similar conditions, then the airport's level of confidence in its staffing decisions is raised. If one forecast predicts 6 inches of snow, and another forecast predicts 1 inch of snow, Newark Liberty prepares for 6 inches of snow.

work progressed, the frequency of calls shifted from once every 12 hours to once every 24 hours. Newark Liberty also held teleconferences with airlines, initially two to three times per day, during which the airport and airlines shared information about developments for both groups.

Newark Liberty Staff Response to Sandy

In preparation for Sandy, Newark Liberty brought in its entire staff in advance of the storm, switched to 12-hour shifts, and put staff up in hotels next to the airport. Teams were bussed between the airport and the hotel following their shifts. Immediately following the storm, staff conducted a thorough walk-through of all facilities to ensure they were safe enough for people to occupy them. When a certain facility lost its alarm system, Port Authority enlisted staff to monitor the area for fire 24/7. Where glass windows were blown out, staff closed the section of the building to the public.

Challenges in Hurricane Recovery

Because of the widespread and serious impacts that Sandy inflicted on the region, certain basic needs of Newark Liberty and its staff were difficult to meet during immediate days following the hurricane. For example, food was difficult to obtain for days, and many staff at the airport went up to 24 hours without eating. Other impacts that had secondary effects on the region, such as not having electricity to pump gas into delivery trucks, reduced access to materials, people, and other resources that are valuable in recovery. To address this issue, Newark Liberty decided to provide gasoline free of charge to its employees so that they could get to work. Although the airfield was operational within 24 hours, airlines had difficulty with staffing because employees couldn't get to work. Widespread hurricane impacts limited their staffing and overall ability to return to normal operations. The Metropolitan Transportation Authority and New Jersey Transit experienced damage to its transit system infrastructure that took a week or more to return to normal. Similarly, most people in the Mid-Atlantic region were not prepared to fly following Sandy, so flights at Newark Liberty were reduced for a significant amount of time. Flights were reduced beginning Oct 29 and did not return to normal until the week of November 10.

Using Disasters as Learning Experiences

Newark Liberty recognizes that it cannot plan for every potential impact and events that are planned for seldom play out as expected. A detailed plan is the preliminary mechanism to establish a flexible framework on how the airport will react to a weather event. Real-time airport action adjustments during an event require clear communication and one person or a group of people to make decisions for events that are unanticipated. Newark Liberty has learned through its experience with Hurricane Sandy that these types of major events that put serious and widespread stress on infrastructure promote flexibility, creativity, and better working relationships among partners, airlines, tenants, and staff. Shared experiences build better teamwork that can be carried into future initiatives.

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Phoenix Sky Harbor International Airport

Introduction

Phoenix Sky Harbor International Airport is one of the ten busiest airports in the nation, processing on average 1,200 airline operations per day. The airport has three main runways, three terminals, and approximately 3,000 acres of land within its fenceline. Although the airport does not experience a wide variety of significant weather events, Sky Harbor usually endures at least one monsoon season storm, which brings heavy rains, lightning, and sometimes hail. Dust storms, also known as "haboobs," and very high temperatures can also impact airport operations.

This case study explores how these events have previously affected the airport, how the airport responds to them, gaps in the airport's ability to respond to the events, and lessons learned from the airport.

Airport Overview

- IATA Designator Code: PHX
- Location: Phoenix, AZ
- Average 1,200 airline operations per day
- Average 100,000+ daily passengers

Lessons Learned

- Strong relationships and communication with partners and airlines help build capacity during planning, response, and recovery
- Previous impacts and experiences can effectively justify new investments

Weather Stress on Sky Harbor Assets and Operations

The Phoenix area experiences a monsoon season every summer, and Sky Harbor tends to experience at least one monsoon storm that can damage airport infrastructure through heavy winds, rain, and sometimes hail. On September 27, 2014, a thunderstorm caused wind and water damage in two of the airport's terminals. The storm and consequent cleanup process took the airport (up to) 6 hours to return to normal operations.

For Sky Harbor, every storm has unique characteristics in how it impacts the airport. On September 8, 2014, the airport experienced a major thunderstorm that damaged embankments along roads to the airport, which had never been impacted previously. The September 27th thunderstorm blew off roofing in certain places. Sky Harbor has found that operational flexibility is essential for preparation for a wide of variety of potential impacts. Other microbursts have been reported to tip over airplanes and damage hangars.

