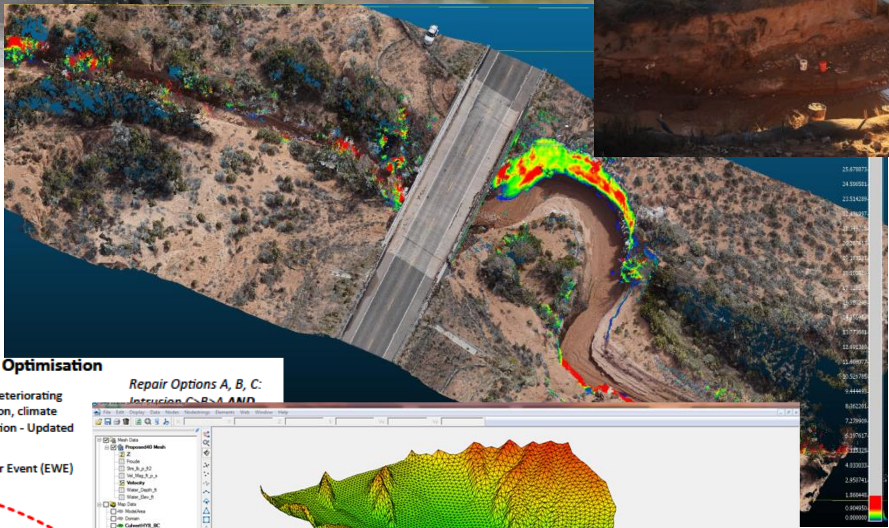
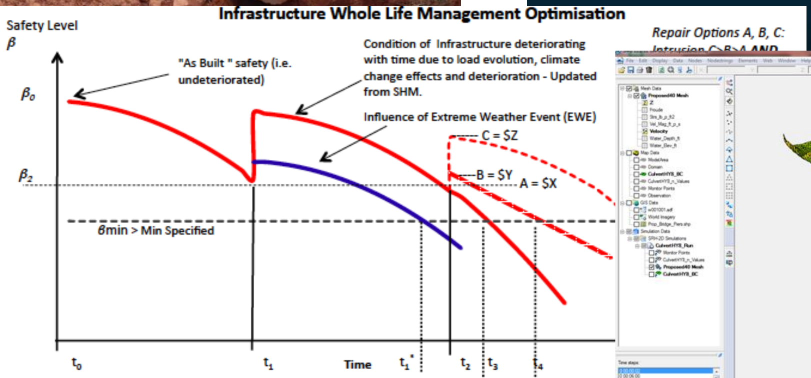
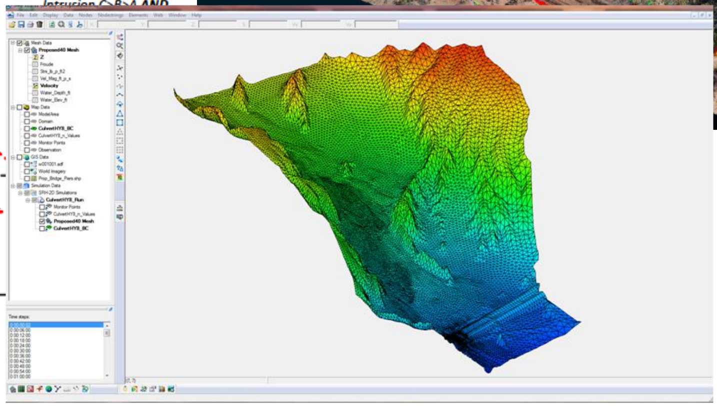
Arizona DOT Infrastructure Resilience
Designing, Funding, and Building Resilience into a $1Billion Construction Program
Blending Risk/Science/Technology/Engineering







Steven Olmsted

Arizona DOT

Environmental Planning

2nd International Conference on Resilience to Natural Hazards and Extreme Weather Event

Nov 13 – 15, 2019

ADOT

Asset Management

Asset Management Risk Register - 25
Weather/Natural Hazard Risks – 6 (links to 6 other)
Agency – Extreme Weather Trends
Asset – Flooding, Scour, Pump Stations
Asset – Landslide/Slope Failure
Asset – Rockfall
Asset – Culvert Failure
Activity – Redundant Routes

Table 6-1 Risk Type

Risk Type	Affect
Agency Risk	Risk to the agency that affects the implementation of the strategic goals of the asset management plan. Examples include changes in leadership, legislative actions, unfunded mandates and the ability to convey the importance of asset management to decision-makers and the public.
Financial Risk	Affect the availability of adequate funding or accurate prediction of future funding needed to implement the TAMP. Examples include inflation, unexpected funding shortfalls, solvency of the Highway Trust Fund, financial markets, interest rate increases and inaccurate predictions in financial plans.
Program Risk	Affect the ability to deliver a program of projects in a timely manner and meet performance targets. Risks may include the inability to effectively manage data, the loss of institutional knowledge via attrition, competing spending priorities, inaccurate cost-estimates and construction/materials price volatility.
Asset Risk	Affect individual assets, such as structural deterioration, extreme weather and obsolescence. Assets risks include flooding, landslides, hazardous materials spills, collisions with bridge elements and assets that do not meet current design standards.
Project Risk	Associated with projects to restore or replace individual assets. An example of a project risk is the impacts associated with lengthy construction detours in areas where redundant, alternative routes don't exist. Project delivery risks include delays caused by environmental, utilities, right-of-way, geotechnical, procurement, scope creep and inter-governmental agreements.
Activity Risk	Associated activities like routine maintenance, including slow or inadequate response to damaged assets (e.g., pothole or guard rail repair) or extreme weather events (e.g., clearing blocked drainage structures, repairing scour weakened bridge foundations or risks to workers such as heat, fires, etc.).

