Priority-Setting for the Future Interstate System with Emergent and Future Conditions

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Acknowledgements

- Hampton Roads Planning District Commission
- Hampton Roads Transportation Planning Organization
- Dwight Farmer, Executive Director, HRPDC and HRTPO
- Camelia Ravanbakht, Ph.D., Deputy Executive Director, HRTPO
- John Carlock, AICP, Deputy Executive Director, HRPDC
- US Federal Highway Administration

Risk and Resilience Analytics

Risk analysis …

An influence of *scenarios* to *priorities*.

Lambert et al. (2016, 2014, 2013, 2012, 2011, 2010, 2009)

The effect of uncertainty on objectives.

ISO 31000 (2009)

What can be done in what time frames, what are the tradeoffs, and what are the impacts of current decisions on future options

Haimes (1991)

What can go wrong, what are the likelihoods, what are the consequences

Kaplan and Garrick (1981)

Measure of the probability and severity of adverse effects.

Lowrance, *Of Acceptable Risk* (1976)

Risk, Safety, and Security *Programs*

What risks are addressed

What are the resources

What is monitored and evaluated

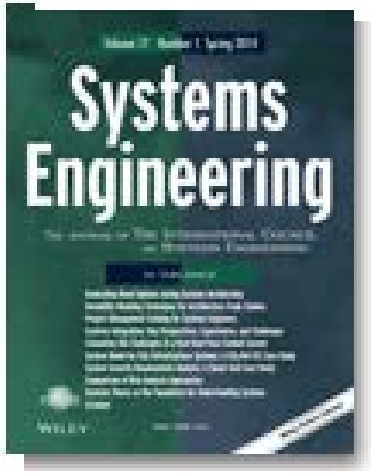
Sources: Teng, Thekdi, and **Lambert** 2012a, 2012b

Scenarios **are**:

- Projected from stakeholders
- Related to aspirations or advocacy positions

Scenarios **not necessarily**:

- Mutually exclusive or complete
- An event space
- Objective or primitive mathematical constructs
- Repeatable across experts and elicitations



Sources: Thorisson, Lambert, et al. 2016; Karvetski and Lambert 2012

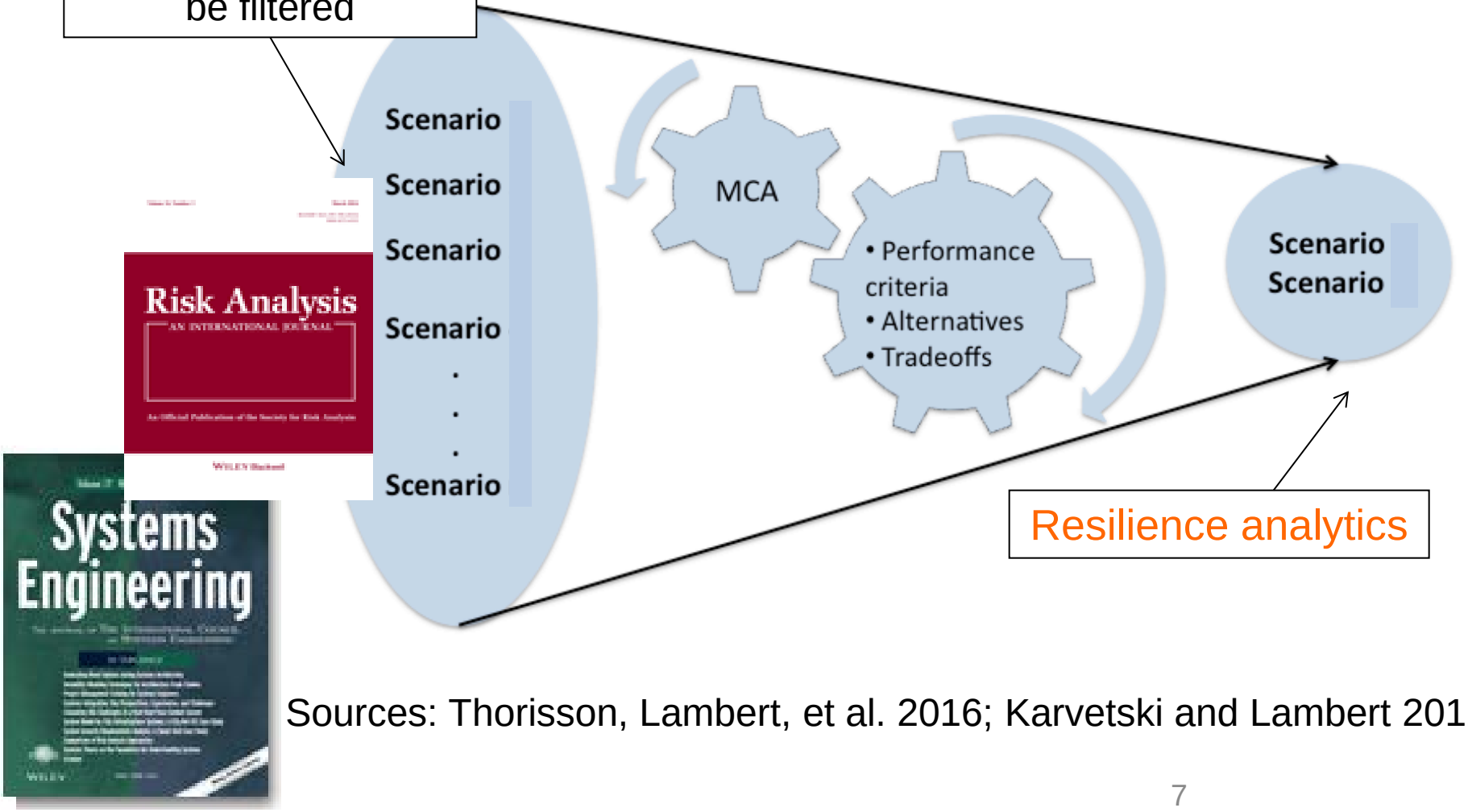
Emergent & Future Conditions

- **Regulatory**
  - New guidelines or increasingly stringent national or international trade policies.
- **Technological**
  - Immediate, unforeseen shifts in the directions of energy technologies (such as nuclear technologies, coal technologies, or promising renewable energy technologies).
- **Cyber**
  - Known and unknown conditions of data/information and control systems
- **Geopolitical**
  - Shifts in the geopolitical power relating to fossil fuels and natural gas that influence availability and costs of these energies.
- **Behavioral**
  - Changes in societal viewpoints or lack of acceptance of energy legislation.
- **Climate and others**
  - Disruption of infrastructure services, commercial energy grid failures, destruction of energy systems, and deterioration of energy and other infrastructure systems.

Sources: Thorisson, Lambert et al. 2016;
Nakićenović, N. (2000). Energy Scenarios. Chapter 9 in United Nations Development Programme. United Nations Department of Economic and Social Affairs. World Energy Council. World Energy Assessment. New York 2000

Opportunities, threats, and the influential scenarios

Hazard scenarios to be filtered



Sources: Thorisson, Lambert, et al. 2016; Karvetski and Lambert 2012

Foundations in decision and behavioral sciences

resilience analytics in **multiple time frames**

Hamilton and Lambert (2016)

Hamilton Dissertation

Iteration and evolution

scenario-based **preferences** & **risk analysis**

Karvetski et al. (2009)
Schroeder and Lambert (2011)
Karvetski et al. (2011a and b)
You et al. (2013)
Parlak et al. (2012)
Karvetski and Lambert (2012)
Hamilton et al. (2013a and b)

Adjust weights based on baseline scenario

Mise-en-scene

scenario-based preferences

Montibeller et al. (2006)
Ram et al (2009)
Ram and Montibeller 2012
Stewart (2013)

Separate additive model for each scenario
Robustness based on regret

Preference aggregation across scenarios

scenario analysis and multicriteria

Goodwin and Wright (2001)
Belton and Stewart (2002)

Evaluate alternative-scenario pairs

multicriteria analysis

Corner et al (2001)
Montibeller and France (2010)

Dynamic mcda

Transitional object

Motivation

- Recent Hampton Roads efforts address climate
  - HRPDC studies and reports
  - Cooperative efforts with Univ. VA, Old Dominion Univ., Va. Institute of Marine Science
- Transportation planning
  - Newly developed Project Prioritization Process for Long-Range Transportation Plans
  - Other plans (VTRANS2035, Transit Vision, etc.)