In addition to thunderstorms, Sky Harbor has experienced other significant weather events. During the hot summer months, aircraft can be grounded when air temperatures reach 120 degrees Fahrenheit in the shade, the threshold above which airframes have not been tested for safety. A final prominent weather stressor is large dust storms, known as haboobs. Phoenix experienced a significant haboob in 2011, which covered the runways with dust, producing significant quantities of fine-grained particulate across the airport. The dust was so fine that it infiltrated the terminals through window margins. The particulates have a similar profile to smoke from burning material and this triggered terminal fire alarms. As a precaution, the airport shuts off all fire alarms and places staff in strategic locations to provide active

Notable Weather Events/Stressors

- Thunderstorms
- Hail
- Heat waves
- Heavy rain
- Dust storms/haboobs

Impacts to Operations and Infrastructure

- Reduced flight traffic
- Extensive cleanup in facilities and runway
- Damaged roofing and terminals
- Damage to aircraft

fire-life safety observations throughout the terminals during such events to ensure that building occupants are safe from fire risks.

Useful Practices

- Using lessons learned to inform new investments and decisions
- Communication with partner organizations to inform preparation and response efforts
- Tabletop exercises with relevant stakeholders

Useful Resources and Practices

Haboob warnings are normally broadcast ahead of time, providing airport operators time to prepare for their effects. These dust storms also happen with enough frequency that Sky Harbor has developed some best practices to minimize damage and cleanup time. In previous haboobs, dust entered the airport buildings through automatic sliding doors. The dust remains airborne and can activate fire alarms sensors as well as enter HVAC systems. Prior to the onset of the storm, Sky Harbor will override automatic doors to keep them shut. Additionally, Phoenix has developed informal partnerships with nearby cities, including Tempe and Mesa, to help each other during these dust storms, and Sky Harbor has therefore been able to borrow vacuums and sweepers to clean up the dust.

A strong working relationship with NWS, airlines, TSA, and other partners has also been a strong component of Sky Harbor's weather preparation and response. Maintaining these relationships through regular meetings and tabletop exercises keeps Sky Harbor's management and their partners aware of each group's service offerings as well as the appropriate people to contact during emergency preparation and response efforts. For example, NWS will call Sky Harbor when significant weather is imminent within the next hour, after which the airport will put out an emergency notification alert that passes relevant information to up to 500 partners and stakeholders. Sky Harbor also incorporates recommendations of realistic weather scenarios from NWS into their tabletop exercises.

Gaps/Challenges in Response

- Lengthy recovery times due to contracting procedures
- Out-of-date technology

Challenges in Response

Recovering from weather events can sometimes take Sky Harbor more time than desired, due to contracting processes. The airport has been working on roofing damaged by the September 27th thunderstorm. For smaller repair projects, the airport has on-call contractors to do job order contracting. While the airport can bring on these contractors fairly quickly, there is a cap on how much can be spent on repair projects. When repair costs reach a certain point, Sky Harbor must bid the project out to contractors, extending the repair time. Facilities staff are very good at returning operations to normal, but major types of construction can be delayed through bidding processes, executing contracts, and other procurement mandates the City of Phoenix Aviation Department must follow as a public entity.

Sky Harbor's management is considering developing a new emergency operations center (EOC) in the coming years. The new EOC would bring new technology to replace its more outdated services. For example, the airport's weather forecasting technology, such as its lightning detection system, is old and can sometime be challenging to use. Currently, the airport prevents this gap from being a problem by maintaining its strong relationship with NWS. In the future, it hopes to replace its outdated technology at the EOC—and elsewhere at the airport—with new and improved resources.

Lessons Learned

Sky Harbor's awareness of costs and recovery times has prompted its planning and response programs. Impacts from previous events have motivated the airport to consider new technologies

and practices that improve upon existing ones. As the airport considers building a new EOC, it reflects on its past significant weather experiences and the planning, forecasting, and infrastructural investments it can make to bolster its operations from significant weather.

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Seattle–Tacoma International Airport

Introduction

Seattle–Tacoma International Airport, or Sea-Tac, is the 15th busiest airport in the United States, handling more than 34.7 million passengers in 2013. Operated by the Port of Seattle, the airport serves 29 airlines providing domestic and international flights. Seattle experiences thunderstorms and lightning, fog, heavy rain, high winds, snow, and ice. Because the frequency of these events varies, Sea-Tac has responded to events in varied ways. For example, rain and fog occur at the airport frequently and therefore plans to address these events are more practiced. Ice, however, occurs less frequently and has challenged the airport's weather response and ability to maintain operations. This case study discusses impacts from an ice event in January 2012 and Sea-Tac's impacts and lessons learned from the weather event.