Life Cycle Plan

A Climate Engineering Assessment for Transportation Assets (CEA-TA)
Incorporating Probabilistic Analysis into Extreme Weather and Climate Change Design Engineering

Steven Olmsted, Arizona Department of Transportation; Alan O'Connor, Trinity College Dublin; Constantine Samaras, Carnegie Mellon University;
Beatriz Martinez-Pastor, Trinity College Dublin; Lauren Cook, Carnegie Mellon University

Abstract

Transportation infrastructure is a complex system of assets required to deliver a myriad of services and functions. As fiscal constraint for the development and rehabilitation of such structures remains; and endless retrofitting continues to be cost prohibitive; new and novel approaches to long term planning and project development, engineering design, and life cycle assessment are paramount. The management of these infrastructure systems has now evolved from a decentralized, project-based focus, to one that now encompasses enterprise wide endeavors – administration, technology adoption, planning, design, construction, operations and maintenance. In addition, the expansion of risk analysis for extreme weather management and climate change adaptation has complicated the long term delivery of these complex transportation systems. At the 2015 Transportation Research Board (TRB) Annual Meeting, Session 197: *Mainstreaming Climate Change and Extreme Weather Resilience into Transportation*, the Arizona Department of Transportation (ADOT) introduced the challenge ahead for public entities to coordinate a host of known and unknown extreme weather and climate change issues. That challenge – Continue considering the balance between predictable asset deterioration curves, the sudden and unpredictable nature of extreme weather events and long term climate trends, new models for risk assessment and life cycle cost analysis, and appropriate adaptation strategies. This multiple part challenge necessitated a new end-to-end engineering approach to incorporate such current and future risks. At the 2016 Annual Meeting ADOT submitted a paper representing the core of that new approach – a Resilience Program and an ADOT/United States Geological Survey Partnership. That paper was graciously recognized as a best paper by the TRB Special Task Force on Climate Change and Energy. In the spirit of continuing that forward progress – this paper presents the remaining parts needed to develop a new end-to-end engineering-based asset adaption process – a structured sequence to incorporate extreme weather and climate change adaptation into the design engineering process. The paper benefits from preeminent researchers in the two integral, and practice ready, remaining parts – probabilistic modeling for engineering design and infrastructure system design life cycle outcomes for extreme weather and climate change in a transportation engineering setting.

Arizona DOT Resilience Program

Transportation infrastructure is a complex system of assets required to deliver a myriad of services and functions. The expansion of risk development for extreme weather management and climate change adaptation has complicated the long term delivery of these complex transportation systems.
In order to develop an innovative approach, the first step was to create a system process that allowed for a shift from a deterministic preset design parameter and/or frequency basis, statistical risk of failure, and historic project and programs budgeting focus – i.e. extreme events not considered – to a probabilistic analysis approach that inputs additional data, vulnerabilities, and considerations not previously considered. In 2015 and 2016 ADOT focused on linking scientific evidence-driven data capture with the design engineering processes through the development of a partnership with the United States Geological Society (USGS). Extensive 2-D/3-D engineered modeling underway.

(CEA-TA) – A Structured Sequence

Identify EX W & CC project and program candidates - *Vulnerability Assessment*

2015 FHWA Pilot Project - The study examined baseline (historical) and potential future extreme weather conditions, focusing on temperature and precipitation variables. Two future analysis periods were selected: 2025 to 2055 (referred to subsequently as 2040, the median year), which reflects the time horizon of ongoing long-range planning efforts, and 2065 to 2095 (2080), roughly associated with the expected design lifespans of some critical infrastructure types, such as bridges. To provide a long term baseline against which to compare the projections, the team also examined temperature and precipitation observations from 1950 through 1999. The report was issued by FHWA in the Spring of 2016.

WHY IS MOVING TO A PROBABILISTIC APPROACH EVEN NEEDED?

This question could cover pages and pages. The short answer is easy. In addition to sustainable transportation attributes, there is growing consensus that if transportation systems are going to incorporate extreme weather and climate change, consideration must be developed that account for hydrometeorology/climatology, hydrology, hydraulics, and hydrodynamics. Since all these areas continue to adopt advanced mathematical modeling approaches, it is therefore logical that transportation systems and projects develop also incorporate these progressions.