Motivation (cont.)

- Adaptations were identified, though had not been integrated to regional planning, with a few exceptions
- Primary focus had been rise of sea level
- Methods and tools were needed for climate impacts to be considered in long-range plans

Motivation (cont.)

- Tools for informing adaptation decisions
  - Where to protect, accommodate, retreat
- Must describe how climate impacts can affect investment priorities
  - Where to invest in new infrastructure or maintenance
- Moving forward
  - Incorporating climate change and adaptive management into local and regional plans, including LRTP
  - Utilizing scenario analysis across economic and other infrastructure sectors

Purpose and Scope

Address the influences of climate scenarios to long-range transportation planning.

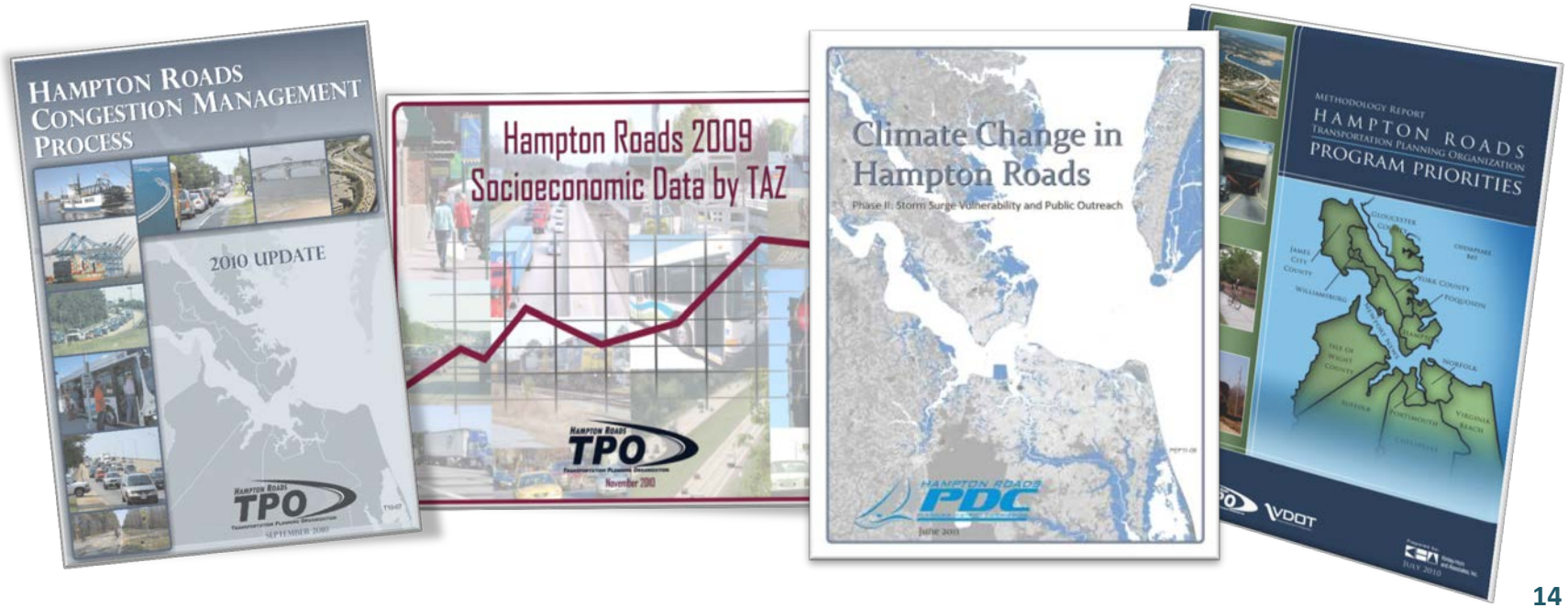
- Climate combines with other factors: Economy, regulation, maintenance/repair, technology, ecology, demographics, etc.
- Which scenarios are an advantage to strategic plans? Which are disruptive to strategic plans?
- Where should investigative resources be focused to avoid regret and belated action?

Agenda

- Motivation / Purpose
- **Foundation**
- Technical Approach
- Results
- Conclusions

Foundations

- Virginia and Hampton Roads efforts on climate and transportation planning
- Recent work with US Army Corps of Engineers, VTrans2035 Office of Intermodal Planning and Investment, FHWA

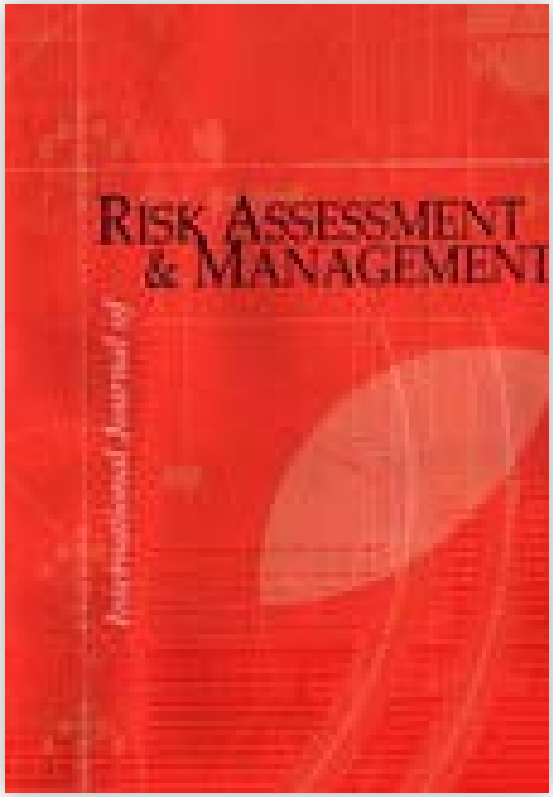


Foundations (cont.)

- Virginia Governor's Commission on Climate Change, 2008.
- Chesapeake Bay Land Subsidence and Sea Level Change, 2010 (VIMS)
- Sea Coast and Sea Level Trends, 2009 (VIMS)
- The Chesapeake Bay and Global Warming, 2007 (NWF)
- Hampton Roads 2030 Long-Range Transportation Plan, 2007 (HRTPO)
- Prioritization of Transportation Projects for Hampton Roads 2035 Long-Range Transportation Plan: Project Evaluation and Scoring-Final Report, 2010 (HRTPO)
- Climate Change in Hampton Roads Phase I: Impacts and Stakeholder Involvement, 2010 (HRPDC)
- Climate Change in Hampton Roads Phase II: Storm Surge Vulnerability and Public Outreach, 2011 (HRPDC)
- Critical Infrastructure Protection and Resiliency Strategic Plan, 2008 (Commonwealth of Virginia)

Int. J. Risk Assessment and Management, Vol. 15, Nos. 2/3, 2011

imate change scenarios: risk and impact analysis r Alaska coastal infrastructure



Priority-setting for Alaska coastal villages vulnerable to erosion and climate change

Karvetski, Lambert, et al. 2011, pp. 258-273

Copy available by email to lambert@virginia.edu

IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS—PART A: SYSTEMS AND HUMANS, VOL. 41, NO. 1, JANUARY 2011

Integration of Decision Analysis and Scenario Planning for Coastal Engineering and Climate Change

Climate change and other scenario impacts to infrastructure systems

Karvetski, Lambert, et al. 2011, Vol. 41(1): pp. 63-73

Copy available by email to lambert@virginia.edu

Journal of Risk Research
Vol. 14, No. 2, February 2011, 191–214

Routledge
Taylor & Francis Group

Scenario-based multiple criteria analysis for infrastructure policy impacts and planning

Multimodal transportation policies influenced by climate change and other scenarios