Airport Overview

- IATA Designator Code: SEA
- Location: Seattle, WA
- 34.7 million passengers in 2013

Lessons Learned

- Assigning newest, most efficient equipment to prioritized runways helps maintain those areas
- Ice that falls on a layer of snow is easier to clear than ice that bonds directly to pavement
- Communication systems that connect to all related groups helps ensure that the right information is getting to the right people

Vulnerabilities to Ice Storms

In January 2012, Seattle experienced a snow and unforecasted ice event. Although Sea-Tac could manage the snow, 12 hours of freezing rain that followed forced the closure of its three runways, preventing flights from coming in or out of the airport for 4 hours. Because Sea-Tac could not address the continuous freezing rain, it was at a standstill. Aircraft also could not operate because they too were covered in ice. Sixteen skylights in the airport's main terminal building were broken due to ice falling from the top of the building. One skylight had to be replaced from inside the building.

Notable Weather Events/Stressors

- Ice
- Snow
- Fog
- Heavy winds
- Thunderstorms and lightning

Impacts to Operations and Infrastructure

- Runway closure
- Broken windows
- Repair costs

Useful Resources

Following the ice event, Sea-Tac began to restore operations. Removing ice was one of the first steps. Fortunately, by the time the freezing rain began, Sea-Tac had closed its west runway and let snow build up on it, with the benefit that ice formed on top of a snow surface as opposed to bonding directly to the pavement. This enabled Sea-Tac to mitigate ice accumulation on top of the snow covering the runway more efficiently. On the remaining two operating runways, the airport continued to apply deicing chemicals and plow runways and taxiways until there was acceptable friction. A contractor handled plowing selected taxiways, with special attention given to in-pavement lighting that could be damaged by the metal plows. All airlines deiced aircraft at

Useful Practices

- Allowing snow to build up on an auxiliary runway before an ice storm
- Assigning the newest, most efficient equipment to the highest priority runways
- Proactive use of deicing chemicals
- Communication systems
- Weather alert system to determine staffing levels

their gates, as Sea-Tac does not have deicing pads. Replacing the broken glass at the terminal took approximately 4 months. As a temporary measure, Sea-Tac used plywood to cover the fractured windows. Snow/ice guards were also installed on the building ledges to prevent large sheets of ice and snow from falling off the building onto the skylights.

The experience gained in the 2012 event will facilitate more effective strategies to mitigate surface conditions. Staff will pretreat surfaces as much as possible, applying solid chemical first, then liquid and sand if needed. Using surface sensors to monitor falling pavement temperatures, visual inspections, and traffic flow, staff can determine the optimal time to apply the deicing chemicals. When the forecast warrants, Sea-Tac uses a two-team approach, with the newest and most efficient equipment assigned to the "East" team for the two easternmost runways. The "West" team concentrates on the westernmost runway. If equipment on the East team malfunctions or there are significant accumulations of snow and/or ice, Sea-Tac may choose to close the west runway and send all equipment to the eastern runways and taxiways.

Because a snow event preceded the ice event, communication lines were already set up to handle winter weather. Staff had a texting/paging system on their phones, as well as an email system and the online PASSUR OPSnet collaborative decision-making tool. PASSUR OPSnet, which Sea-Tac uses daily, facilitated over 200 communications with the airlines to discuss the condition of the airport and aircraft. The webpage showed NOTAMS, snow advisory alerts, and other useful information. Although there is an automatic email alert whenever an update is made on OPSnet, tenants are encouraged to keep the OPSnet display page open on their computers for quick reference to changing conditions.

Sea-Tac follows a snow alert rating system that determines appropriate staffing levels for certain amounts of precipitation. The airport issues a Snow Watch when the snow level is below 1000 feet, a Modified Snow Alert when up to 3 inches of snow or ¼ inch of freezing rain is anticipated, and a Snow Alert when more than 3 inches of snow and/or ¼ inch of freezing rain are anticipated. If a particular status is activated, corresponding steps are taken. Prior to the onset of ice, Sea-Tac was under a Snow Alert status, their highest level. Staffing was handled by employees doing 12-hour rotations, and hotels were provided near the airport. All staff arrived at work with the appropriate clothing to handle the icy conditions.

