

System Resiliency



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Access  **Ohio**
2045

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Executive Summary

Advances in forecasting methods and technology have improved the prediction of “extreme” weather events and preparation for major geological events. Yet the frequency and severity of such events continues to be hard to predict and restoring the safety and reliability of the transportation systems is a resource-intensive and time-consuming exercise. Floods or rockslides can endanger motorists, inflict substantial damage to infrastructure, disrupt commerce and mobility, and uproot households and communities. Weather-related impacts to maintenance, mobility, and life-cycle costs are becoming higher priorities for agencies but require a corresponding increase in internal and external coordination. In this context, agency responsiveness and agility are central to the success of long-term asset preservation.

The Federal Highway Administration (FHWA) defines resiliency as the ability to prepare for changing conditions and withstand, respond to, and recover rapidly from disruptions. As a concept, resiliency has applications in several realms and disciplines at ODOT. However, this paper’s focus is the physical resilience of infrastructure in the face of extreme weather and environmental conditions. As a framework for planning, resiliency is a way for the Ohio Department of Transportation (ODOT) and its partners to ready itself for the uncertain impacts weather-related events will have on its transportation system.

WHY RESILIENCY?

Resilience is an important goal for long-range planning for many reasons:

- Weather-related events inflict costly impacts, whether in terms of maintenance, mobility, or increased life-cycle replacement costs.
- The viability and reliability of state infrastructure is a key factor for economic development.
- Recent federal policies require resilience as a planning factor.
- Resiliency affects every element of a transportation system, including planning, capital investments, operations, maintenance, and asset management.

These wide-reaching implications and applications support an increasing role for resiliency in Ohio’s long-range transportation plan.

WHERE ARE WE NOW?

As evidenced through recent planning documents, ODOT has already taken significant steps to integrate resiliency as a factor within existing asset management strategies. This proactive response lays a foundation for longer-term preparedness planning. Such actions and ongoing analyses can help the agency explore several near- and long-term challenges and strategies, including:

- Increasing severity and frequency of intense weather events such as flooding, droughts, fires, or other natural disasters.
- Building on lessons learned from short-term disaster preparedness exercises.
- Assessing asset-level vulnerability to understand where the greatest risks lie.
- Evolving new performance measures surrounding resiliency planning.

WHERE ARE WE HEADED?

This paper offers insights for how ODOT can consider resiliency within Access Ohio 2045 (AO45). The challenges created by extreme weather or natural disasters offer opportunities to embrace longer term planning practices and introduce adaptive approaches. Fostering these approaches can advance ODOT's mission to provide a safe, reliable transportation system. These opportunities include:

- *Enhanced Coordination*: improved data collection and management practices will continue to inform ODOT's planning around resiliency. Understanding how and where this system is most vulnerable will allow ODOT to identify strategies for response.
- *Enhanced Systems Based Planning*: systemwide, district-level data collection also enables ODOT to move from an asset-level approach to systems-level analysis.
- *Enhanced Applicability of Data*: these impacts can highlight new design standards for threatened asset types, and have broader applications for informing economic development strategies.

Introduction

AO45 CONTEXT

The Ohio Department of Transportation (ODOT) is developing the long-range transportation plan Access Ohio 2045 (AO45). AO45 will build on ODOT's long established foundation of strategic transportation investments that support broader state economic, societal, and environmental goals. AO45 is an opportunity to further ODOT's reputation as a national leader, to prepare for current and future challenges, and to position the state for continued prosperity.

AO45 will provide ODOT with a strategic blueprint to manage the changes facing the transportation system, a reference point to align ODOT's ongoing policies, plans, and programs. The blueprint involves the support of partners and builds a strategy fueled by data driven, performance-based decisions.

This white paper helps "set the stage" for AO45 by exploring system resiliency in Ohio. The information and findings developed in this white paper can help ODOT integrate resiliency as a strategic consideration in AO45 development.

Defining Resiliency

Today's transportation infrastructure faces an uncertain future. As weather becomes less predictable from season to season, state DOTs confront the challenge of preparing for unknown impacts. Intense weather is increasing in frequency and duration, prompting ODOT to consider how these changes may affect Ohio's transportation system. Weather-related events may affect a variety of critical transportation system facilities, connections, and assets. For example, increased flooding could affect port operations, impact bridge and culvert integrity, and disrupt interstate mobility for prolonged periods due to standing water or rockslides. Given these potential consequences, ODOT has already begun to prepare for risks. AO45 offers an opportunity to review those ongoing strategies and explore other system-based ways to incorporate resiliency into the long-range planning process.

