

INTEGRATING CLIMATE RESILIENCE INTO TN STATEWIDE TRAVEL DEMAND MODELING

2025 TNMUG Presentation

PROJECT TEAM



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BUILDING TRANSPORTATION RESILIENCE

Why it Matters

 Transportation resilience is critical – when roads fail, recovery stalls

 Natural hazards disrupt lives, not just infrastructure putting travelers and first responders at risk

 TSM lacks hazard considerations and the ability to model resilience scenarios.

Current Action

 TDOT is acting now, prioritizing resilience to reduce emergency repairs and improve safety

 Phase I: Research best practices for TDM-resilience integration and provide recommendations for TSM.

Future Vision

 Empower TSM users to model natural hazard impacts and enhance network resilience long-term.



AGENDA

- 01** Introduction
- 02** Research Process
- 03** Understanding Travel Modeling Practices in Response to Natural Disasters
- 04** State-of-the-Practice Prediction Models of Natural Disasters
- 05** State of Tennessee Resiliency Planning
- 06** Scenario Development and Evaluation
- 07** Implementation Recommendations

RESEARCH PROCESS

- Goals
- Process
- Project Terminology

GOALS



GOAL #1

Identify **current practices** of other DOTs in travel demand modeling, forecasting, or planning in response to natural disasters



GOAL #2

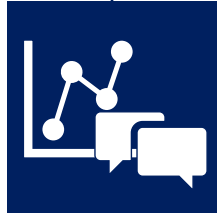
Review **state-of-the-practice climate resources** for compatibility with integration into the TSM framework



GOAL #3

Assess Tennessee's **current resiliency planning efforts** and provide **recommendations** for enhancing the TSM

PROCESS



Understanding Travel Modeling Practices in Response to Natural Disasters

- Literature Review
- Survey
- Interviews
- Trend Analysis



Understanding State-of-the-Practice Climate Assessment Resources

- Identify Resources
- Develop Evaluation Criteria
- Evaluate Resources
- Synthesize Results



State of Tennessee Resiliency Review/ Scenario Development

- Review Available Tennessee Resources
- Identify Resilience Scenarios for TSM
- Develop Evaluation Criteria
- Evaluate Resilience TSM Scenarios



Document and Report Research Findings

- Implementation Specifications for Selected Scenarios
- Summary Report of Research Findings

PROJECT ORIENTATION

Phase 1: Understand Impacts

Example Inputs: Asset Data, Hazard Data, Climate Projections

Example Analysis: Asset Exposure, Vulnerability Scoring

Example Outputs: Assets likely to lose service, level of impact, and duration of closure

Phase 2: Understand Transportation System Performance under Impacts

Example Inputs: Assets likely to lose service, level of impact, and duration of closure

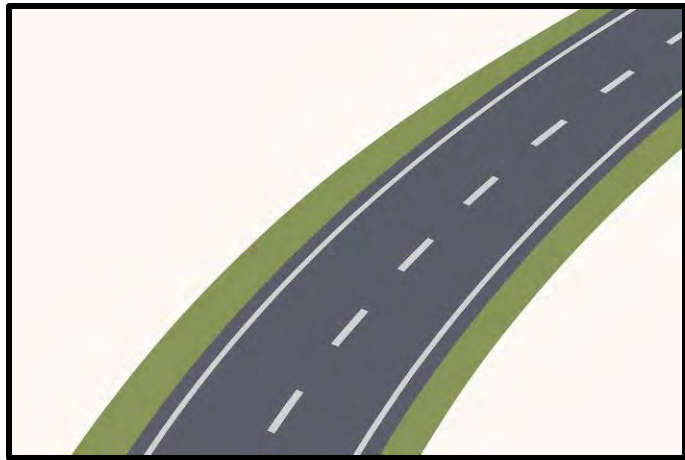
Example Analysis: Trip Assignment under impacted roadway network conditions