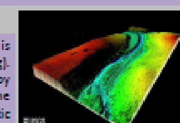
Develop economic analysis process - *Justification*

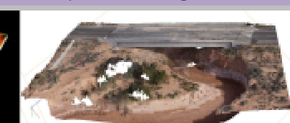
An economic analysis for the CEA-TA process would consist of using a probabilistic approach to life cycle cost analysis. The life cycle cost of an infrastructure asset such as a roadway or bridge, is the total cost to an agency throughout the asset's useful life. This includes the planning, design, construction, maintenance and decommissioning phases of infrastructure delivery. State DOTs typically initially approach this process without considering risk and uncertainty that future conditions will be different from the past, and assume a uniform distribution of annual maintenance costs and major reinvestment intervals. Long-lived infrastructure must perform under future climate conditions and climate-influenced usage that deviates from the historical data now populating infrastructure economic analysis and asset management models. Climate change impacts, such as sea-level rise, storm surges, changes in precipitation, hotter temperatures, and others are potential vectors of infrastructure failure and should be taken into consideration in infrastructure economic analysis and asset management models.

Resilience Program
Economic Analysis Pilot
US 191 MP 436 to Chinle
PROJECT NO. 191 AP 436 H8676 01 C
FEDERAL AID NO. STP-191-E(214)T
Apache County
Holbrook District

Design probabilistic modeling approach to produce an array of results - *Quality Control*

Optimize operation and maintenance of an increasingly aging stock, which is subjected to evolving loads (e.g. both live loading and climate induced loading). In response to this challenge the past decade has seen increased interest by infrastructure owners and managers in the use of probabilistic methods for the assessment/management of their assets. Employed once a deterministic assessment has rendered a repair/rehabilitate/replace now scenario

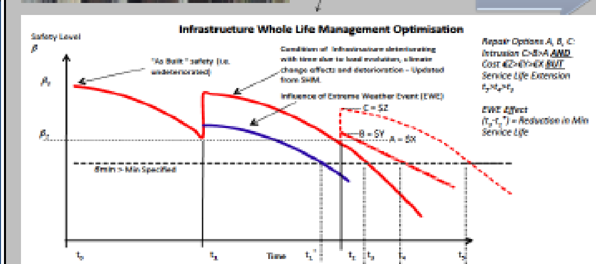




Define limits of simulation runs that incorporates latest science/engineering - *Policy*

Climate models can provide insight into future conditions, projecting air temperature, precipitation, evapotranspiration, and other factors of interest to engineers, at various temporal and spatial resolutions. However, there is a considerable disparity in the outputs provided from climate models for impacts analyses and the inputs needed by engineers for planning and design. These discrepancies include mismatches in temporal and spatial scales, complicated data extraction and preparation requirements, sizeable model, data, and scenario uncertainties, and a lack of direction for the rigorous selection of models for use in different engineering applications.
Innovative change examples:

- Every Day Counts – 4 : Collaborative Hydraulics: Advancing to the Next Generation of Engineering (CHANGE)
- NCHRP 15-61 - Applying Climate Change Information to Hydrologic and Hydraulic Design of Transportation Infrastructure
- NCAR - *The Future Intensification of Hourly Precipitation Extremes* - Andreas F. Prein et al. December 2016
- LiDAR, UAS/UAV, 2-D water modeling, 3-D visualization and animation tools
- Translational organizations to provide rigorous standards for interpretation of climate data, development of a single, simplified user interface that accesses all downscaled data sources, and tools that automatically post-process data based on defined standards



Systematically record location and resilience efforts GIS/TAMP - *Risk Management*

ADOT has been systematically capturing data sets for extreme weather and climate change use through an extensive geographic information system (GIS) effort that will subsequently support ADOT's transportation asset management planning (TAMP). ADOT's studies showed concerns with the climate and extreme weather vulnerability of bridges, culverts, pavement, and roadside vegetation / stabilization. Legislation - Focus in MAP-21 on performance based management and risk-based asset management plans; Inclusion of "resilience" in FAST Act.

Develop life cycle models to monitor investment - *BCA/ROI*

Civil infrastructure systems are among the largest local, state and Federal investments, and these infrastructure systems are critical to U.S. economic, environmental and social outcomes. Yet longstanding underinvestment in infrastructure has resulted in the poor condition of much of U.S. infrastructure, with an estimated $3.6 trillion of re-investment needed by 2020. New methods for benefit cost analysis, return on investment studies, and major rehabilitation timeline analyses are needed that incorporate probabilistic approaches, and minimize regret by DOTs under a changing climate. The results of CEA-TA provides that method.

Acknowledgments

The completion of this project would not have possible without assistance from many stakeholders both within and outside ADOT that contributed to this effort. Specifically, the International Symposium - *Transportation Resilience: Adaptation to Climate Change and Extreme Weather Events*, June 16-17, 2016 at the European Commission in Brussels, Belgium that was the catalyst for the transatlantic partnering. The ADOT author wishes to acknowledge the efforts and support of: ADOT State Engineer's Office and ADOT Environmental Planning.