According to Federal Highway Administration (FHWA) definition, resiliency offers a planning framework to "prepare for changing conditions and withstand, respond to, and recover rapidly from disruptions."¹ Definitions and applications of resiliency vary widely, but ODOT's focus, and the focus of this paper, is preparation for extreme weather events through proactive planning and adaptive practices. Facing an ever-changing forecast, resiliency emphasizes adaptiveness to withstand intense weather and natural disasters. Through current planning initiatives, ODOT is making strides in this direction. This paper highlights and reviews ODOT's previous and ongoing efforts on system resiliency, then connects this work to potential future directions.

Four major themes define the role of resiliency as Ohio plans the future of its transportation system:

- 1. Intensifying weather, increasing costs** - weather-related impacts may increase ODOT's maintenance and capital spending in response to events. Adaptive strategies can provide a proactive, cost-efficient approach.

¹ <https://ops.fhwa.dot.gov/publications/fhwahop15024/index.htm>

2. **Ohio is *already* well-positioned** - Ohio's inland location protects the state from coastal weather, such as hurricanes, and more intense temperature gains experienced in the southern United States. Building on the well-known geographic advantages of Ohio's freight network, a reputation for resiliency may frame Ohio as an attractive state for long-term investments.
3. **Federal requirements as an opportunity for ODOT** - the FAST Act now requires states to consider resiliency as a planning factor. These requirements are an opportunity to consider resiliency-related strategies as part of long-range transportation plans.
4. **An adaptive, agile approach to preservation:** the life-cycle of transportation assets may be determined by sustainable and resilient design standards that shape ODOT's future capital investments. Beyond these designs, however, ODOT's responsiveness to weather events may be central to systemwide preservation. Adaptive capacity may define the long-term resiliency of the state's transportation network, as well as associated impacts for mobility and economic competitiveness.

These four themes are woven throughout this paper, which begins with a brief literature review describing Ohio's climate forecasts, as well as approaches adopted by other state DOTs in planning for these patterns and events. After describing ODOT's efforts in further detail, the paper concludes with a discussion of future directions Ohio can explore to improve the resiliency of its transportation system.

Applications of Resiliency in Planning

Resiliency is increasingly used to guide preparedness planning across a variety of sectors at national, state, and local levels. Economists employ the term to absorb the shocks of downturns. Disaster recovery teams prepare to deploy aid for storms or conflicts occurring on scales previously unwitnessed. Some larger municipalities are establishing dedicated staff (such as Chief Resilience Officer) to coordinate cross agency responsiveness.

In transportation planning, the turn towards resiliency has prompted several state DOTs to adopt asset-level analysis and system-wide approaches to prepare for weather-, disaster-, and climate-related impacts. While asset-level analysis considers how these events may affect specific types of transportation infrastructure, the system-wide approach asks how DOTs can anticipate the cumulative impacts of these changes across states and regions. These approaches are relatively recent at the state level, gaining traction over the last decade.

To date, ODOT's work has primarily focused on asset-level analysis, most notably through 2016's Infrastructure Resiliency Plan & Statewide Climate Variability Study. Ohio's work in this realm matches several peer DOTs currently pioneering applications of resiliency in transportation planning, such as Washington, Michigan, Iowa, Massachusetts, and Colorado. For example, Washington State DOT (WSDOT) completed its first vulnerability assessment in 2011.² This early example allowed WSDOT to identify vulnerable facilities, evaluate and rank risks, and begin exploring strategies to reduce those risks.

More recently, planning authorities are beginning to understand that disasters and intense weather are blind to jurisdictional boundaries and, in turn, are approaching resiliency through broader, systems-level applications. 2017's Post Hurricane Sandy Transportation Resilience Study in NY, NJ, and CT provides an

² <http://www.wsdot.wa.gov/NR/rdonlyres/B290651B-24FD-40EC-BEC3-EE5097ED0618/0/WSDOTClimateImpactsVulnerabilityAssessmentforFHWAFinal.pdf>

example of this approach. As a partnership between the FHWA; the New York, New Jersey, and Connecticut DOTs; the Federal Transit Administration (FTA); the Port Authority of New York & New Jersey; the New York Metropolitan Transportation Authority; and four metropolitan planning organizations, this study identified feasible agency-wide strategies to reduce and manage intense weather vulnerabilities, including an analysis of recent storm damage, facility-level vulnerability assessments, and an evaluation of potential adaptation strategies.³ These strategies, especially considered across multiple agencies and jurisdictions, represent best practice examples of resiliency planning in transportation.