Example Outputs: Travel Time, VMT/VHT, Network Capacity, OD Matrix, Trip Volumes

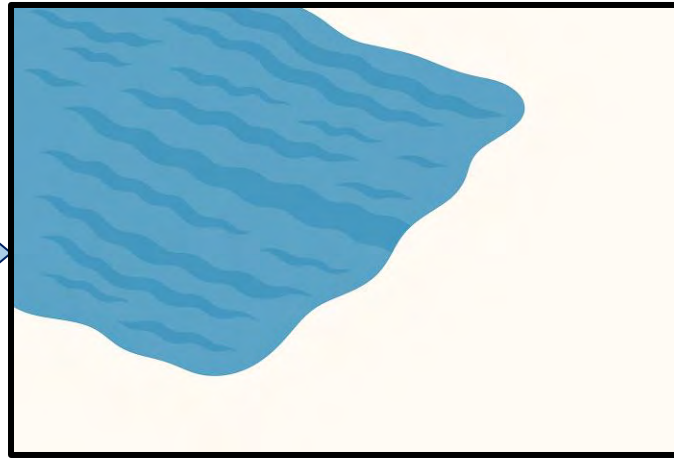
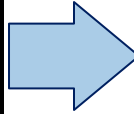
RESILIENCE PLANNING TERMINOLOGY

- **Vulnerability:** Susceptibility of transportation assets to damage or disruption from hazards.
- **Exposure Assessment:** Identifies transportation assets located in hazard-prone areas.
- **Vulnerability Assessment:** Evaluates susceptibility based on exposure, sensitivity, and adaptive capacity.
 - **Sensitivity:** Asset characteristics that increase the likelihood of damage from a hazard.
 - **Adaptive Capacity:** Ability of an asset or system to cope, adjust, or recover.
- **Criticality:** Importance of an asset to overall network function and emergency response.

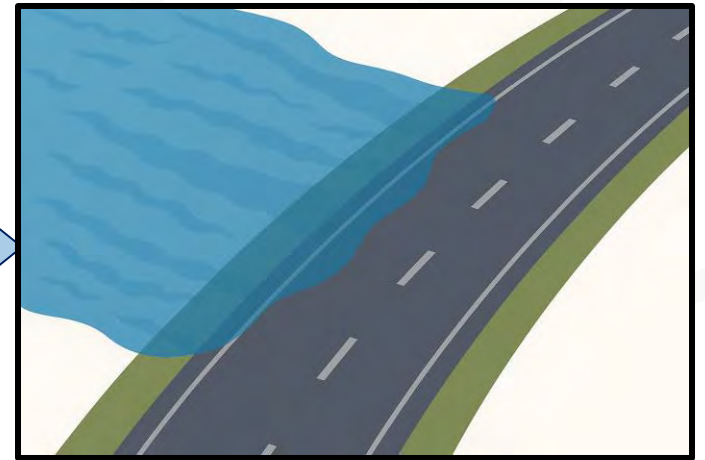
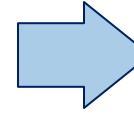
Exposure Analysis Process