Resilience Building Methodology

- Identify key stressors and associated weather-related risk - Identify vulnerable assets
- Pilot climate data modeling
- Compile data – GIS Resilience Database - systematically record known locations – 500 locations currently
- Screening tool utilized to prioritize
- Risk-based asset management life cycle method – new end to end engineering process implemented - project level statistical decision theory
  - Identify <u>root cause</u> during different stages of asset lifecycle (creation, maintenance, preservation, rehabilitation/reconstruction, end of life)
  - Identify <u>proxy indicator</u> or <u>direct</u> engineering approach
  - Identify mitigation strategies / decision trees, including adaptation options and selection criteria - <u>probabilistic</u> risk modeling is an option
- **R**esilience Investment **E**conomic **A**nalysis (RinVEA) – resilience spend justification

ADOT / FHWA
2015 Vulnerability Assessment

ADOT / FHWA
2018 Asset Management – Infrastructure Resilience

2019 Resilience Building

ADOT

ADOT Resilience GIS Database

Data

- ADOT's USGS Data
  - Flood gauges
  - Wildfire
  - Drought
- Layers from ADOT's USGS Flood map
- Dust storm data (I-10 pilot)
- 5-yr program priority project information
- Bridges (including scour program)
- Culvert
- ADOT system base layers

Data

- ADOT/USGS Project Work
- Resilience (Extreme Weather and Climate) Building
- Resilience Investment Economic Analysis assessment locations
- Climate Engineering Assessment for Transportation Asset (CEA-TA) locations
- Every Day Counts CHANGE 2-D modeling projects
- 2050 and 2100 climate data downscaling mapping
- Pavement

ADOT Resilience Screening Tool

- Agency/SEO/Division/District/5-yr Construction Program
- TAMP Risk Register
- Resilience Risk Register
- Resilience Program Screening
- Resilience Program Screening
  - All historical actions
  - All known locations
  - All current need catalogued (GIS)
- Design/Construction/Operations/Maintenance
- Projects I.D.'d and Prioritized
- Financial Tool Box Opened
  - Justification (RinVEA)
  - Build Consensus

ADOT

Resilience Building Project #1 – SR 191 Chinle, AZ

- Protect the new $5.2M roadway investment
- Address severe erosional and drainage issues that has led to a 25%-100% degradation at sixty-one (61) of the eighty-six (86) corrugated metal pipe (CMP) drainage structures
- Address drainage excavation, barrow and slope stabilization issues
- Address severely compromised stormwater management capabilities
- Comply with and proactively address expected regulatory actions on stormwater management, FHWA Order 5520, Presidential Executive Order on Federal Flood Risk Management, and MAP-21 asset preservation performance requirements
- Upgrade ADOT's application of risk-based assessment modeling at the asset class, project development, and localized hydrological event level
- Further ensure use of SR 191 in the remote far northwest of Arizona and a main Apache County connector between SR 264 and US 160 in the advent of an extreme weather event
- Pilot ADOT's Resilience Investment Economic Analysis (RinvEA)

ADOT

Resilience Building Project #1 – SR 191 Chinle, AZ



- Pre-and post-construction conditions of this project
- Example of a $275,000 resilience building outlay that improved asset management, the roadway asset lifecycle, and created a more resilient road segment by measurably improving the ability for the drainage facilities to convey up to the 50-year
- RinvEA is now one major component of financial decision making as it relates to asset management – infrastructure resilience



ADOT

Resilience Building Project #2 SR 160 Laguna Creek

$1m gabion basket bank protection - bridge now protected to the 500-yr storm event

Laguna Creek Construction

ADOT

Laguna Creek - Pilot Reach Monitoring in Dynamic Channels
Understanding bank erosion and impacts to infrastructure