Challenges to Prepare for Ice

Forecasting snow and ice is a challenge. Traditionally, snow and ice events in Western Washington are generated from warm moist air from the southwest (Pacific Ocean) colliding with cold air from the north (Frasier River Valley). The convergence of the two air masses determines the location, accumulation, and type of precipitation, referred to as the convergence zone. Forecasting services are supported by NWS as well as a paid service, WeatherSentry. Sea-Tac remains in close contact with these services year round for inclement weather events and especially when there is potential for snow and ice. Due to the unique atmospheric conditions, the 2012 ice storm was difficult to predict and the weather services were not able to provide much advance warning.

Lessons Learned

Sea-Tac's experience with the January 2012 ice storm demonstrates that less common events—and particularly unexpected events—can have greater impact on an airport, as airport staff, airlines, and partners, in addition to airport design, are less accustomed to handling such events. The airport will continue to incorporate these lessons learned on an ongoing basis.

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Ted Stevens Anchorage International Airport

Introduction

Ted Stevens Anchorage International Airport is a 4,612-acre complex with three runways and the world's largest floatplane base, the Lake Hood Seaplane Base. The airport operates 24 hours per day and serves as an important geographical point for passenger and cargo aircraft traveling to and from the Pacific. It therefore relies on its operations and maintenance staff to ensure that airside and landside operations run smoothly.

Anchorage experiences some significant weather events that pose notable risk to these operations, including volcanic eruptions, heavy winds, and snowstorms. This case study explores these events and lessons learned from Anchorage's approaches in planning for, responding to, and recovering from them.

Airport Overview

- IATA Designator Code: ANC
- Location: Anchorage, AK
- Nearly 5,000,000 passengers served in 2012
- One of top five airports in the world for cargo throughput
- World's largest floatplane base

Lessons Learned

- Strong relationships and communication with partners and airlines help build capacity during planning, response, and recovery
- Previous impacts and experiences inform new approaches and resources to be used in response
- Methods to secure and protect equipment from wind can leave them exposed to other impacts

Past Weather Events

Volcanic Eruptions

In March 2009, Mount Redoubt Volcano, nearly 100 miles southwest of Anchorage, erupted, causing ash to fall near the airport and shut it down for about 18 hours. Though the ash reduced visibility at the airport, its primary impact on the airport was the cleanup it required from the airport afterwards. Fortunately for the airport, snow was already on the ground as the ash fell. Maintenance staff could therefore blow snow back onto the runways and then remove the snow-ash mix from the runway, reducing cleanup time.

Wind

In 2003, Anchorage experienced unexpected high winds over the course of 5 hours with gusts reaching up to 100 mph. Aside from some minor damage to perimeter facilities and removed roofing in its south terminal, the biggest impact to the airport was cargo containers and other debris blown across the airfield. In its GA facility, up to 20 aircraft were damaged. Those that were not tied down were overturned, and those that were tied down were essentially flying in place until their wings butterflied to the point of snapping off. Anchorage was given short notice of the strong winds, and the forecast given was less severe than what actually occurred. Roofing has since been repaired to original specifications.

Snow

In 2002, Anchorage received 27 inches of snow in 24 hours. Although the airport managed to stay open throughout the storm, the airport experienced

Notable Weather Events/Stressors

- Snow
- Volcanic eruptions
- Strong winds

Impacts to Operations and Infrastructure

- Damage to aircraft
- Extensive cleanup of paved surfaces
- Grounded flights (volcanic eruptions)

some inefficiency. Although aircraft could continue to land at the airport, fewer were departing, causing saturation in the terminal. Anchorage had to close down one of its runways to make space for parking planes. Following the event, operations and maintenance employees were able to clear the snow from airside and landside properties within 24 hours.

Useful Practices

- Scaling back operations to maintain priority functions
- Reviewing resources to handle excess dust and other irregular conditions
- Incorporating lessons learned from experience
- Comprehensive communication systems

Responding to Events

In general, Anchorage approaches most weather events with the intent to prioritize the continuation of operations without putting significant stress on its employees. Because the airport provides such a critical function for aircraft needing to land in the Pacific Northwest, Anchorage tries to stay open through the duration of an event. Therefore, operations staff will determine their priorities, scale back the operations they maintain, and try to reduce the amount of impact during periods of highest operations.