Similarly, ODOT's asset-level assessment and vulnerability efforts could lay the groundwork for further systems and long-range planning applications. For example, ODOT could evaluate the mobility costs and safety implications of detours and redundancy options at network or corridor levels (travel time delay, safety risks/exposure, capacity constraints, fuel costs, etc.) to inform adaptive strategies. The following sections identify opportunities already embedded in current plans and initiatives and explore linkages to strengthen system planning as part of AO45 development.

³ <https://www.nymtc.org/LinkClick.aspx?fileticket=gDowaOsCwqU%3D&portalid=0>

Where Are We Now?

CURRENT POLICIES, PLANS, AND PRACTICE

Resiliency provides an adaptive framework for state-level transportation agencies to respond to changing, evolving conditions and risks. Facing this heightened volatility, the benefits of resiliency planning are all the more apparent, and range from short-term cost-savings to long-term sustainability. Recent federal legislation and policy require resiliency in state and metropolitan long-range transportation plans (LRTP). 2016's FAST Act focuses on a "performance-driven, outcome-based approach to planning," which includes resilience as a planning factor for statewide and metropolitan plans. Moreover, the FAST Act mandates that statewide and metropolitan planning address "the resiliency and reliability of the transportation system."

For ODOT, this shift towards resilience directly manifests in two core planning documents: Access Ohio 2045 (the state's LRTP) and the Transportation Asset Management Plan (TAMP). States must publish a risk-based TAMP to describe, "how the highway network system will achieve a desired level of condition and performance while managing the risks...at a minimum practicable cost over the life cycle of its assets."⁴ While statutory, these requirements are an opportunity to move resiliency towards the center of ODOT's strategic priorities, placing a greater emphasis on the long-term performance and adaptability of Ohio's transportation system. ODOT's 2016 TAMP began to work from this framework, enabling the agency to "better manage and mitigate the risks associated with unexpected events such as flooding or unusual price fluctuations...and identify investment strategies that will reduce the likelihood that the event will occur or reduce the impact if it does take place."⁵ Additionally, ODOT's 2017 TAMP specifically cites flooding as an "extraordinary weather event" in its discussion of risks and asset management.⁶

With ongoing responses to these mandates, national and state best practices are emerging to guide planning. On a federal level, a 2014 Federal Highway Administration Order, FHWA Order 5520, establishes the agency's policy on preparedness and resilience to extreme weather events.⁷ This directive calls for risk identification to current and planned transportation systems, and integration of weather impacts into FHWA planning, operations, policies, and programs.

At the state level, one of the greatest challenges is devising broadly applicable strategies from short-term events, pilots, or disasters. For example, interviews with ODOT's Emergency Operations section demonstrate how "exercise" training activities may eventually become standardized practice.⁸ While risk and emergency management practices are a longstanding role for state DOTs, the advent of resiliency-based planning asks states how the everyday possibilities of "disasters" or "emergencies" influence long-term decision-making.

⁴ <https://www.law.cornell.edu/cfr/text/23/515.5>

⁵ https://www.dot.state.oh.us/districts/D07/Documents/2016_MAASTO_PRESENTATION/ODOT%20Revised%20TAMP%20May%202016.pdf

⁶ <https://www.dot.state.oh.us/AssetManagement/Documents/TAMP%208.30.17.pdf>

⁷ <https://www.fhwa.dot.gov/legisregs/directives/orders/5520.cfm#par7>

⁸ Phone Interview with Leslie Bricker, ODOT Emergency Operations. 28 March 2018.

In response, state DOTs, including ODOT, are beginning to consider weather-related impacts on particular types of assets. Vulnerability assessments provide an analysis of where weather events will most greatly impact identified asset classes. The analysis underscoring these assessments considers factors, such as sensitivity and adaptive capacity, to rate their overall vulnerability. Ohio has used the FHWA Vulnerability Assessment Screening Tool (VAST) to evaluate its most-threatened assets, discussed in further detail later in this paper. DOTs in Michigan, Iowa, Alaska, Connecticut, Maine, New York, and Massachusetts have also utilized VAST to understand and rate the vulnerability of individual assets and asset classes based on regional weather forecasts.

Elsewhere, states are also beginning to consider how lessons learned from disaster recovery can inform strategies towards long-term climate resilience. For example, the New York State Department of Transportation (NYSDOT) is leading the shift from asset-level analysis to system-wide operations and planning. In 2011, NYSDOT began focusing on moving adaptation strategies into operations, replacement and rehabilitation cycles, and design specifications.⁹ More recently, 2017's aforementioned Post Hurricane Sandy Transportation Resilience Study in NY, NJ, and CT leverages lessons learned, as well as future projections, to offer regional recommendations for long-term adaptation and resilience.