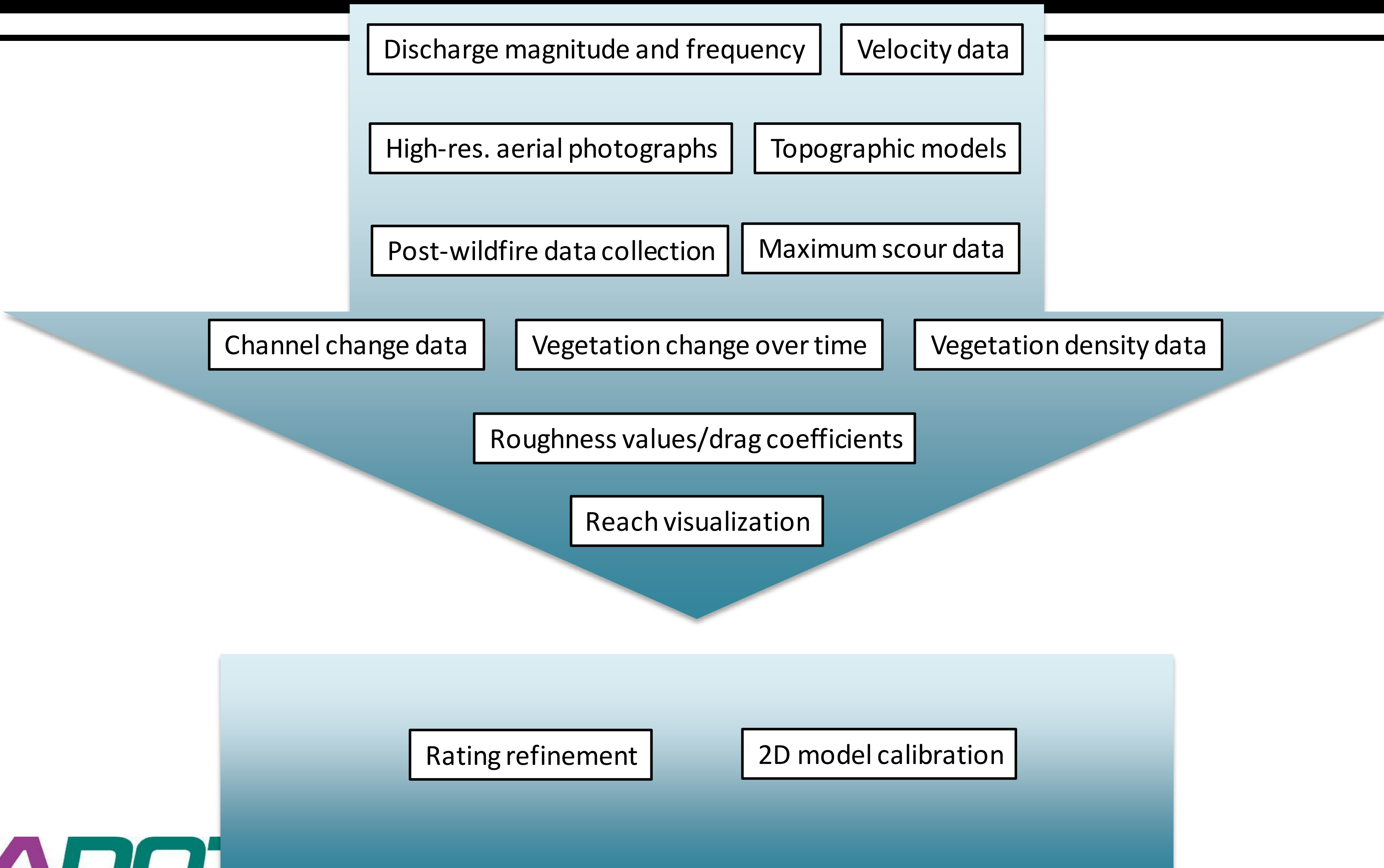
5-yr ($1m) ADOT – USGS Partnership

Laguna Creek Reach Monitoring Pilot:

- Rapid deployment stream gage
- Surface velocity radar sensor
- Particle tracking video cameras
- Indirect discharge measurements
- Repeat LiDAR scans of bridge structure and surrounding channel
- sUAS (drone) survey
- Approved Fact Sheet
- Cloud project data availability
    - ScienceBase
    - Earth ResourcesObservation and Science (EROS)