Roadway Data

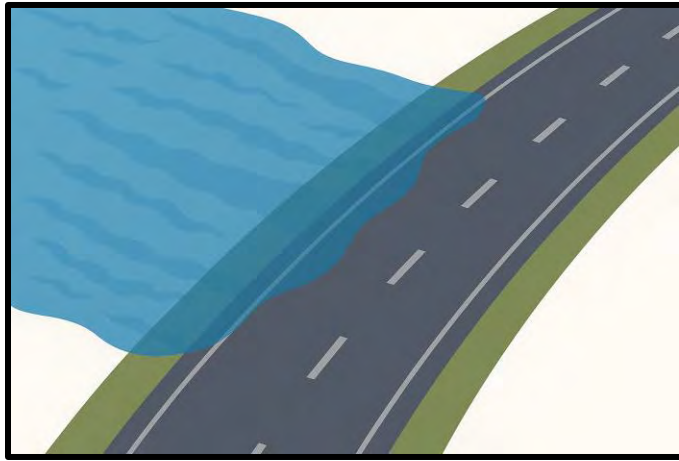


Flood Spatial Data

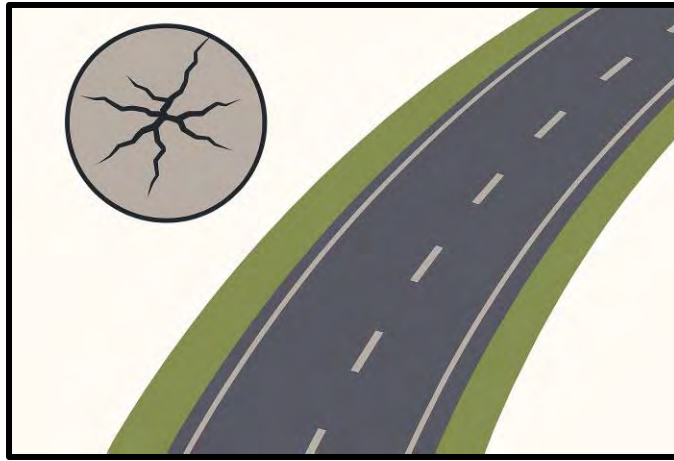


Exposure Analysis

Vulnerability Analysis Process



Exposure Analysis



Sensitivity Analysis



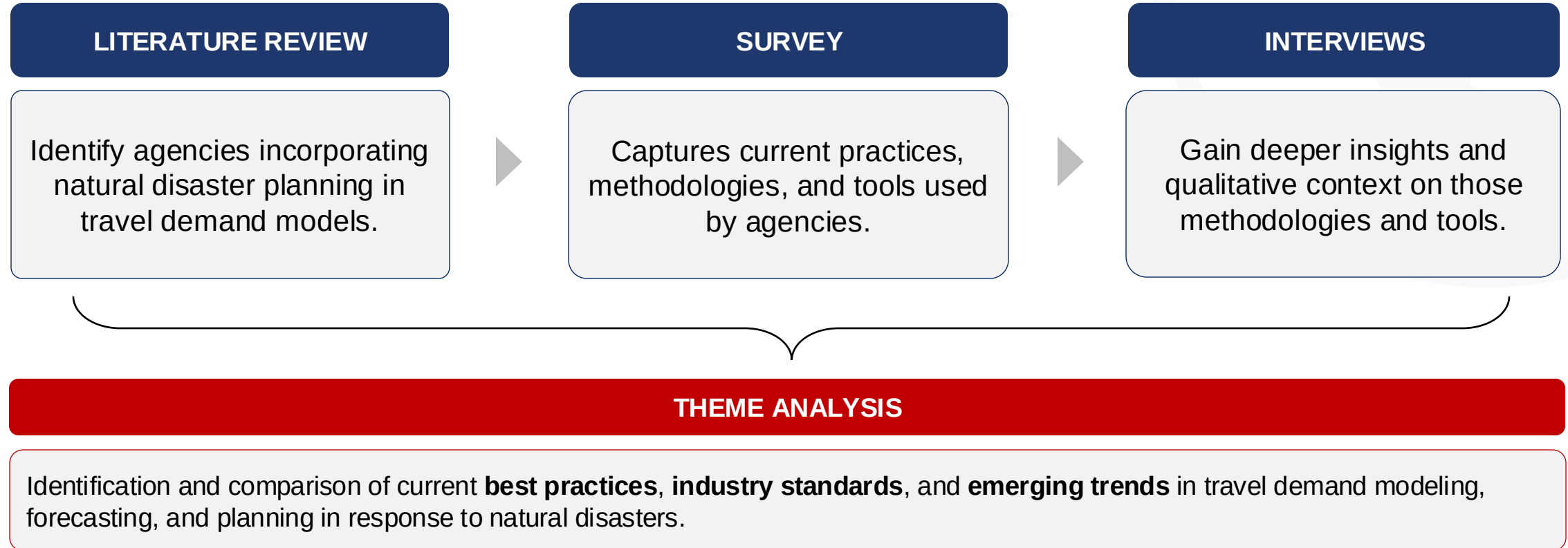
Adaptive Capacity Analysis

Vulnerability

UNDERSTANDING TRAVEL MODELING PRACTICES IN RESPONSE TO NATURAL HAZARDS

- Methodology
- Key Takeaways
- Recommendations

METHODOLOGY



METHODOLOGY

LITERATURE REVIEW

26 PAPERS

- 12** Proof of Concept
- 5** Literature Review
- 12** Guidance and Best Practices
- 3** Implementation in Practice

SURVEY

23 RESPONSES

- 16** State DOTs
- 4** Metropolitan Planning Organizations
- 3** Other Entities

INTERVIEWS

5 INTERVIEWEES

- 3** State DOTs
- 1** USDOT Volpe Center
- 1** Port Authority

INTERVIEW INSIGHTS

US DOT Volpe Center

- Utilize AequilibraE routing engine with TDM outputs for scenario analysis to estimate system-wide impacts under hazard and investment scenarios.