Still, many agencies face a gap between literature and practice. A la carte considerations of individual assets or programs may be too piecemeal an approach, yet sweeping systems-level recommendations remain difficult to fully implement. As ODOT continues to evolve its risk-based asset management practices, its next step could be to bridge these isolated efforts into a cohesive, systemwide strategy.

SIGNIFICANCE OF RESILIENCE PLANNING

In sum, the role of resiliency in planning is established and expanding. As we become accustomed to the unpredictability of major weather events, abnormal is the “new normal.” Weather-related impacts to maintenance, mobility, and life-cycle costs may become higher priorities for transportation system planning. In this context, agency responsiveness and agility are central to the success of long-term asset preservation.

Resiliency affects every element of a transportation system, including planning, capital investments, operations, maintenance, and asset management. Cross-agency coordination between key ODOT Divisions and Offices such as Statewide Planning, Program Management, Asset Inventory, Technical Services, Emergency Transportation Operations, and Districts is critical for ODOT's execution of resiliency goals. For example, during existing rehabilitation and replacement cycles, capital projects planning can consider data trends for vulnerable assets. Additionally, ongoing data collection can further performance measurement, such as using operations data monitoring to observe resiliency factors.

TRENDS AND LITERATURE REVIEW

As weather intensifies, one of the foundational aspects of resiliency planning is understanding how Ohio's transportation system may absorb these impacts. This section offers an overview of recent literature on trends, highlighting the greatest impacts to ODOT and economic development in Ohio.

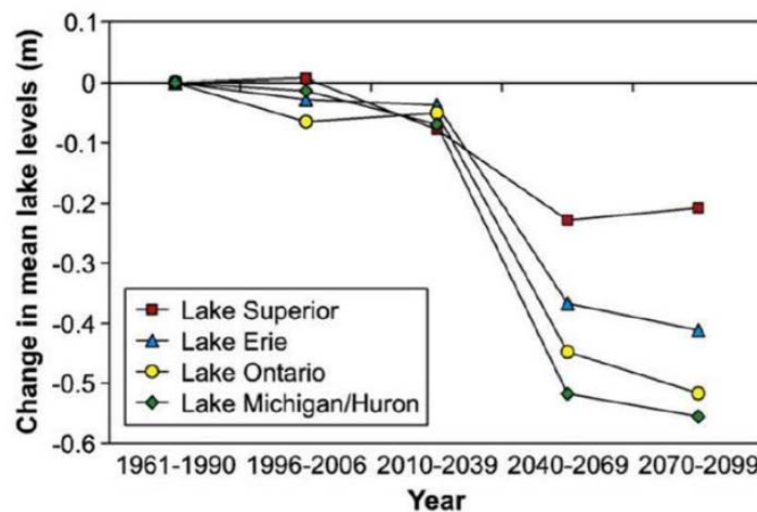
⁹ https://www.dot.ny.gov/divisions/engineering/technical-services/trans-r-and-d-repository/C-08-09_synthesisfinalReport1.pdf

Fundamentally, intense weather events are occurring more frequently, increasing the need to study and anticipate these patterns and impacts. Looking at the trends of extreme weather events over time, Ohio shows an increase in recent decades. According to the Federal Emergency Management Agency (FEMA) declared disasters reports, Ohio has experienced 54 Emergency Declarations since 1956, when reporting began.¹⁰

Weather impacts vary widely, affecting a broad swath of factors ranging from air quality to soil stability. Some of the most palpable impacts are seen in storm intensity. “Heavy” rainfall events (in which more than 1 inch of rain falls over 24 hours) are increasing, while “non-heavy” events (where less than 0.1 inch falls over 24 hours) have decreased, leading to increased droughts.¹¹

These strong storms cause sporadic flooding in Ohio’s lakes and river floodplains, as well as increased incidence of potholes, washed out culverts, and bridge damage.¹² Simultaneously, lake levels are also dropping and forecasted to drop further, impacting shipping and ports at Ohio’s bodies of water, such as Lake Erie and the Ohio River. According to 2016 water level forecasts from the National Oceanic and Atmospheric Administration’s Great Lakes Environmental Research Laboratory, by 2040, Lake Erie may drop more than one foot, and remain at that level or below beyond 2100.¹³ As seen in *Figure 1*, these trends are consistent across all the Great Lakes.¹⁴

FIGURE 1: FORECASTED GREAT LAKE LEVELS



Economic impacts due to declining lake levels are significant, especially at the ports of Toledo and Cleveland. These storm events could hinder navigability at Ohio’s ports and also require additional maintenance efforts.

¹⁰ Ohio Department of Transportation. (2016). Ohio DOT Infrastructure Resiliency Plan (p. 8). White River Junction, VT: RSG.