Schroeder and Lambert
2011, Vol. 14(2): pp. 191-214

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Alaska USA Coastal Erosion

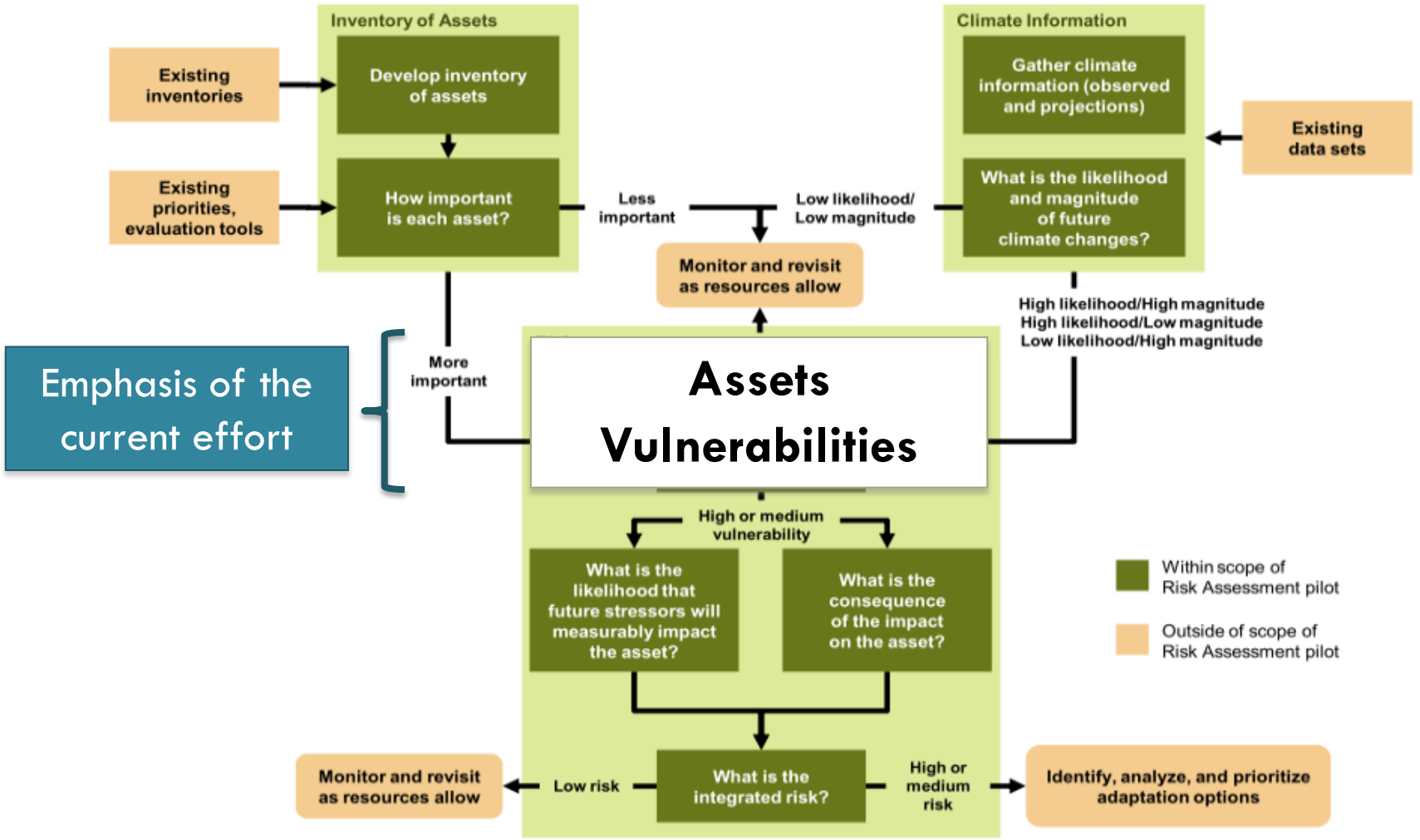
200 communities with erosion concerns and accelerating climate change

Source: Karvetski, C.W., J.H. **Lambert**, et al. 2011. Climate change scenarios: risk and impact analysis for Alaska coastal infrastructure. *Int. J. Risk Assessment and Management*, 15(2/3): 258–274.

Agenda

- Motivation / Purpose
- Foundation
- **Technical Approach**
- Results
- Conclusions

Technical Approach



Technical Approach (cont.)

Step 1.

Understand the Hampton Roads regional long-range transportation plan

Multicriteria analysis of 155 strategic project priorities

Step 2.

Identify climate conditions

Based on survey of Hampton Roads climate change and transportation technical reports

Step 3.

Build climate scenarios

Mixing conditions of climate, maintenance, technology, economy, regulation, etc.

Step 4.

Assess which are the influential scenarios

Technical Approach (cont.)

Step 5. Focus modeling/analysis on the influential scenarios

Step 6. Additional perspectives. Repeat the Steps 1-5, substituting transportation projects by

- **Existing transportation assets**

Highway sections, bridges, tunnels, operations systems

- **Traffic analysis zones (TAZs) vulnerable to climate**

2011 Hampton Roads climate study and others

- **Multimodal transportation policies**

2009 VTrans twenty-year horizon multimodal policies

Performance Criteria

- Three categories of criteria for project priority-setting
  - Project utility
  - Economic vitality
  - Project viability

- Dozens of subcriteria specific to the project types
  - Highway
  - Interchange
  - Bridge/tunnel
  - Intermodal
  - Transit

"Bridge and Tunnel" Weighting Factors		
Criteria and *Subcriteria*	Weighting	# of Criteria
PROJECT UTILITY		
Congestion Level:	30	3
Infrastructure Condition (Bridge Sufficiency, Tunnel Condition, Obsolescence)	20	
Bridges		1
Tunnels		3
System Continuity and Connectivity	10	1
Safety and Security:	10	3
Cost Effectiveness (Cost/VMT)	15	1
Land Use/Future Development Compatibility	10	1
Modal Enhancements:	5	3
PROJECT UTILITY TOTAL	100	16
ECONOMIC VITALITY		
Total Reduction in Travel Time	30	1
Labor Market Access:	20	2
Addresses the Needs of Basic Sector Industries:	30	4
Increases Opportunity:	20	2
ECONOMIC VITALITY TOTAL	*100*	*9*
PROJECT VIABILITY		
Funding	50	1
Process/Project Readiness	50	6
PROJECT VIABILITY TOTAL	*100*	*7*
TOTAL	*300*	*32*

Performance Criteria (cont.)

- Score ranges represent significance among the criteria
- Importance was assessed by TPO/MPO public-involvement activities
- Assessment has not yet considered climate or other worst- and best-case scenarios




Projects of the Long-Range Plan

- Total of 155 projects with thirty-year horizon
- Project are rated on each of the criteria
- Projects are ranked within types (highway, interchange, bridge/tunnel, intermodal, and transit)
- Particular of the projects could be robust to climate scenarios
  - With respect to (i) project scores and (ii) project rankings

Scenarios that Include Climate

- Up to five scenarios
  - Sea-level, seasons, storms, ecosystem, etc.
- Scenarios reflect evidence and experience of diverse stakeholders
- Scenarios mix climate-change with other factors (economic, regulatory, ecological, technological, etc.)
- Scenarios are updated with new available information
- **Question**: Do the scenarios influence or disrupt strategic project priorities of the long-range transportation plan

Scenarios that Include Climate

Scenarios

Conditions

	S1. Scenario 1	S2. Scenario 2	S3. Scenario 3	S4. Scenario 4	S5. Scenario 5
Climate Conditions					
Increase in sea level rise	☑	☑	☑	☑	☑
Increase in storm surge	☑	☑	☑	☑	☑
Increase in precipitation	☐	☐	☐	☐	☐
Increase in stormwater	☐	☐	☐	☐	☐
Increase in storm frequency	☐	☐	☐	☐	☐
Increase in days below freezing	☐	☐	☐	☐	☐
Increase in extreme heat days	☐	☐	☐	☐	☐
Increased occurrence of drought	☐	☐	☐	☐	☐
Non-Climate Conditions					
Economic recession	☐	☑	☐	☐	☐
No further increase on federal government debt cap	☐	☐	☐	☐	☐
Increased wear and ear on public infrastructure	☐	☐	☑	☐	☐
New technology for maintenance / inspection	☐				
Increase in traffic demand	☐				
Increase in area tourism	☐				
Population growth	☐				
Energy shortage	☐				
Changes in land use regulation	☐	☐	☐	☐	☐
Increased infectious desease occurrence	☐	☐	☐	☑	☐
Increased loss of forest and plant life	☐	☐	☐	☑	☐
Increased mortality of native animal species	☐	☐	☐	☐	☐