Oregon DOT

- Adjusts TDM inputs (link availability, capacity, tolls); uses extreme tolls to simulate closures due to model limitations.

North Carolina DOT

- Employed proprietary agent-based City Simulator with NCDOT networks.

Port Authority of NY & NJ

- Used Travel Time Skim files from NY Best Practices Model; estimates disruption impacts for bridge/tunnel closures.

Vermont Trans

- Developed Network Criticality Index through probabilistic hazard scenarios run in TransCAD.

KEY TAKEAWAYS

PHASE 1: UNDERSTAND IMPACTS

- **Vulnerability:** Growing use of detailed vulnerability assessments with geospatial hazard and asset data.
- **Hazards:** Primarily on spatial hazards (flooding, landslides); limited attention to regional hazards (wildfire, severe storms).
- **Scale:** Segment-level analysis is common; asset-level detail adds precision but complicates system-wide modeling.
- **Timeframe & Scenarios:** Commonly existing and mid-century (2050)

PHASE 2: UNDERSTAND TRANSPORTATION SYSTEM PERFORMANCE UNDER IMPACTS

- **Emerging Practice:** Climate resilience integration in travel demand modeling interest is growing.
- **Approaches:** Range from detailed asset-level adjustments to simplified outage assumptions.
- **Translation:** Typically involves adjusting link capacity or availability.
- **Metrics:** Common measures include trip counts, travel time, VMT, and VHT.

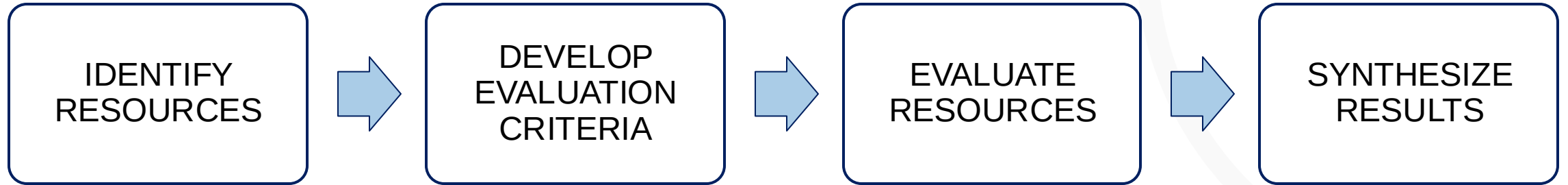
RECOMMENDATIONS

- **Organizational Strategy:** Align internal/external teams for long-term resilience planning.
- **Phase 1 Tool Selection:** Prioritize open-source and sustainable tools over proprietary systems.
- **Phased Implementation:**
 - Start with exposure modeling
 - Progress to indicator-based vulnerability assessments
 - Advance to detailed vulnerability analysis
- **Phase 2 Scenario Modeling:** Standardize routines and outputs for efficient planning and evaluation.