¹¹ Phone Interview with Dev Noyogi, Indiana State Climatologist. 7 November 2013. From ODOT Vulnerability Assessment.

¹² www.bioone.org/doi/pdf/10.1016/j.jglr.2010.03.012.

¹³ <http://changingclimate.osu.edu/webinars/ppt/andrew-gronewold.pdf>.

¹⁴ Hayhoe, VanDorn, Croley, Schlegal, Wuebbles (2010). Regional climate change projections for Chicago and the US Great Lakes. J Great Lakes Res 36:7-21.

such as additional harbor dredging, to ensure that these ports continue to be an economic asset for the state of Ohio. To illustrate these costs, dredging the Port of Toledo currently costs \$5 per cubic yard. Dredging the Port of Toledo's #1 slip would cost an estimated \$0.88-\$2.6 million, while dredging the entire Port of Toledo Authorized Federal Harbor Channel would cost an estimated \$90 million.¹⁵

Lakefront and marina access would also be affected, including costly damage to infrastructure like docks and barriers. These effects are already felt across the state. For example, portions of the Ohio River were closed to commercial navigation in 2005 and 2017.¹⁶ If these events occur more frequently, Ohio can expect economic losses within industries reliant upon the health of these waterways.

In addition to declining lake and river levels, the potential for increases in average temperatures, heavy storm events, and frequency and duration of droughts could impact related elements of Ohio's transportation system. *Table 1* lists these potential impacts of these trends.

TABLE 1: MAJOR WEATHER IMPACTS TO OHIO'S TRANSPORTATION SYSTEM

Weather Effect	Potential Impact on Transportation
Increasing average temperatures	- Compromised pavement integrity - Power failures - Sagging bridges and buckling railroads (inadequate clearance) - Disruption in labor schedules (fewer eligible hours for construction work)
Increasing heavy storm events	- Slope erosion and surface runoff - Roadway flooding and rockslides - Increased potholes - Washed out culverts and damaged bridges - Overcapacity of stormwater systems - Inability of clay soils (especially SE Ohio) to absorb heavy precipitation and roadway slips
Increasing frequency and duration of droughts	- Reduced soil permeability - Increased surface runoff/higher maintenance costs - Impairment of wetland mitigation areas and other natural resources

¹⁵ "Port Asset Values and Economic Impacts" July-September, 2010 issue of Great Lakes Seaway Review. Authors: Dale Bergeron (University of Minnesota) and Gene Clark (University of Wisconsin).
<http://changingclimate.osu.edu/assets/pubs/sr-port-asset-2010.pdf>

¹⁶ <https://www.nytimes.com/2005/08/15/us/drought-threatens-crops-and-shuts-river-in-midwest.html>;
<https://www.reuters.com/article/us-usa-barges-closure/ohio-river-closed-to-shipping-after-lock-failure-industry-group-idUSKCN1C72B3>

Other natural disasters can have direct and indirect economic impacts on the state. For example, February 2018's rockslides were a major safety risk, prompting ODOT recovery efforts, but also impacted travel time reliability and interstate commerce flows. These effects are especially pronounced in Southeastern Ohio, where limited redundancy in the roadway network increases the impacts of closures. The costs of responding to these storms, droughts, floods, and other weather-related phenomena will continue to grow. Globally, natural disasters (including weather, health and seismic events) caused \$1.7 trillion globally in damages between 2000 and 2012.¹⁷ States and regions are also beginning to calculate, and even forecast, economic losses due to natural disasters and other extreme weather. For example, the Oregon Department of Transportation notes that \$22.3 million was spent on landslide repairs for a coastal highway from 1995-2000.¹⁸ On a regional level, Florida's Hillsborough Metropolitan Planning Organization's 2040 LRTP included a vulnerability reduction study, which estimated \$266 million in direct, transportation-related economic losses over the next 20 years without any risk mitigation investments.¹⁹



However, this uptick in weather-related events also presents some opportunities for Ohio. Ohio's central location helps insulate the state from coastal weather impacts, making it a desirable location for industry siting and corporate relocations. Without these threats of sea level rise, hurricanes, or other threats faced by coastal communities, Ohio faces fewer risks, making the state more attractive to new industry or corporate re-locations.

This advantage is particularly true for many technology industry jobs. Technology companies are beginning to seek facilities in lower-risk environments, considering factors like long-term water availability and the likelihood of intense weather.²⁰ In particular, stable environments are key for large server facilities. A 2011 Area Development survey of site selection trends for data centers found, "The best cities for data centers are in the central and southwestern United States due to the lower incidences of natural disasters," and that many companies are shying away from coastal locations due to the likelihood of hurricanes and earthquakes.²¹ Because Ohio is less prone to these types of disasters, the state maintains a geographic advantage for attracting these facilities and associated jobs.