Combinations of climate conditions

Combinations of non-climate conditions

Scenarios that Include Climate

Scenarios

Criteria

	S1. Scenario 1	S2. Scenario 2	S3. Scenario 3	S4. Scenario 4	S5. Scenario 5
[PU-Highway] Congestion Level					MAJOR INCREASE
[PU-Highway] Continuity and Connectivity					
[PU-Highway] Cost Effectiveness		MAJOR INCREASE	minor decrease		
[PU-Highway] Land Use Pattern Compatibility				MAJOR INCREASE	
[PU-Highway] Safety and Security	minor incre				increase
[PU-Highway] Infrastructure Condition	MAJOR INCR				
[PU-Highway] Modal Enhancements					
[PV-All] Additional Funding					
[PV-All] Prior Commitment					
[PV-All] Federal Mandates	minor decre				
[PV-All] Project Readiness					
[EV-Highway and Bridges/Tunnels] Travel Time Reduction					MAJOR INCREASE
[EV-Highway and Bridges/Tunnels] Labor Market Access		minor decrease			
[EV-Highway and Bridges/Tunnels] Sector Industries Satisfaction					

Adjustments of the criteria importance for each of the five scenarios

Several Perspectives of Prioritization

- Priority-setting for

  (a) Projects, (b) Assets, (c) TAZs, (d) Multimodal policies

- Scenarios may disrupt priority-setting

  in any/all of (a) to (d)

- Adopt existing multi-criteria priority-setting

  tools and find what is the influence of climate change

- Do climate scenarios influence priority-setting in (a) to (d)
- Does climate combine with other emergent conditions to influence priority-setting in (a) to (d)

  –Economic, regulatory, maintenance/repair, demographic, environmental, others

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Sample of Results

Projects Scores and Prioritization under Climate-Change Scenarios

Projects Scores

Below are the scores (out of 100, with 100 being the best) that each project received under the baseline and each scenario.

Projects …

Scenarios

Project Scores

	Bri…	Bri…	Bri…	Bri…	Bri…	Bri…	Bri…	Bri…	Bri…	Bri…	Bri…	Bri…	Bri…	Bri…	Bri…
	Inte…	Inte…	Inte…	Inte…	Inte…	Inte…	Inte…	Inte…	Prim…	Prim…	Prim…	Urba…	Urba…	Urba…	Urba…
Baseline	207	202	201	190	187	178	171	160	242	220	176	173	165	150	139
S1. Scenario 1	207	202	201	190	187	178	171	160	242	220	176	173	165	150	139
	206	202	201	188	185	178	1					3		150	140
	207	202	201	190	187	178	1					5		150	139
S4. Scenario 4	207	202	201	190	187	178	171	160	242	220	176	173	165	150	139
S5. Scenario 5	211	202	201	173	170	167	174	147	231	212	183	160	157	148	130
Base Score	211	202	201	190	187	178	174	160	242	220	183	173	165	150	140

Sample of Results (cont.)

Project Rankings

The project rankings table below provides the ranking of each design for each scenario.
The first project ranking within each scenario is considered to be the best performing.

Projects …

	Bridge Interstate	Bridge Interstate	Bridge Interstate	Bridge Interstate	Bridge Interstate	Bridge Interstate	Bridge Interstate	Bridge Interstate	Bridge Primary	Bridge Primary	Bridge Primary	Bridge Urban	Bridge Urban	Bridge Urban	Bridge Urban	Bridge Urban
Baseline	1	2	3	4	5	6	7	8	1	2	3	1	2	3	4	5
S1. Scenario 1	1	2	3	4	5	6	7	8	1	2	3	1	2	3	4	5
	1	2	3	4	5	6								3	4	5
	1	2	3	4	5	6								3	4	5
S4. Scenario 4	1	2	3	4	5	6	7	8	1	2	3	1	2	3	4	5
S5. Scenario 5	1	2	3	5	6	7	4	8	1	2	3	1	2	3	5	4
Base Ranking	1	2	3	4	5	6	7	8	1	2	3	1	2	3	4	5

Scenarios

Project Ranking

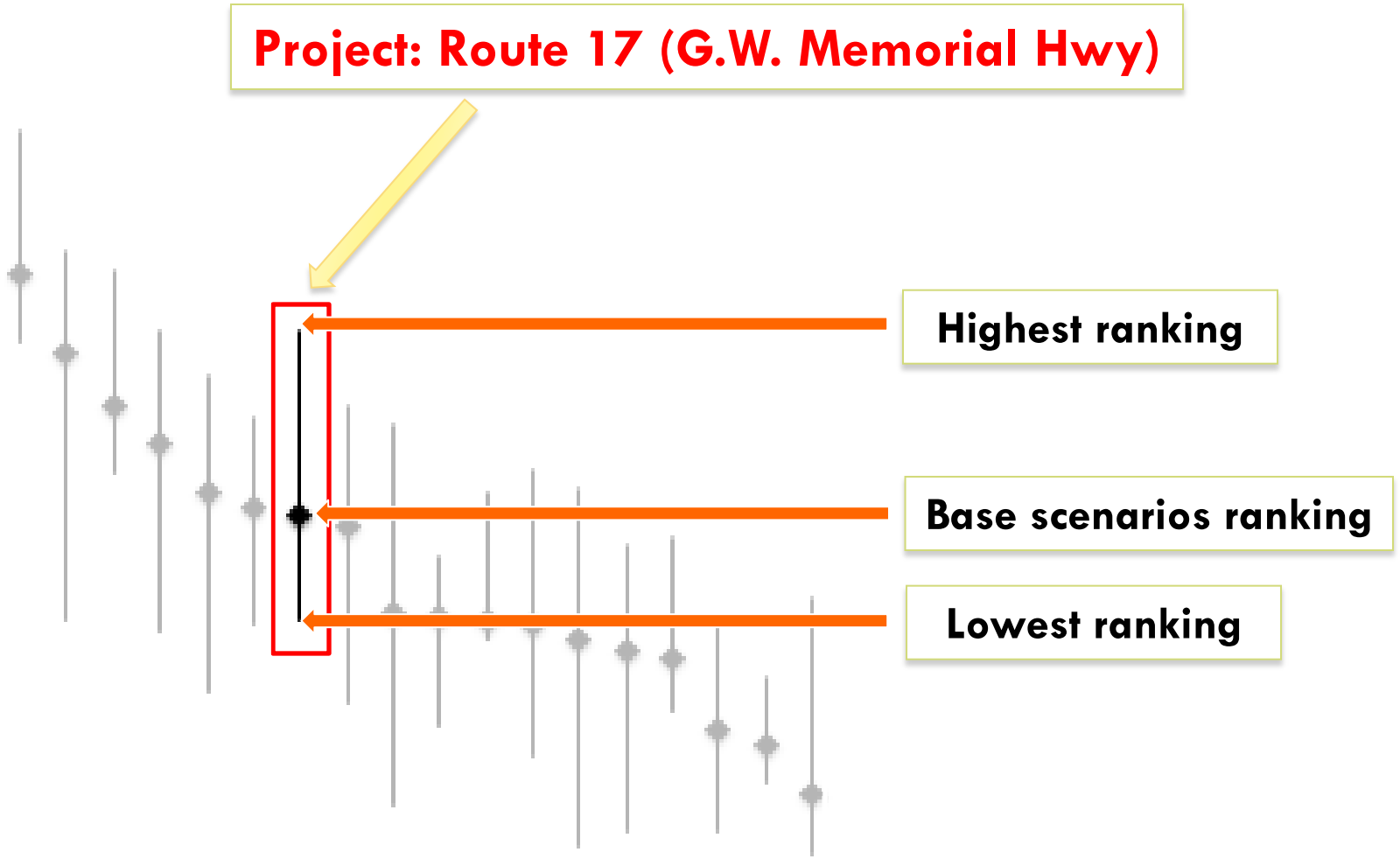
Sample of Results (cont.)

155 Strategic Transportation Projects

Each vertical bar indicates sensitivity of project ranking to climate scenarios

Project rankings

Sample of Results (cont.)



Sample of Results (cont.)