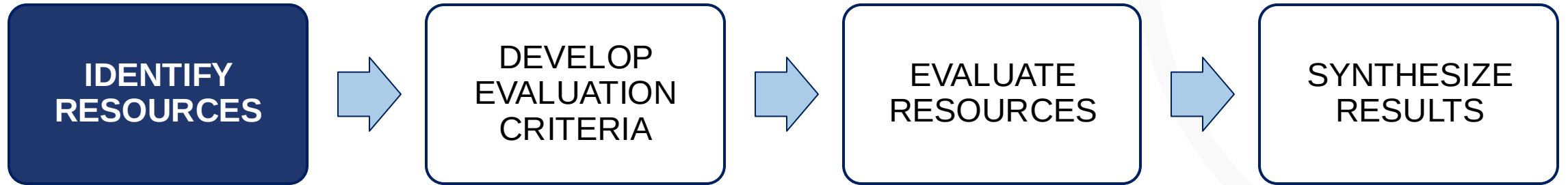
STATE-OF-THE-PRACTICE PREDICTION MODELS OF NATURAL DISASTERS

- Methodology
- Key Findings & Recommendations

EVALUATION METHODOLOGY



METHODOLOGY

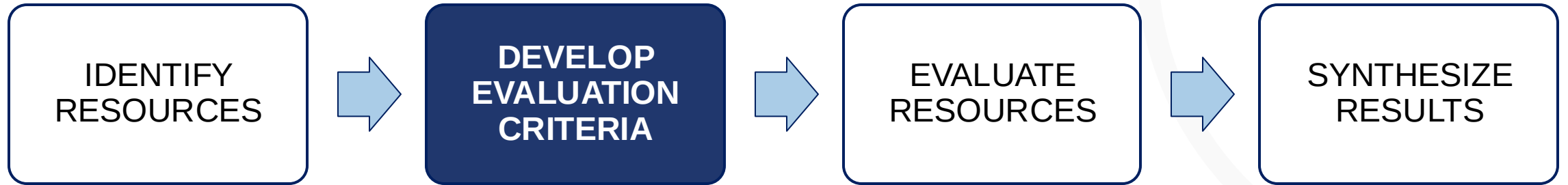


47 Total Resources

40 Climate & Hazard Exposure Data

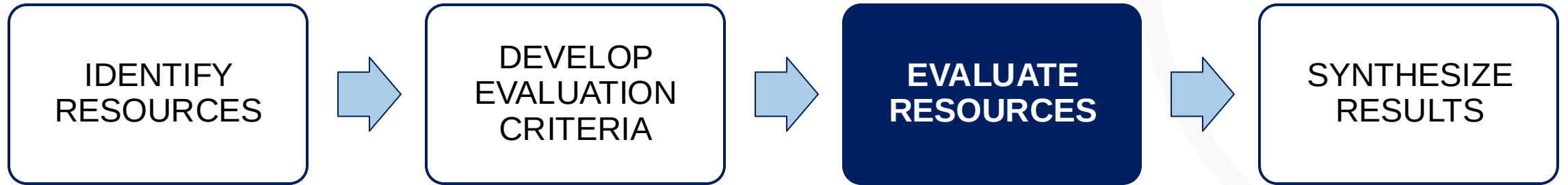
7 Data Tools & Models

METHODOLOGY

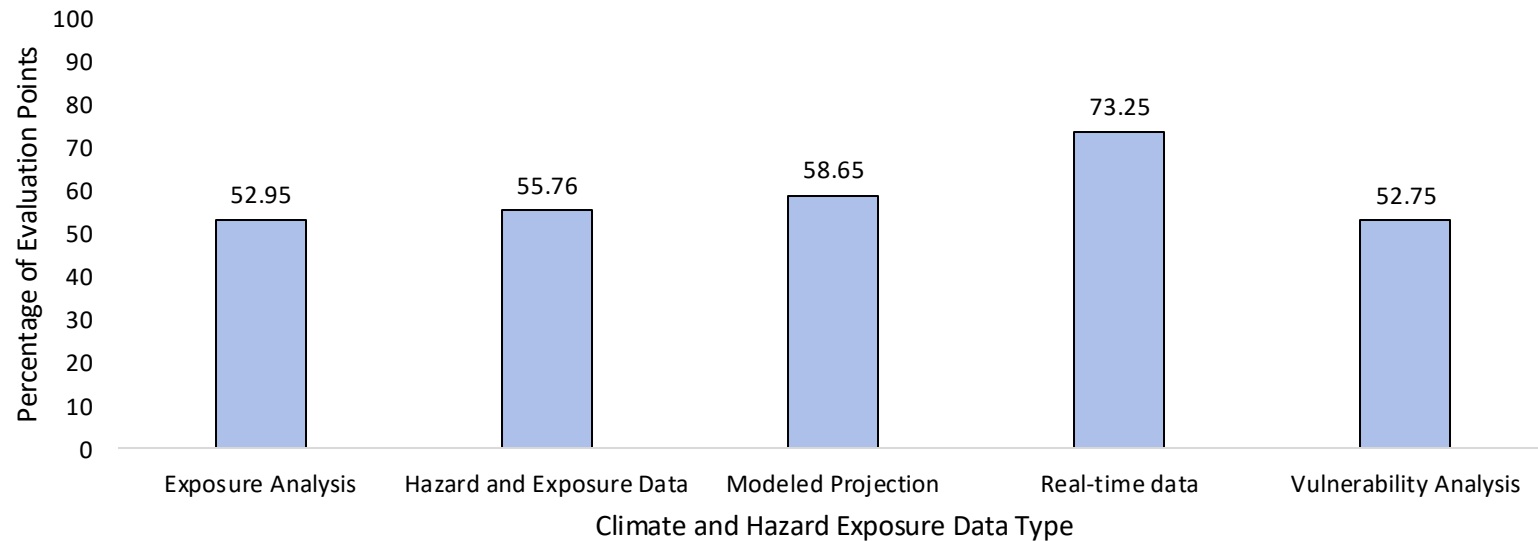


- **Output and Application to TSM**
- **Quality and Credibility**
- **Spatial, Temporal & Hazard Coverage**
- **Ease of Use and Flexibility**