¹⁷ United Nations International Strategy for Disaster Reduction, 2012 <http://www.unisdr.org/we/inform/disaster-statistics>

¹⁸ <https://www.oregon.gov/ODOT/Programs/TDD%20Documents/Climate-Change-Adaptation-Strategy.pdf>

¹⁹ https://www.fhwa.dot.gov/environment/sustainability/resilience/pilots/2013-2015_pilots/florida/final_report/appendix_b/flappxb.pdf

²⁰ <https://www.earthmagazine.org/article/thirsty-business-how-tech-industry-bracing-water-scarce-future>

²¹ <http://www.areadevelopment.com/siteSelection/jan2011/data-center-disaster-recovery39992.shtml>



This climate stability and associated economic growth could also result in population growth, inviting migration from coastal cities and other areas. AO45's Economic Development white paper provides additional insight on these important relationships between location, economic growth, and transportation resiliency.

Ohio's location and natural resources present challenges, but opportunities exist for investment in the resiliency of the state's transportation system. Ohio's well-known geographic advantage for logistics and distribution is a solid foundation; the state is within a one day's drive of more than 60 percent of North America's manufacturing capacity, and within 600 miles of 60 percent of the North American population.²² By continuing to make investments in long-term resiliency, Ohio's embrace of freight-dependent industries may be unmatched by competitor states facing more significant weather-related impacts.

In upcoming decades, many cities and states anticipate population losses due to disruptive weather. Economic development forecasts consider which labor markets may attract the types of corporate relocations associated with this trend. Ohio's central location, diversifying economy and educational institutions are factors in the state's economic resiliency, and this nexus offers opportunities for additional coordination and planning. For example, rural Ohio continues to attract distribution and logistics industries requiring enhanced access, such as the 2017 opening of an automated distribution center, McLane Company, which brought 425 new jobs to Findlay.²³ In eastern Ohio, drilling in the Utica and Marcellus shales creates significant traffic demand, as well as impacts on local road networks. This activity will continue to affect eastern Ohio's roads. According to JobsOhio, four natural gas-fired power plants are under construction for completion by mid-2018, totaling \$4.5 billion of capital investment.²⁴ While a boon for regional economic development, ODOT may need to continue working with energy industry groups to ensure the long-term resiliency of eastern Ohio's transportation network.

²² <http://jobs-ohio.com/media-relations/media-room/strategic-location/>

²³ <http://www.areadevelopment.com/newsItems/12-11-2017/mclane-company-distribution-center-findlay-ohio.shtml>

²⁴ https://jobs-ohio.com/site/assets/files/2335/jobsohio_2016_annual_report.pdf

ODOT Response

To date, the majority of ODOT's resiliency-related work has focused on asset management, rating the vulnerability of assets threatened by intense weather. The following plans summarize recent and ongoing ODOT efforts to implement risk and resiliency-based practices.

OHIO DOT INFRASTRUCTURE RESILIENCY PLAN (2016)

2016's Ohio DOT Infrastructure Resiliency Plan sought to highlight which ODOT facilities face the greatest weather-related risks and impacts. Using an assessment tool described in greater detail below, these assets were identified and ranked by type. This list of threatened assets provided ODOT with the foundation to incorporate this vulnerability analysis into project prioritization. The study also concluded by identifying ODOT's range of adaptation and sustainability options.

This study had three major recommendations:

1. **Improve data collection and expand ongoing weather analytics:** ODOT's ability to build a more resilient transportation network depends on regular collection and review of data. This study's second phase will implement this recommendation and offer analytical insight to ODOT.
2. **Refine modeling and implement with ODOT Districts:** indicators and methods may also need to evolve to account for innovations in research. With updated modeling methods, analyses should be completed at the district level.
3. **Designate oversight for resiliency efforts and improve internal coordination:** with resiliency-related efforts underway across ODOT, a designated specialist is needed to oversee cross-functional coordination, as well as with external stakeholders.

Additionally, this plan highlights flooding as Ohio's greatest threat. An underlying focus of this study was the high risks Ohio faces due to an increasing number of heavy precipitation events. After reviewing the different types of weather which could impact ODOT's transportation system, heavy rains and floods were identified as the most impactful. Flooding could impair core assets across ODOT's system, including highways, bridges, and culverts. This plan concluded by considering how additional data collection could further decipher the potential impacts of heavy precipitation and flooding.