Learning from past events has greatly informed weather response protocols. If Anchorage has an improved understanding of what needs to be done to minimize impacts, it will act to ensure staff have sufficient working equipment and clear protocols to follow in order to collect and remove any ash that falls in a volcanic event. The airport now has ash kits to clean computers and other electronic equipment and has added air filters to airfield lighting generators, airport vehicles, and building HVAC and generator systems in order to maintain operation. Anchorage has access to FAA checklists on how to handle volcano eruption, although these only outline generic activities to be undertaken instead of Anchorage-specific information.

During the wind event, Anchorage staff believed that they did what was possible to prepare and react. GA aircraft left outside were secured to the ground, even though the airport was given little advance notice of the incoming strong winds. Although those GA aircraft were left outside and exposed to the wind, the GA community in Anchorage, mostly private pilots, often cannot afford hangar space. Additionally, half of the GA aircraft are sea planes, whose owners prefer to keep them closer to the shore, rather than in hangars on the other side of the airport.

Snow, on the other hand, is a much more common event, occurring frequently throughout 6 months of the year. As a result, one of Anchorage's most useful assets in responding to snow events is its vast experience with handling snow. Through routine snow maintenance work, airport employees have established a proven procedure for handling nearly any intensity of snowfall. In anticipation of events, the airport keeps a callout roster and preference list for employees to migrate their normal 8-hour shift to a 12-hour shift by staying after their normal shift or coming into work before their normal shift. Snow events are controlled through their snow and ice control plans—Anchorage does not have an extra set of plans for a severe event. Regardless of the intensity of the storm, they tackle it through the same procedures.

Forecasting

The NWS office is one block from the airport and a phone call away, providing highly accessible personal access to NWS's resources. Furthermore, Anchorage's foreman and operations leads can access NWS's website and data on their mobile devices from anywhere in the airport in order to track ash clouds, snowstorms, or any other event. The airport uses the Vaisala monitoring system to monitor pavement temperatures and conditions.

During weather events, the airport staff use all resources readily available to them, including NWS and free weather forecasting websites. Anchorage has used commercial forecasting products, but staff have the same level of confidence in publicly available services. Although Anchorage reviews maintenance procedures during events to measure their effectiveness, staff have not done the same for weather forecasting, largely because they have not determined an effective way to track this.

Communications

During the volcanic eruption, Anchorage did not have any comprehensive communications system set up. Airport operators mostly made phone calls back and forth with partners and participated in daily conference calls with FAA traffic controllers and weather centers. The airport also received updates each morning on the volcano's activity. Additionally, airlines have been very useful resources for various types of weather events, given that they closely track significant weather events in relation to their operations. If Anchorage stays in communication with the airlines, staff have a better understanding of surrounding weather conditions as well as their own.

Similar to other airports, a significant challenge for Anchorage is effectively communicating conditions, protocols, and needs to stakeholders and partners. Through exercises, pre-season snow meetings, and monthly user meetings, Anchorage works to explain how they operate to partners. Their airport communications center has been maintaining and testing an electronic notification system, which allows staff to customize any message they want to send to airport, police, fire station, and other representatives. The system, which can connect to desk phones, cell phones, email addresses, and other modes of communication, has proven to work well and plans are in place to build it up.

Toolkit Suggestions

Anchorage staff think that they are doing all they can from a personnel standpoint to prepare for, respond to, and recover from significant weather events. Operations staff know their roles and responsibilities in an emergency. The airport uses past experience to inform additional resources to bolster the resiliency of its infrastructure. Anchorage did note however that it would be useful to be able to compare forecasted weather with actual weather and create a record log to understand past events and how they actually turned out.

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Toronto Pearson International Airport

Introduction

Toronto Pearson International Airport is Canada's busiest airport, processing over 45% of Canada's air cargo and handling more than 400,000 flights and 36 million passengers annually. Toronto Pearson is managed by the Greater Toronto Airports Authority (GTAA). This case study explores the impacts of and lessons learned from extremely cold and icy conditions that

Airport Overview

- IATA Designator Code: YYZ
- Location: Toronto, Canada
- More than 400,000 flights handled annually
- About 36 million passengers per year

Lessons Learned

- Check with ground crews and other partners well before weather events to ensure all are prepared
- Find efficient ways to clearly communicate with passengers, tenants, and the media

Notable Weather Events/Stressors

- Snow
- Ice
- Heavy precipitation and flooding
- Thunderstorms
- High winds

hit Toronto and much of the U.S. and Canada in early 2014, which created major delays and closure of the airport.