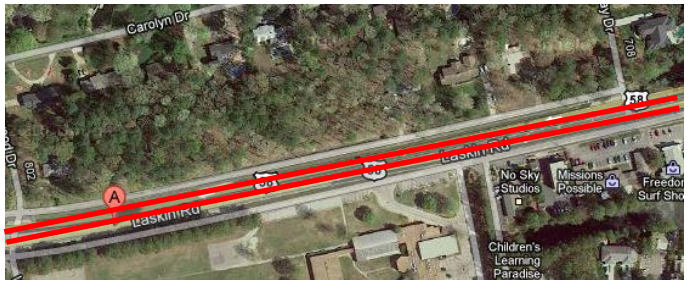
Dam Neck Road

Baseline Ranking	**18**
Highest Ranking	**3** (S5. Traffic Scenario)
Lowest Ranking	**20** (S4. Ecology Scenario)
Influential Criterion	PU-HW.C1 Congestion Level

Dam Neck Road

Laskin Road

Laskin Road

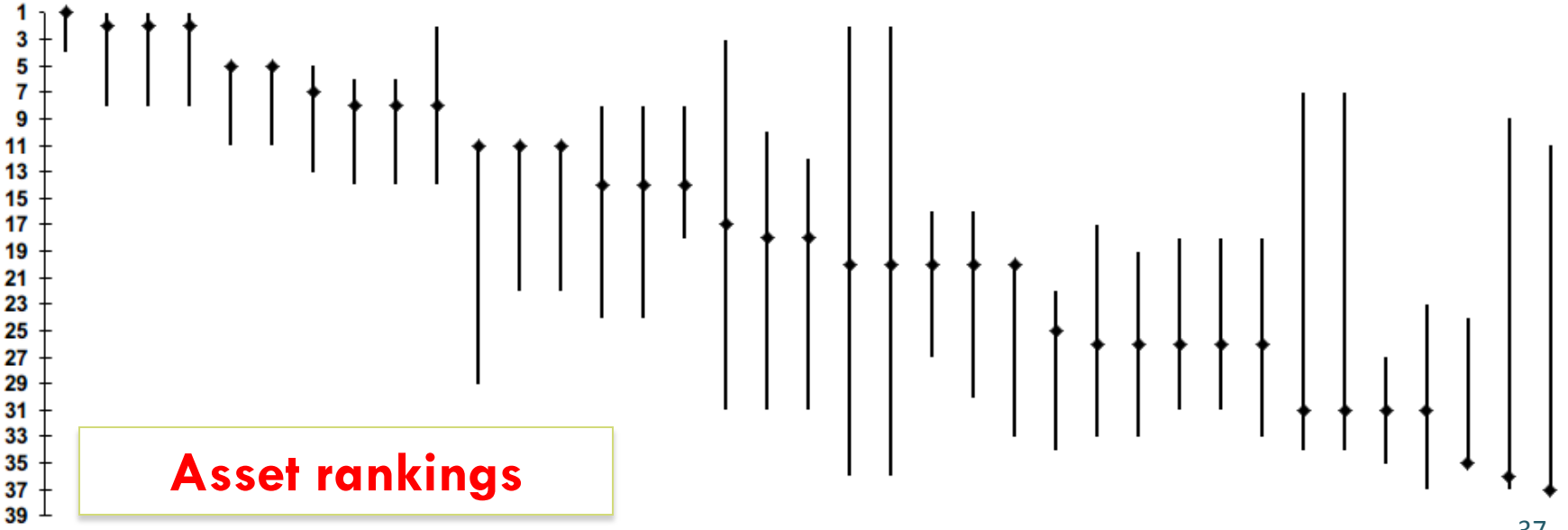


Baseline Ranking	**20**
Highest Ranking	**15** (S1. Climate Scenario)
Lowest Ranking	**42** (S2. Economy Scenario)
Influential Criterion	PU-HW.C3 Cost Effectiveness

Sample of Results (cont.)