METHODOLOGY



Average Evaluation Percentage Score by Type



KEY FINDINGS & RECOMMENDATIONS

CLIMATE & HAZARD EXPOSURE DATA

- **Key Findings:**
 - **Modeled projections:** good for future planning, but complex and uncertain.
 - **Exposure/hazard data:** easy to use, broad coverage, often rely on secondary sources.
 - **Real-time data:** highly accurate, frequently updated, but hard to integrate.
 - **Vulnerability data:** limited, mostly for high-level planning.
- **Recommendations:**
 - Use high-quality, well-documented datasets
 - Validate multi-hazard datasets

DATA TOOLS AND MODELS

- **Key Findings:**
 - **Integration Challenges:** Most tools need customization to suit TSM integration.
 - **Public Tools:** FHWA has tools that can be used for exposure (RDR Tool) and vulnerability analysis (VAST).
 - **Custom Tools:** Agencies use GIS-based methods and consultant-developed platforms (e.g., City Simulator, ArcadisGen, Stantec).
- **Recommendations:**
 - Leverage FHWA's RDR Tool Suite or VAST.
 - Consider customization and consultant-developed tools for advanced assessments

STATE OF TENNESSEE RESILIENCY PLANNING

- Identified Resources
- Recommendations for Integration

IDENTIFIED RESOURCES

EXISTING PLANNING EFFORTS

9 PLANS

- Transportation Resilience Improvement Plan
- State Hazard Mitigation Plan
- Rapid Emergency Evacuation Planning / Assessment for Tourist Attractions and Isolated Communities
- Transportation Asset Management Plan

HAZARD DATA

4 RESOURCES

- Emergency Relief (ER) Database
- Damage Assessment Forms
- Unstable Slope Management Plan
- Elevation Data (LiDAR)

ASSET DATA

16 RESOURCES

Roadway Network Data

- Pavement Management System
- Highway Performance Monitoring System Submittal

Bridge Data

- Bridge Management System
- National Bridge Inventory

Other

- Stormwater System Layers
- Socioeconomic Traffic Analysis Zones
- Emergency Evacuation Centers

RECOMMENDATIONS FOR IMPLEMENTATION



Planning

- Identify stakeholders using existing plans (TEMP, TAMP, TRIP).
- Improve cross-agency coordination for resilience.
- Validate assessments with SHMP hazard data.
- Complement long-term goals (e.g., T-REX).
- Monitor plan updates for new resilience info.



Asset Data

- Use TDOT asset data for vulnerability analysis.
- Align Highway Network File with LRS.
- Merge roadway datasets into one Phase I layer.
- Add bridge data for complete network analysis.



Hazard Data

- Validate Phase I results with ER Database.
- Translate Phase I impacts into Phase II capacity estimates.

SCENARIO DEVELOPMENT AND EVALUATION

- Maturity Levels
- Methodology
- Proposed Scenarios
- Evaluation Criteria

MATURITY LEVELS

1

LEVEL 1 – INITIAL

- Uses existing asset & public hazard data.
- Manual updates; short-term deployment.
- Requires technical expertise for data interpretation & TSM configuration.

2

LEVEL 2 - DEVELOPING

- Adds advanced datasets (no field collection).
- Enables automated vulnerability assessments using public tools & scripts.
- Requires expertise in assessments & TSM setup.

3

LEVEL 3 - ADVANCED

- Incorporates targeted data collection & hazard modeling.
- Runs multi-scenario assessments with specialized programs.
- Needs robust TSM configuration and scripting.

4

LEVEL 4 - INTEGRATED

- Combines real-time/historical data with advanced modeling.
- Direct integration into TSM for scenario-based analysis.
- Requires major TSM enhancements and high-level programming skills.