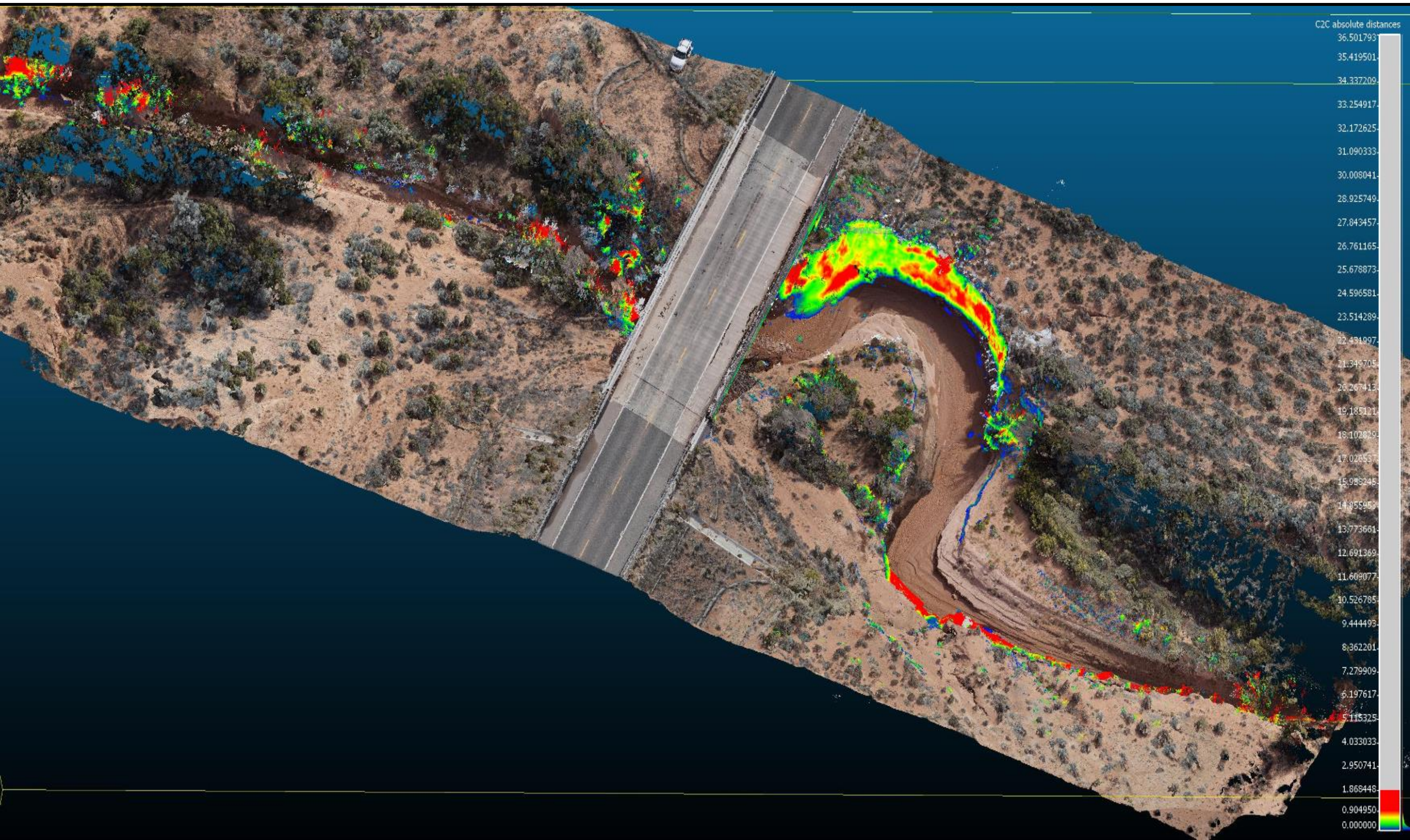
USGS

Reach Monitoring Products *Collecting data for the future*



ADOT

3-D Erosion Change Detection Mapping



Resilience Building Project #2 – Laguna Creek

November 2017 – State Route 160 Laguna Creek Bridge (Final grading and seeding)

ADOT

Post Construction Monitoring

USGS Drone Data Capture – On-going Monitoring - Built Condition and Wash Meander / Ox-bow

ADOT

Resilience Building Projects

- #3 – SR 95 Fortuna Wash Bridge - Bridge and Bank Stabilization

$9.3m bridge now protected against Fortuna Wash floodwaters flowing over the road, secured the $500m in area economic impact, reduced/eliminated considerable detour

- #4 – I-8 Foothills Blvd to Dome Valley - Roadway and CMP Improvements

$14m Roadway deterioration and clogged and corroded drainage structures due to storm events and aging repaired. Ten (10) Corregated Metal Pipes (CMP) ranging in size from 24" to 60". Vulnerable NHS asset improved - Access for City of Yuma, Yuma Port of Entry, State of California, Yuma International Airport, USMC Air Station Yuma, Barry M. Goldwater Air Force Base, Port of San Luis SR 95, MP .01 Mexico Border

- #5 – I-17 New River Bridges Structures #1290 and #1291 – Upgrade structures

$2.5m 6-inch deep concrete floor approximately 3 feet below the channel bed underneath the bridges. Cutoff walls at both upstream (approximately 4 feet deep) and downstream (approximately 6 feet deep) ends of each of the concrete floors under the bridges. Vulnerable NHS asset improved in and out of Maricopa County and its 4.2m residents, access to and from Northern Arizona regions including Flagstaff, AZ. USGS upstream Peak Discharge Computation for Flood: August 19th, 2014 Discharge 39,300 ft3/s

ADOT

Resilience Building Projects

- #6 – SR 80 St. David Bridge - Bridge replacement

$11m bridge replacement to replace a structure that has reached end of life. Severe erosion issues due to confluence of the Dragoon and San Pedro rivers. Fourth EDC CHANGE Program SRH 2-D modeling effort.

- #7 – SR 79 Gila River Bridge - Bridge replacement

$30m 1500' bridge replacement and mitigating 4000' additional floodplain. First project to proceed through all phases of the CEA-TA. Specifically includes Innovation in Design and Drainage Engineering design contract component. Includes seven (7) EDC initiatives. Pilot 2-D, 3-D, 4-D, 5-D

- #8 – I-10 Gila River Bridge – Bridge replacement

$75m 1500’ bridge replacement - The existing river crossing includes two quarter-mile-long bridges, one for east- and one for westbound I-10, each carrying two lanes of traffic over the Gila River. They are critical pieces of infrastructure on I-10, a Key Commerce Corridor that connects Arizona’s two largest metropolitan areas and supports significant commercial and economic growth for the region, the state and the country.