Perspective: Priority-Setting of Transportation Assets

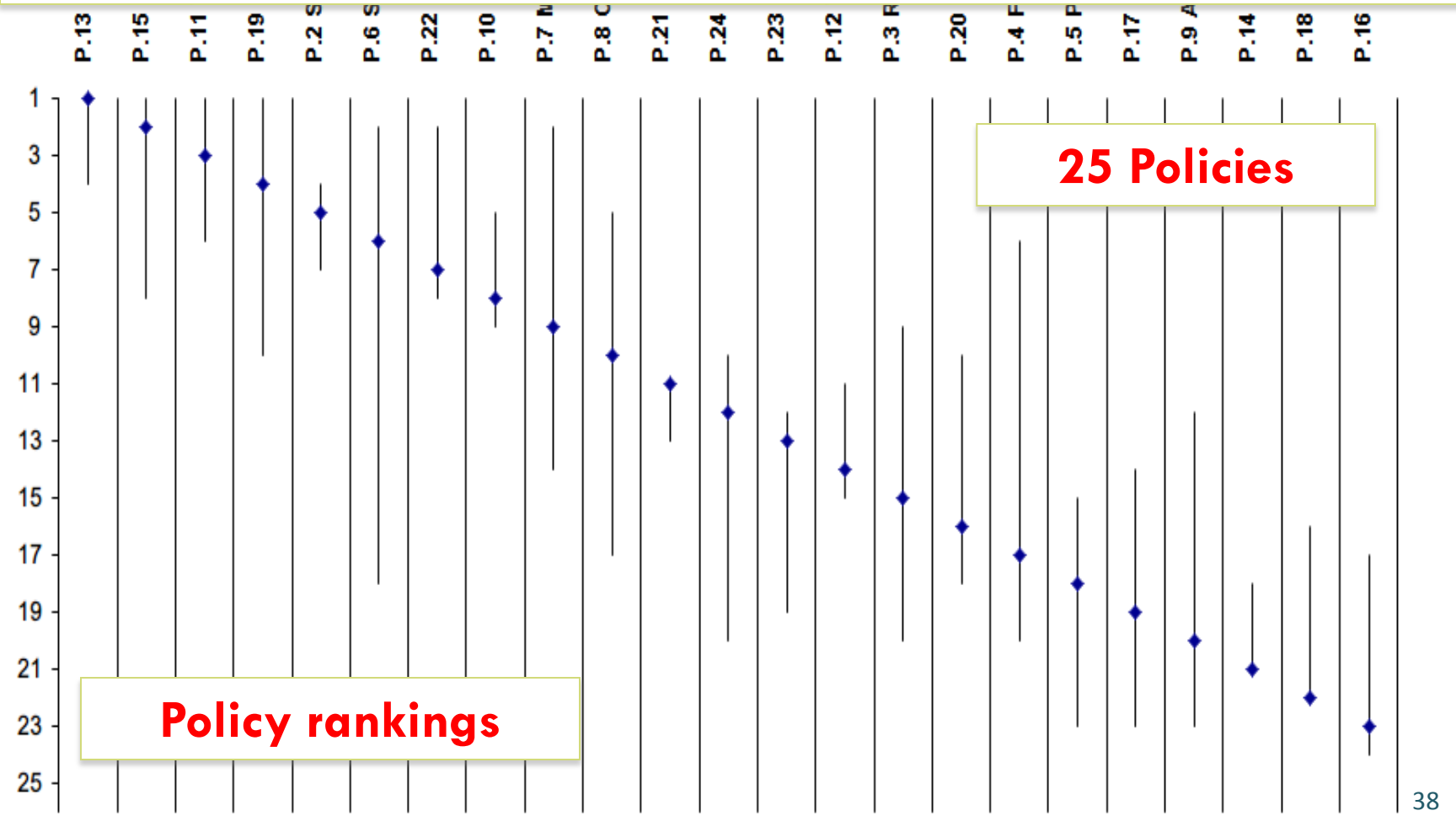
37 Assets



Asset rankings

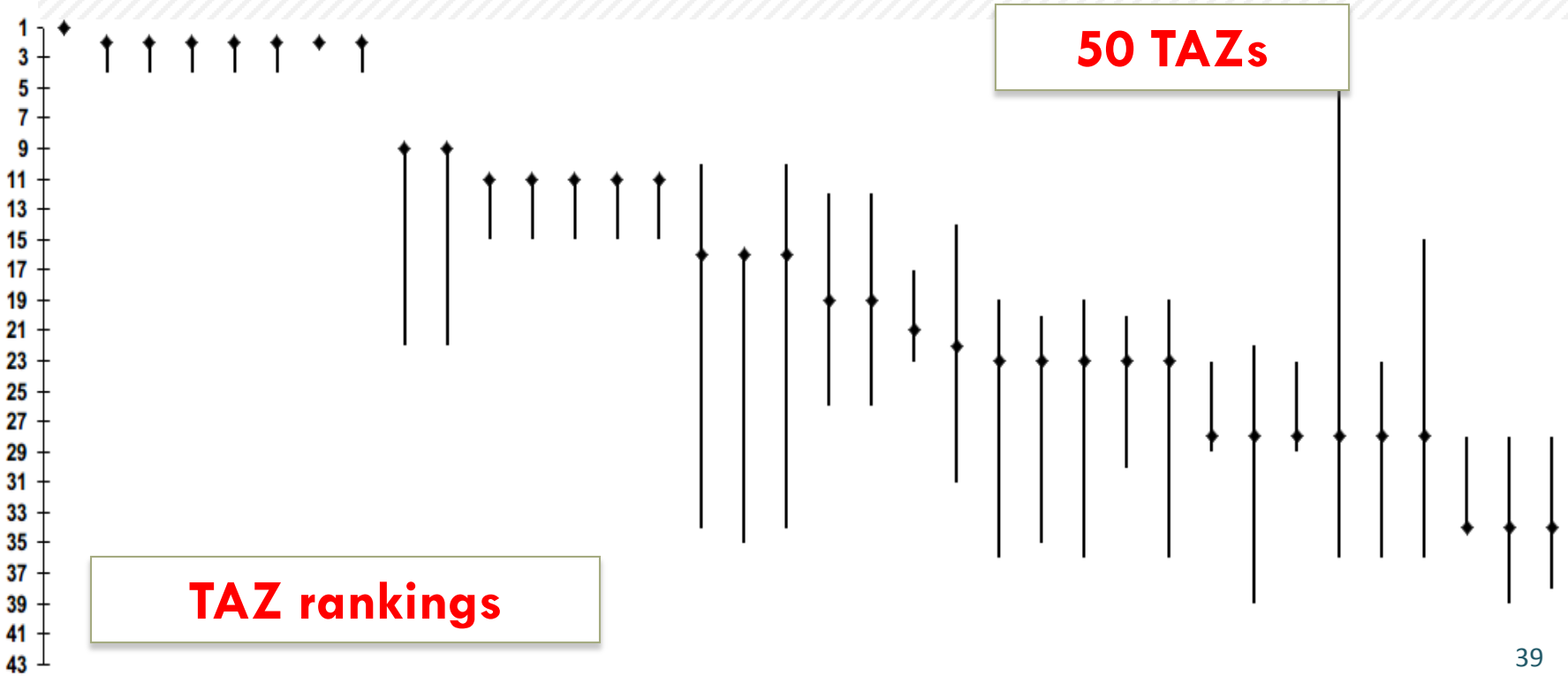
Sample of Results (cont.)

Perspective: Priority-Setting of Multimodal Policies



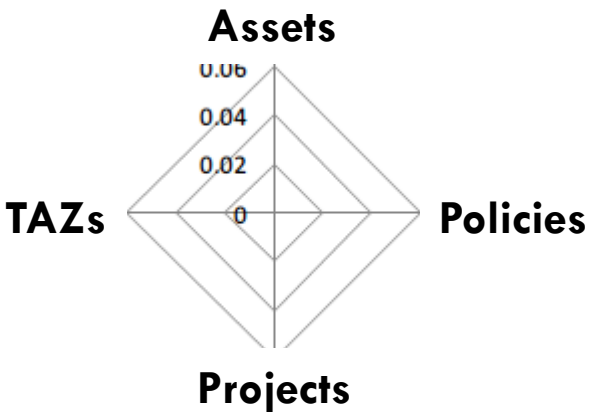
Sample of Results (cont.)

Perspective: Priority-Setting for Vulnerability of Traffic Analysis Zones

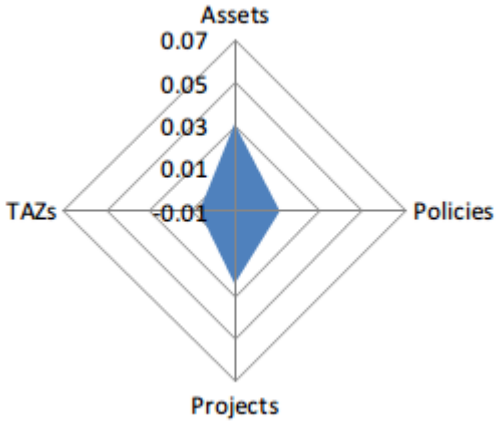


Sample of Results (cont.)

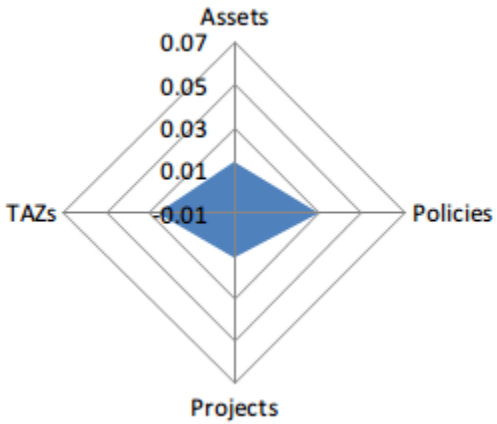
S0. Base Scenario



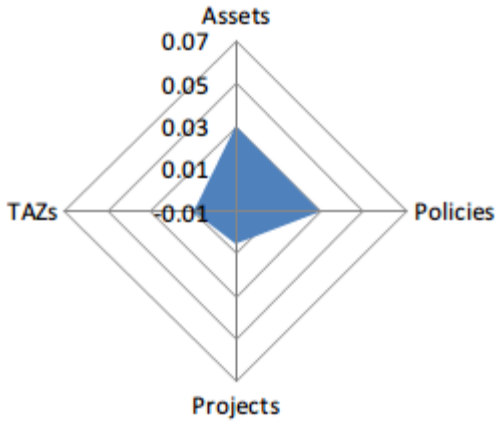
S1. Climate Change



S2. Climate + Economy

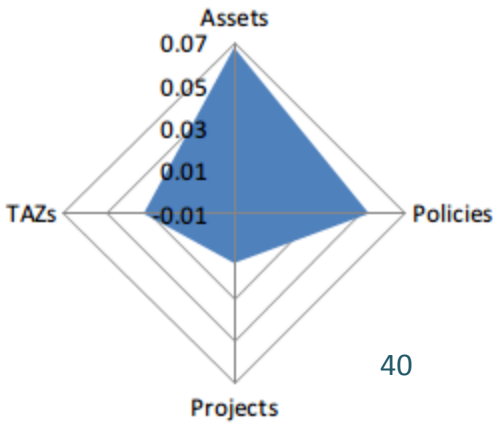


S3. Climate + Wear / Tear



S4. Climate + Ecology

S5. Climate + Traffic Demand



Sample of Results (cont.)

Influential Scenarios

	Priority-Setting in Several Perspectives			
	Projects	Assets	TAZs	Policies
S1. Climate Change	*			
S2. + Economy			*	
S3. + Wear and tear				
S4. + Ecology				
S5. + Traffic demand		*	*	*

* = most influential scenario(s)

Sample of Results (cont.)

- Implementation and impact to decision making
  - Results influenced priority-setting in the Long Range Transportation Plans
  - Methods are transferred to other states via a website
- Workshops and trainings
  - Hampton Roads Planning District Commission
  - Hampton Roads Transportation Planning Organization
  - Virginia Department of Transportation
  - Others

Sample of Results (cont.)

Publication #1. "Climate change influence on priority setting for transportation infrastructure assets"

Focuses on Hampton Roads transportation assets

Copy available by email to lambert @virginia. edu

Lambert, J.H. et al. 2013. *ASCE Journal of Infrastructure Systems*. 19(1):36-46.

Sample of Results (cont.)

Publication #2. "Quantifying the influence of climate change to priorities for infrastructure projects"

Focuses on projects of the 2034 Hampton Roads Long-Range Transportation Plan

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You, H., J.H. Lambert, et al. 2014. IEEE *Transactions on Systems Man and Cybernetics: Systems*. 44(2):133-145.

Sample of Results (cont.)

Publication #3. "Climate and other scenarios disrupt priorities in several management perspectives. "

Focuses on climate impacts to priorities for policies, projects, assets, geographic locations, etc.

Copy available by email to lambert @virginia. edu

You, H., E.B. Connelly, J.H. Lambert, and A.F. Clarens 2015. Springer journal *Environment Systems & Decisions.* 34:540–554.