METHODOLOGY

- Identified six scenarios from project research, focused on Level 2 and Level 3 maturity.
- Outlined Level 4 scenarios for potential future growth.
- Developed evaluation criteria to compare and prioritize scenarios.
- Selected four scenarios for implementation based on evaluation results, TDOT feedback, and program considerations.

PROPOSED SCENARIOS



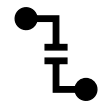
Advanced Flood Assessment

Uses AI-driven predictive flood modeling to simulate statewide flooding and guide TSM capacity adjustments.



Advanced Landslide Assessment

Applies probabilistic curves to predict landslide potential and inform TSM network capacity changes.



Indicator-Based Vulnerability Assessment

Automates FHWA's VAST methodology to assess asset vulnerability under current and future conditions for TSM integration.



Indicator-Based Criticality Index

Identifies and prioritizes critical transportation segments essential for emergency access and core services during hazards.



RDR Exposure/Disruption Analysis – Flood

Evaluates flood exposure and disruption using RDR tools integrated with TSM workflows for resilience planning.



Modified RDR Exposure/Disruption Analysis – Vulnerability

Enhances RDR tools by adding vulnerability factors to better represent network performance under hazard conditions.

EVALUATION CRITERIA

	Description	Weighting
Availability of Inputs	Accessibility and cost of hazard/asset data; complexity of processing.	30%
Transferability & Scalability	Strength of Phase 1 to Phase 2 translation assumptions and methodologies.	20%
Ease of Development	Level of technical expertise and effort required for TSM integration.	20%
Relevance	Practical utility for resilience planning and alignment with TDOT objectives.	30%

IMPLEMENTATION RECOMMENDATIONS

- Evaluation Results
- Final Scenarios
- Next Steps

EVALUATION RESULTS

AVAILABILITY OF INPUTS

- Flood depth data is costly to obtain
- Large datasets increase processing requirements
- Assessments using public data score highest for input availability

TRANSFERABILITY AND SCALABILITY

- Scenarios using qualitative tables for capacity reductions scored lower
- Flood scenarios apply a capacity reduction function for more accurate translation

EVALUATION RESULTS

EASE OF DEVELOPMENT

- Assessments easily run in GIS or with simple scripts ranked highest
- Setting up the RDR Suite requires technical expertise
- Modifying the RDR Suite demands advanced programming skills

RELEVANCE

- Vulnerability-focused scenarios ranked highest
- RDR scenarios include mitigation measures
- Exposure-only scenarios scored lower
- Criticality plays a limited role in TDM

FINAL SCENARIOS

Scenario	Evaluation Rank	Reasoning	Implementation Order
Indicator Based Vulnerability Assessment	1 st	Straightforward to implement, uses public data , and provides statewide coverage . Variety of methods to implement.	First step to narrow down areas for targeted study; scalable for statewide implementation.
RDR Exposure/Disruption Analysis - Flood (use as it is)	3 rd	Uses RDR Tool Suite as designed, includes automated analysis and mitigation testing. Requires advanced flood data with depth.	Second scenario ; flood data acquisition needed. Vulnerability results can help narrow focus if cost is a concern.
Advanced Landslide Assessment	4 th	Uses advanced landslide data for exposure analysis. Could integrate with RDR Tool Suite with exposure and capacity relationship defined by user.	Third scenario ; landslide data acquisition needed. Potential for RDR integration if TDOT adopts the tool suite.
Modified RDR Exposure/Disruption Analysis: Vulnerability	2 nd	Modifies the RDR Tool Suite to include vulnerability, includes automated analysis and mitigation testing.	Fourth scenario ; build off RDR experience from previous scenarios.

FINAL SCENARIOS

#1 INDICATOR BASED VULNERABILITY ASSESSMENT

Phase 1: Indicator-Based Vulnerability Assessment

- Assess assets using exposure, sensitivity, and adaptive capacity indicators.

Translation Step

- Develop method to convert vulnerability scores (1–4) into capacity reduction assumptions.

Phase 2: Scenario-Based Modeling

- Model system performance under scenarios using vulnerability scores and capacity reductions.
- Generate performance metrics for each scenario.



#2 RDR EXPOSURE/DISRUPTION ANALYSIS – FLOOD (USE AS IT IS)

Phase 1: RDR Exposure Analysis

- Use RDR Exposure Analysis Tool and Disruption Analysis Submodule to assess flood exposure.