VULNERABILITY ASSESSMENT SCORING TOOL (VAST)

The centerpiece of 2016's resiliency plan is Vulnerability Assessment Scoring Tool (VAST) analysis. VAST is an FHWA tool developed for state DOTs to assess and rank the vulnerability of various assets. Using a range of indicators, VAST evaluates these risks in three areas: sensitivity, adaptive capacity, and exposure. The tool is adjustable based on the user's desired output. For example, if ODOT is most interested in learning about an asset's adaptive capacity, weighting can emphasize those factors to produce a list of the agency's least-adaptive assets.

The Ohio DOT Infrastructure Resiliency Plan includes VAST results by asset type, prioritized by degree of vulnerability and importance to Ohio's overall transportation system. This entails an evaluation of bridges, culverts, and highways; stormwater management facilities are also rated. A sample output from this exercise, included in the 2016 plan, is a list of ODOT's 10 most vulnerable bridges. VAST is becoming an established

tool among state DOTs to understand their transportation network's vulnerability. DOTs in Michigan, Iowa, Alaska, Connecticut, Maine, New York, and Massachusetts have also used VAST in studies similar to ODOT's 2016 efforts.

In addition to general systemwide vulnerability assessments, VAST can also tackle more specific inquiries. For example, in 2014, Minnesota's Department of Transportation (MnDOT) completed a Flash Flood Vulnerability and Adaptation Assessment Pilot Project. In this study, MnDOT investigated future precipitation and flood risks to develop new options for hydraulic facilities (i.e. culverts). To evaluate options for near-term culvert replacements, MnDOT used VAST to model weather inputs for alternative structures, ultimately determining that larger facilities are more cost-effective, mitigating potential future damages.²⁵

TRAFFIC SYSTEMS MANAGEMENT AND OPERATIONS PLAN (2017)

ODOT's 2017 Traffic Systems Management and Operations plan also offers some opportunities to integrate resiliency-related performance measures. Goals currently organized under "Reliability" offer the closest link to resiliency. For example, one current performance target states that within two hours of a snow event ending, routes should be able to recover speeds within 10 mph of expected speeds. This is an area where ODOT may create additional performance measures around the resiliency of ODOT's transportation system.

TRANSPORTATION ASSET MANAGEMENT PLAN (2017)

ODOT's 2017 TAMP also began adopting a risk-based framework. Though organizational risk remains the plan's focus, weather and disaster preparedness also receive attention, including specific reference to flooding risks. By including weather-related events within ODOT's realm of risks, ODOT can identify investment strategies that will reduce impacts when they do occur.

²⁵ <http://www.dot.state.mn.us/climate/pdf/ExecutiveSummary2.pdf>

Where Are We Headed?

CURRENT OPPORTUNITIES

Building on the 2016 Infrastructure Resiliency Plan & Statewide Climate Variability Study, Ohio is continuing these asset reliability initiatives in ODOT's Office of Statewide Planning and Research. This work has two main goals: 1) refinement of VAST model scales and weights for all three asset types (highways, bridges, and culverts) and 2) adding new factors to the VAST tool.

Due to the 2016 report's emphasis on flooding, these new factors account for research innovation in waterway geomorphology, including recent understandings of flood event indicators. With this augmented data, Ohio can focus further on flood-related impacts to its transportation system. At present, ODOT still faces limitations for recording flood events. This data collection can support the improved design and selection of flood-affected asset types, such as culverts and stormwater infrastructure.



With this increased sophistication, District staff will continue VAST analysis on state assets. The ultimate goal of this phase of data collection is an updated list of critical facilities. Reviewing VAST outputs, ODOT may be able to establish a risk rating for each asset, organized by tier categories) to determine most vulnerable assets in each class.

To prepare for this review process, ODOT is currently coordinating with District staff on VAST implementation. This increased district-level coordination and training may be central to the need for ongoing data collection beyond this current phase of resiliency work. Designated staff oversight may enable regular data collection around critical facilities and incorporation of data into ODOT's Transportation Information Management System (TIMS).

Through this continued data collection, Ohio can understand the overall resilience of its transportation system across districts. Improved and expanded data may inform more meaningful performance indicators for ODOT's adaptive project selection process. For example, federal requirements for a "risk-based asset management plan" are an opportunity to include resiliency strategies from ODOT's asset reliability initiatives in Ohio's TAMP. With bolstered performance measurement, these factors can weigh into project selection and prioritization across ODOT's programs.

FUTURE DIRECTIONS

A proactive focus on resiliency allows ODOT to maximize the value of its current assets and navigate future uncertainties.