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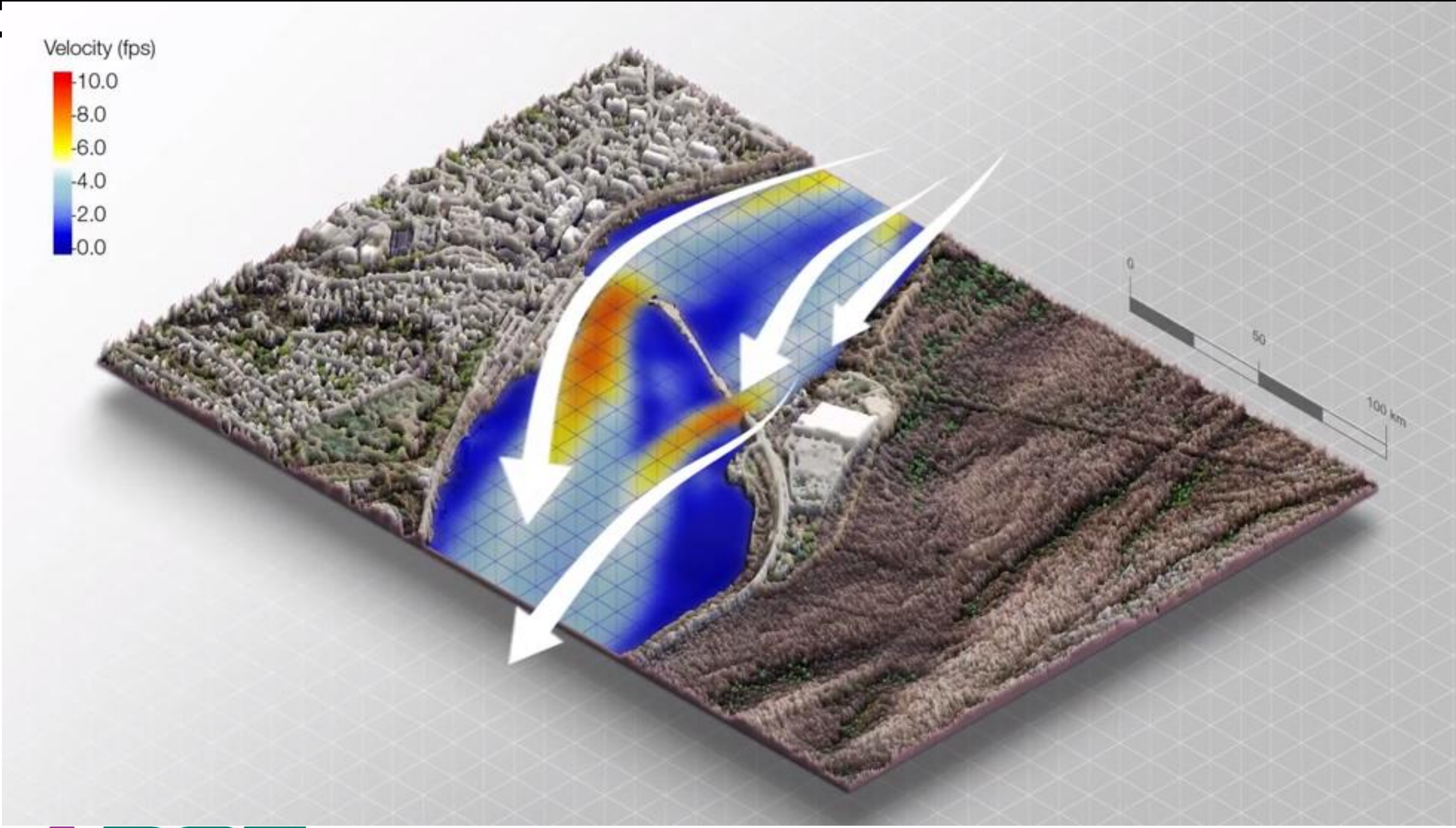
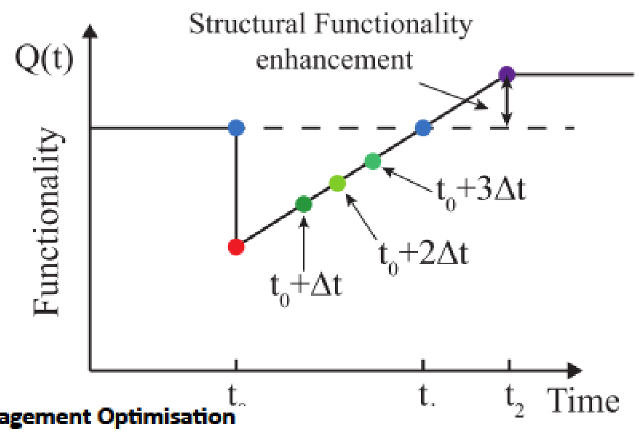
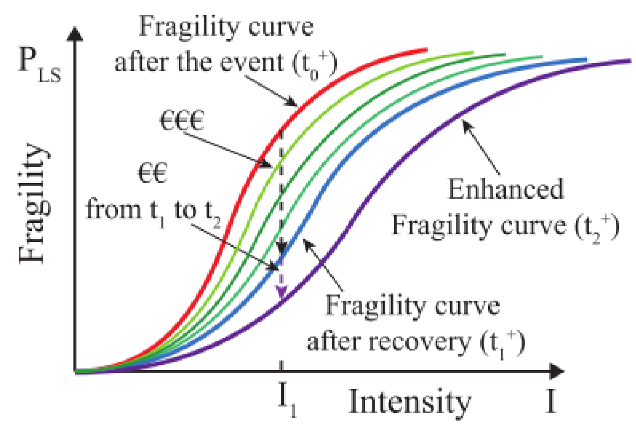
Resilience Building - EDC CHANGE Program 2-D