Translation Step

- Utilize RDR's standardized equation to translate flood depth into roadway capacity reductions.

Phase 2: Scenario-Based Modeling

- Use TSM (not RDR assignment module) network and assignment algorithm for scenario analysis.
- Model system performance using calculated capacity reductions.
- Generate performance metrics for each scenario.

FINAL SCENARIOS



#3 ADVANCED LANDSLIDE ASSESSMENT

Phase 1: Advanced Landslide Exposure Assessment

- Applies probabilistic curves to predict landslide potential.
- Overlay results with asset data to determine exposure.

Translation Step

- Develop method to convert exposure results into capacity reductions, validated by historical landslide data.

Phase 2: Scenario-Based Modeling

- Model system performance under landslide scenarios using assumed capacity reductions.
- Generate performance metrics for each scenario.



#4 MODIFIED RDR EXPOSURE / DISRUPTION ANALYSIS: VULNERABILITY

Phase 1: RDR Vulnerability Analysis

- Modify RDR Exposure Analysis Tool and Disruption Analysis Submodule to assess vulnerability.

Translation Step

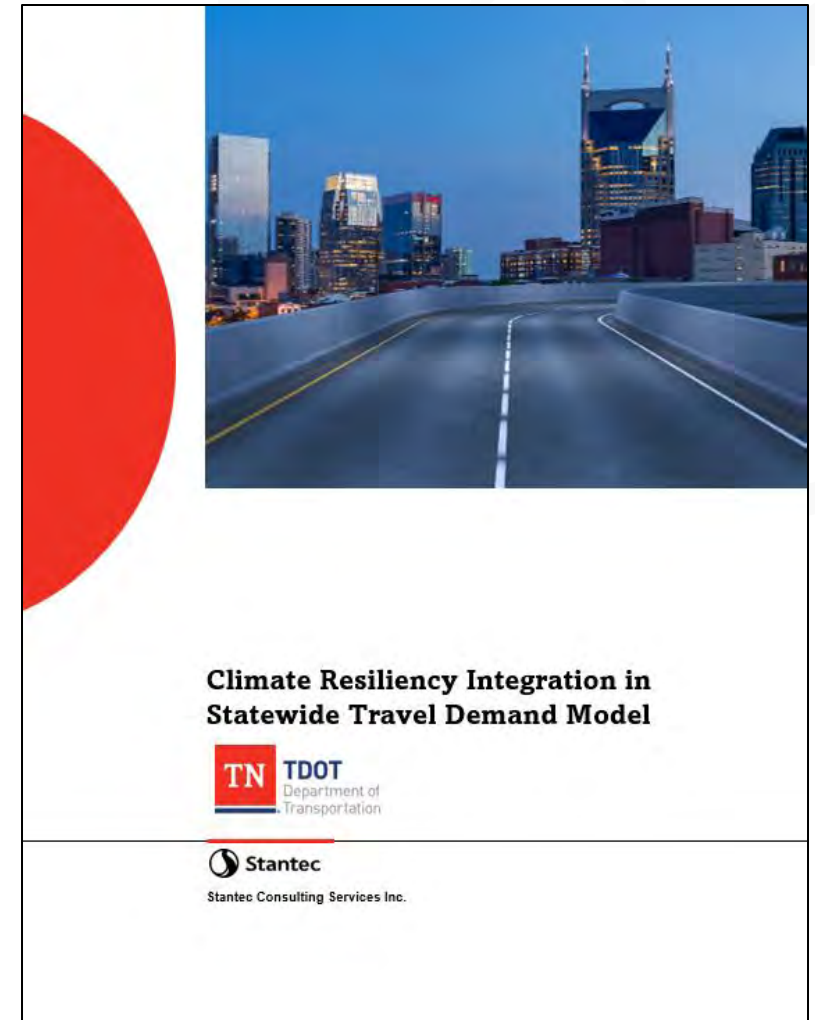
- Develop method to convert vulnerability results into capacity reduction assumptions.

Phase 2: Scenario-Based Modeling

- Use TSM for scenario analysis.
- Model system performance using calculated capacity reductions.
- Generate performance metrics for each scenario.

NEXT STEPS

- **Initial research project completion:** November
- **Deliverables:** Implementation specification sheets for four selected scenarios and summary report of research
- **Next steps:** TDOT will advance toward implementation





QUESTIONS?