"Deep Freeze" Impacts on Toronto Pearson

Between January 5 and 9, 2014, Toronto Pearson International Airport experienced a combination of rain, snow, snowsqualls, and wind chills combined with low temperatures as low as −39°C. The combination of weather stressors severely disrupted the airport's operations, closing the airport for up to 8 hours and diverting numerous flights. The resulting conditions created significant challenges for maintaining ground conditions, managing flight traffic, and communicating with passengers and tenants.

Whenever Toronto Pearson experiences a problem, such as a major disruption caused by weather, it receives a great deal of attention from the media. Reporters, interested in the resiliency of the airport, travel there to talk to any airport employee available. With 1,200 GTAA employees and over 40,000 employees in the airport community, it is challenging for the airport to control its message to the media. The heightened volume of incoming requests to talk in addition to managing other aspects of the emergency response can overwhelm staff.

Additionally, the airport's capacity to communicate with passengers and tenants was limited, as GTAA's website was not configured to provide timely updates on the status of the airport during irregular operations. For example, although some flights were cancelled around 6:00 AM, notifications of the cancellations were not able to be released through the website until noon that day.

For most weather events, Toronto Pearson can manage them when they have planned ahead for them to happen. But, when impacts from the deep freeze began to be felt late at night, workers were caught off guard and problems arose more quickly. Before the storm, Toronto Pearson's hub carrier diverted 20 unplanned arrivals to the airport from Montreal and Ottawa, which eventually led to more arriving aircraft than the airport had gates to accommodate. As flights began to be cancelled, arriving flights outnumbered departing flights, and there was no space for them at the gates. In response, GTAA and airlines decided to deplane the backlog of aircraft as quickly as possible. This led to the deterioration of aprons and gate areas, which consequently increased the amount of time it took for aircraft to move out of the gates and make room for arriving aircraft. To hurry the process of deplaning aircraft, planes would not empty their cargo as passengers exited, causing a faster deplaning rate but major delays in baggage delivery to passengers.

Ground handling, which is outsourced by most airlines at GTAA, was not prepared for the deep cold or the overcrowded aprons and gates. Staff did not have the right coats, gloves, and other equipment to handle the frigid temperatures. In addition, getting additional workers to work in such extreme cold proved to be a challenge. Employees and tenants called in sick to avoid working in sub-freezing temperatures, and many people were working second shifts for other companies in the airport, making them unavailable to provide overtime support.

Lessons Learned

GTAA has used the "Deep Freeze" as a serious learning experience. The authority published a report that assessed Toronto Pearson's response to the event and made recommendations on improving services to its customers (GTAA 2014). Emergency response is also becoming more planning-oriented than reactionary, with GTAA and Toronto Pearson planning with business partners for potential events 1 to 2 weeks, rather than 1 or 2 days, before. Although staff originally assumed business partners were ready, staff now make sure everyone, including contracted ground handlers, is ready. Ground crew inspectors will meet their crews and will notify GTAA that they have their equipment and gear ready for winter operations. Senior members of GTAA's staff will meet with senior staff from the ground handler teams to ensure that all levels of leadership are ready for the season's weather.

GTAA has taken steps to avoid interruptions in communications during future emergencies. The "Deep Freeze" experience motivated airport management to change the protocol for interacting with the media so that information from emergency operations centers is communicated to the front lines and to the media. In addition to public communication through social media and press releases, GTAA is working on a communications application for Toronto airports that passengers can download to their phones to check the status of the airport and their flights. The application is now available for Android and Apple phones and will soon be available for Blackberry phones. GTAA also is working to put server backup systems onto the cloud to avoid the loss of server-based applications in the future. Finally, staff are planning on an investment for a new airportwide public announcement system to spread messages more effectively to airport employees, tenants, and passengers.

Toolkit Suggestions

Based on its experience, GTAA had several suggested features for the AWARE Toolkit. First, it would be helpful to have information to communicate with partners on what defines "significant weather." When each element understands the common definition, communicating impacts becomes easier.

Additionally, understanding the airport's role in the community during significant weather events would provide value to the toolkit. During larger disaster events, airports often can play a critical role in helping communities recover. Disaster planning that integrates the airport beyond the airport-municipality connection can strengthen the surrounding area's resiliency to weather events.

Toolkit Suggestions

- Provide common definitions for partners and stakeholders
- Include methods for integrating the airport into the community
- Communicate opportunity costs

Finally, including the costs of not being prepared for infrastructure or operational failures would provide value to airport authorities. When decisionmakers are concerned with the financial state of an operation, knowing the opportunity cost of resiliency efforts can help communicate the value such efforts have to the airport's long-term goals.

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