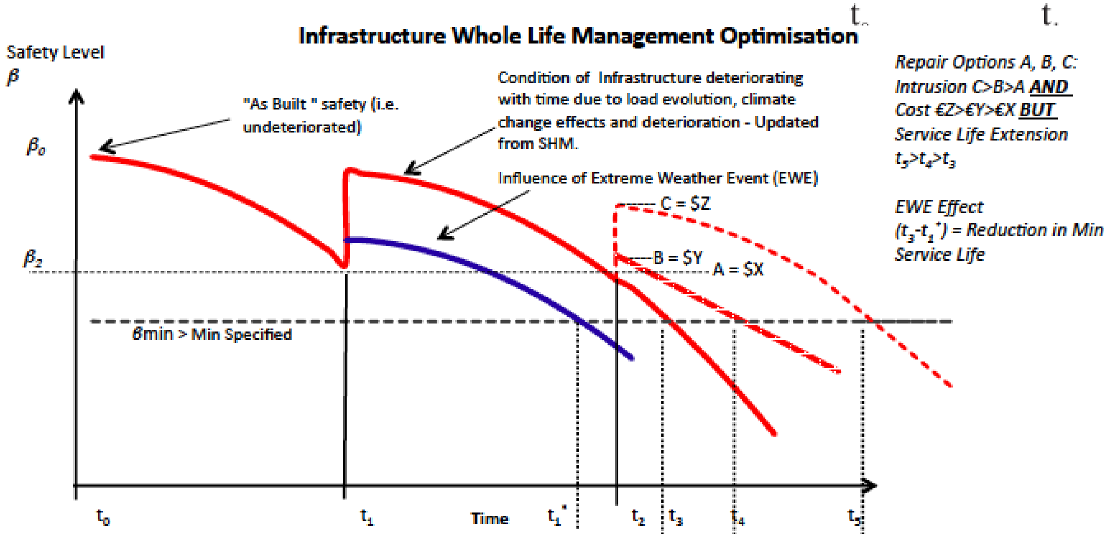


Alan O'Connor - School of Engineering - Trinity College Dublin

Developing an asset class probabilistic engineering approach that assesses the stressors inherent to the built structure itself







Carnegie Mellon University

Constantine Samaras – School of Engineering - Carnegie Mellon University

- Develop Economic Analysis Process
- Develop Life Cycle models to monitor investment
- Account for the differences in the deterioration model with new climate-informed asset management models
- Pilot customized intensity-duration-frequency (IDF) curves

While different methods to quantify the economic impact of climate change for infrastructure can be found in the literature, none of these methods succeed in producing life cycle asset management plans that are robust to a wide variety of future climates. New methods for benefit cost analysis, return on investment studies, and major rehabilitation timeline analyses are needed that incorporate probabilistic approaches, and minimize regret by DOTs under a changing climate.

Part 667 - Developing a Process

- FHWA Emergency Relief Program (ERP) provides funds for the repair and reconstruction of highways and roads that have sustained serious damage from catastrophic failures or natural disasters, including extreme weather events. Since fiscal year 2012, Congress has appropriated approximately $5.7 billion to the ERP.
- MAP-21 and FAST Act National Highway Performance Program External - Asset Management Plan Final Rule
- 23 CFR Part 667 Periodic Evaluation of Facilities Repeatedly Requiring Repair and Reconstruction due to Emergency Events
- Statewide Evaluation §667.1 43 State DOTs shall conduct statewide evaluations to determine if there are reasonable alternatives to roads, highways, and bridges that have required repair and reconstruction activities on two or more occasions due to emergency events.
- Report No. ST2018014 - January 10, 2018 - Office of Inspector General - Improve Guidance on Infrastructure Resilience for Emergency Relief Projects and a Process To Track Related Improvements
- Statewide Evaluation §667.1 43 State DOTs shall conduct statewide evaluations to determine if there are reasonable alternatives to roads, highways, and bridges that have required repair and reconstruction activities on two or more occasions due to emergency events.

Part 667 - Developing a Process

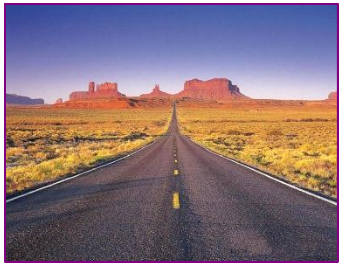
ADOT

Questions?

Steven Olmsted

Arizona Department of Transportation

solmsted@azdot.gov



ADOT