Agenda

- Motivation / Purpose
- Foundation
- Technical Approach
- Results
- **Conclusions**

Summary

Addressed priority-setting for projects, policies, TAZs, and assets

Studied the influence of climate scenarios to long-range transportation plans

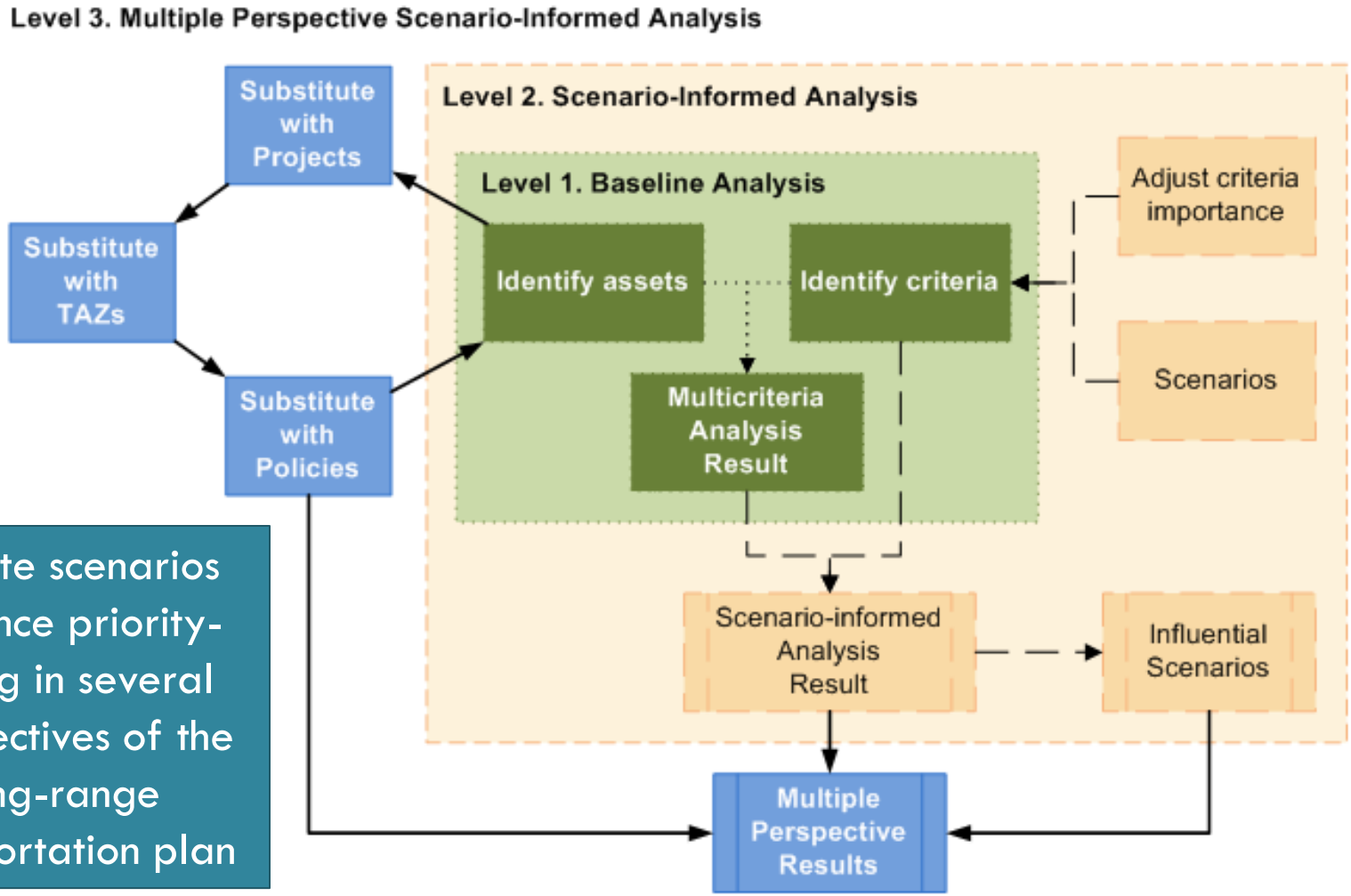
Performed a case study in the region of Hampton Roads, VA

Provided the Excel workbook tools for use by TPOs/MPOs in regions across the nation

Summary (cont.)

- The Virginia pilot has supported the FHWA conceptual model, in three layers:
  - Layer 1: Multicriteria priorities of the regional *Long-Range Transportation Plan*
  - Layer 2: Climate scenarios influence priorities for transportation projects
  - Layer 3: Climate scenarios influence four types of priorities (projects, assets, locations-TAZs, and policies)

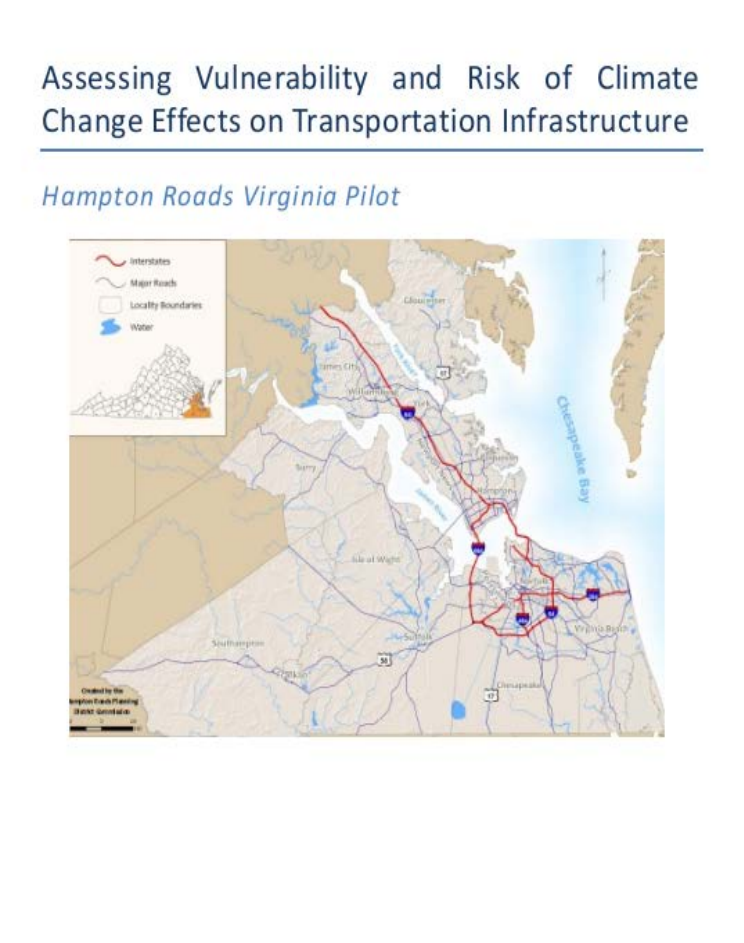
Summary (cont.)



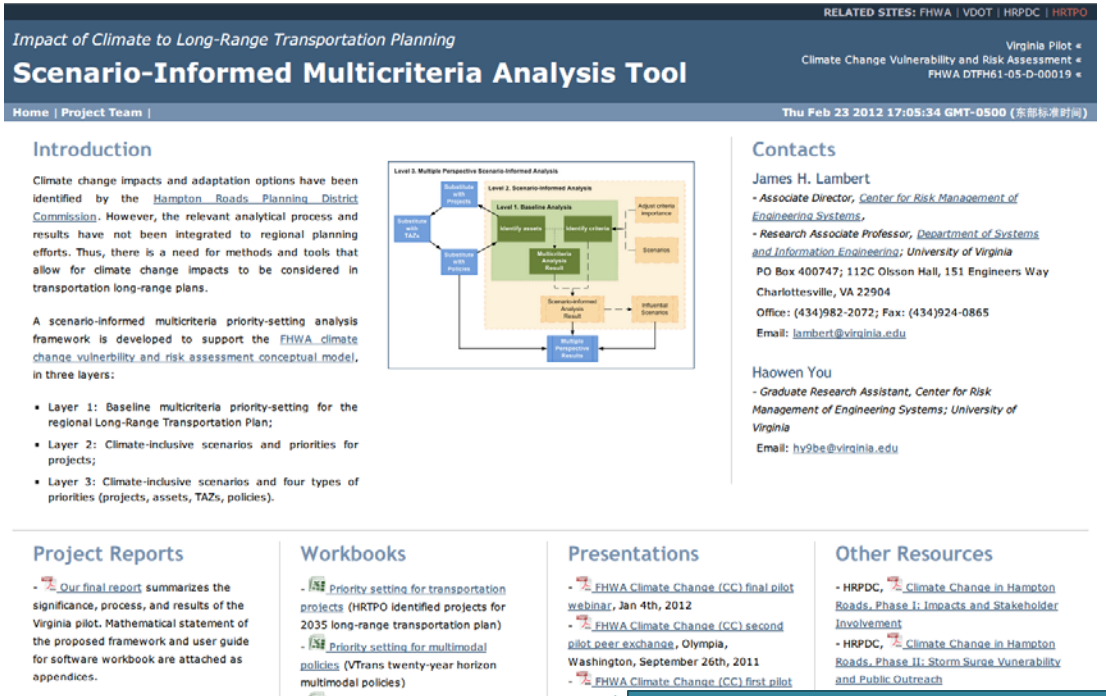
Climate scenarios influence priority-setting in several perspectives of the long-range transportation plan

Summary (cont.)