Enhanced Coordination

Above all, ODOT's capacity for responsiveness depends on internal agency organization and coordination. Consistent data collection is foundational, as are streamlined data management practices. With efforts underway to apply VAST work within ODOT's districts, the interface with centralized coordination is key. These efforts could integrate with ODOT's Transportation Information Management System (TIMS) and other ODOT data management systems to help advance ODOT's asset management aims.

Coordination with ODOT's Emergency Operations support function also provides precedents for how ODOT can coordinate internally and externally around natural disaster events. ODOT's emergency operations trainings partner with agencies such as the Ohio National Guard, Ohio Department of Natural Resources, Ohio State Patrol, and even peer agencies in Indiana. These training exercises emphasize personnel readiness, communications, and mobilization and simulate the agency's response to security threats or disasters. Additional trainings, especially with a focus on natural hazards, would improve Ohio's preparedness for events like floods and rockslides. After action reports and evaluation practices may continue to improve these trainings and provide useful guidance for aligned future resiliency trainings.

Enhanced Systems Based Planning

Systemwide, district-level data collection also enables ODOT to move from an asset-level approach to systems-level analysis. One potential approach to enable this shift is identifying other opportunities for vulnerability assessments earlier in project scoping, as well as in corridor studies. For example, the latter can focus on a corridor's adaptive capacity by identifying how vulnerable assets may impact overall corridor conditions and performance. Drawing from the experiences of peer states, the Colorado Department of Transportation completed an I-70 Risk and Resilience Pilot in fall of 2017 that may prove applicable to ODOT's analysis of Ohio's flood-prone segments of the I-70 corridor.²⁶ This study identifies and prioritizes high-risk assets, which threaten overall corridor performance and includes analysis of design, maintenance, and operational improvements needed to reduce risk in these critical locations. ODOT could move towards similar corridor-level work on its own portion of I-70, or roadways of comparable significance.

Enhanced Applicability of Data

These expanded vulnerability data also offer an opportunity to revise preliminary designs of threatened asset types. For example, ODOT can further investigate thresholds for hardening assets under differing scenarios, such as 15 versus 50-year floods, and adapt asset designs accordingly. Reviewing these projections, ODOT can create new design standards that anticipate weather-related impacts. These specifications can inform vendor selection and procurement, ultimately shaping what types of investments ODOT may make.

²⁶ <https://static1.squarespace.com/static/573a4027e3214017eb2e590c/t/59c19f4dc534a55b61a53506/1505861454387/I-70+Risk+and+Resilience+Case+Study.pdf>

Specific to planning, ODOT can conduct sensitivity tests (using the Statewide Model or other analytical tool) specific to one or more scenarios or situations (such as rockslide event or bridge closure) to assess system performance. Unlike short term target setting, broader measures associated with travel time reliability, operational capacity, or system redundancy could be measured. The analyses could inform detour routing decisions or strengthen other event mitigation or system redundancy strategies.

Additionally, ODOT can work with Ohio's economic development entities, such as JobsOhio, to tie transportation resiliency to economic development goals. By quantifying the social and economic impacts of resilient infrastructure, Ohio can build the case for its stability and security as a site for investment. For example, fiscal impact analysis modeling can demonstrate how much future revenue is associated with a particular transportation investment, compared with construction and maintenance costs. Measures, such as travel time savings or expanded job access, can show how resilient infrastructure implies economic resiliency as well.

Ohio's current asset reliability work lays the foundation to broadly embed resiliency across ODOT Divisions, especially with regard to project selection. With uncertain futures ahead, the long-term viability of transportation in Ohio depends upon moving in this direction, as well as an overall commitment to adaptiveness and responsiveness in planning.

CONCLUSION

ODOT has begun to consider the practices and policies needed to instill resiliency as a core consideration for the preservation of its future transportation system. This paper has emphasized how weather events, natural disasters, and other risk factors could continue to create costly impacts for ODOT. However, Ohio's location buffers it from natural disasters, common in other geographic regions, making the state a desirable location for long-term private sector investment.

Recent plans and ongoing activities (such as VAST) set the stage to explore how short term considerations and preparedness can link to longer term, system-wide assessments that deepen a well-rounded, comprehensive response. ODOT's reliance on extensive system level data and data systems also can allow the agency to explore a growing list of scenarios and situations, diversity which will refine response strategies and strengthen coordination efforts.

Enhanced coordination, systems planning, and data applicability represent emerging opportunities to further integrate resiliency in ODOT's processes. These steps also provide a mechanism and rationale to explore ways to communicate, report on, and measure the resiliency of the state's highway and bridge network. Ohio can become a leader in adaptive approaches which leverage data and shed light on agency resource needs and internal/external collaboration. These efforts could cement the use of such planning to support ODOT's mission and vision.