- A final report describes the significance, methods, and results of the Virginia pilot
- Appendices
  - User guide for software workbook tool
  - Mathematical statement of the Virginia framework



Summary (cont.)



RELATED SITES: FHWA | VDOT | HRPDC | HRTPO

Impact of Climate to Long-Range Transportation Planning

Scenario-Informed Multicriteria Analysis Tool

Virginia Pilot «
Climate Change Vulnerability and Risk Assessment «
FHWA DTFH61-05-D-00019 «

Home | Project Team |

Thu Feb 23 2012 17:05:34 GMT-0500 (东部标准时间)

Introduction

Climate change impacts and adaptation options have been identified by the Hampton Roads Planning District Commission. However, the relevant analytical process and results have not been integrated to regional planning efforts. Thus, there is a need for methods and tools that allow for climate change impacts to be considered in transportation long-range plans.

A scenario-informed multicriteria priority-setting analysis framework is developed to support the FHWA climate change vulnerbility and risk assessment conceptual model, in three layers:

- Layer 1: Baseline multicriteria priority-setting for the regional Long-Range Transportation Plan;
- Layer 2: Climate-inclusive scenarios and priorities for projects;
- Layer 3: Climate-inclusive scenarios and four types of priorities (projects, assets, TAZs, policies).

Contacts

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Project Reports

- Our final report summarizes the significance, process, and results of the Virginia pilot. Mathematical statement of the proposed framework and user guide for software workbook are attached as appendices.

Workbooks

- Priority setting for transportation projects (HRTPO identified projects for 2035 long-range transportation plan)
- Priority setting for multimodal policies (VTrans twenty-year horizon multimodal policies)
- Priority setting for infrastructure assets (Highway, bridges, tunnels, operations systems)
- Priority setting for traffic analysis zones (TAZs) vulnerable to climate (HRPDC studies identified Hampton Roads locations)

Presentations

- FHWA Climate Change (CC) final pilot webinar, Jan 4th, 2012
- FHWA Climate Change (CC) second pilot peer exchange, Olympia, Washington, September 26th, 2011
- FHWA Climate Change (CC) first pilot peer excha
4th, 2011

Other Resources

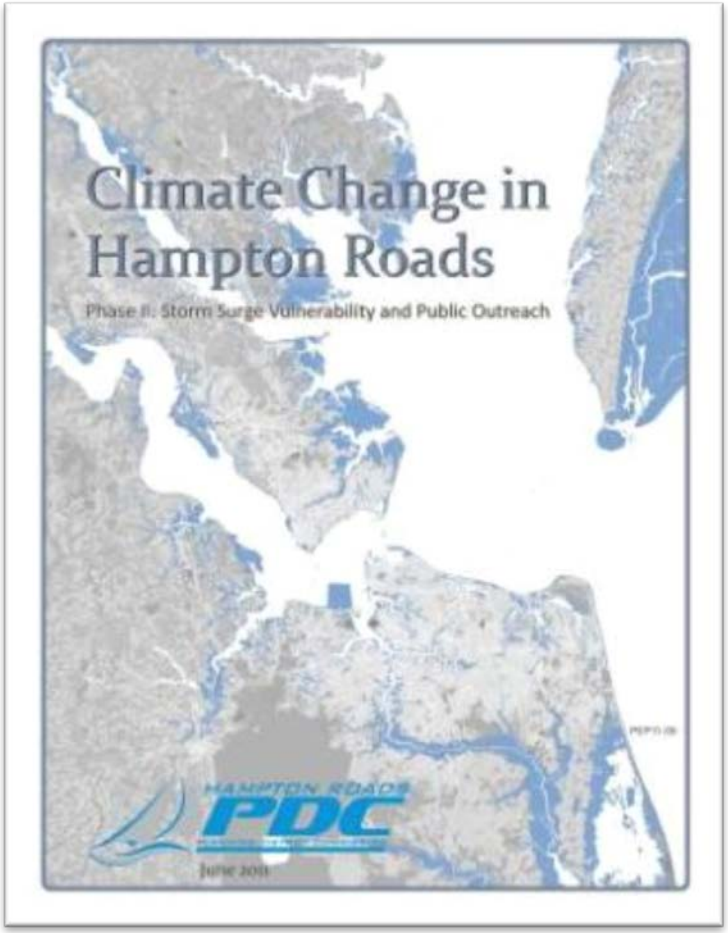
- HRPDC, Climate Change in Hampton Roads, Phase I: Impacts and Stakeholder Involvement
- HRPDC, Climate Change in Hampton Roads, Phase II: Storm Surge Vunerability and Public Outreach

Workbooks made available for technology transfer at:

http://www.virginia.edu/crmes/fhwa_climate/

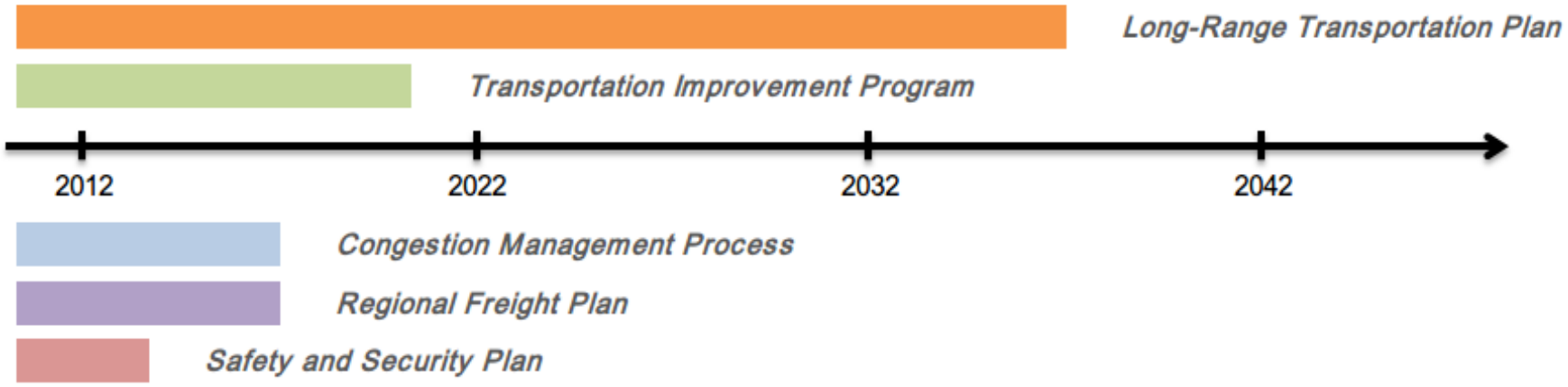
Lessons Learned and Needs

Lesson 1. Ample scientific work including models of climate impacts was available at the initiation of the studies.



Lessons Learned and Needs (cont.)

Lesson 2. The *long-range transportation plan* is an appropriate venue for addressing the impacts of climate change in decision making.



Twenty- to thirty-year horizon of the regional planning efforts

Lessons Learned and Needs (cont.)

Lesson 3. The transportation planners (MPO) used existing scientific and engineering results on climate change for the long-range plan, with effective use of the staff and available resources.

Lessons Learned and Needs (cont.)

Lesson 4. Climate influenced priority-setting in several perspectives of the long-range transportation plan: (i) Projects, (ii) Assets, (iii) Multimodal policies and (iv) Traffic analysis zones.

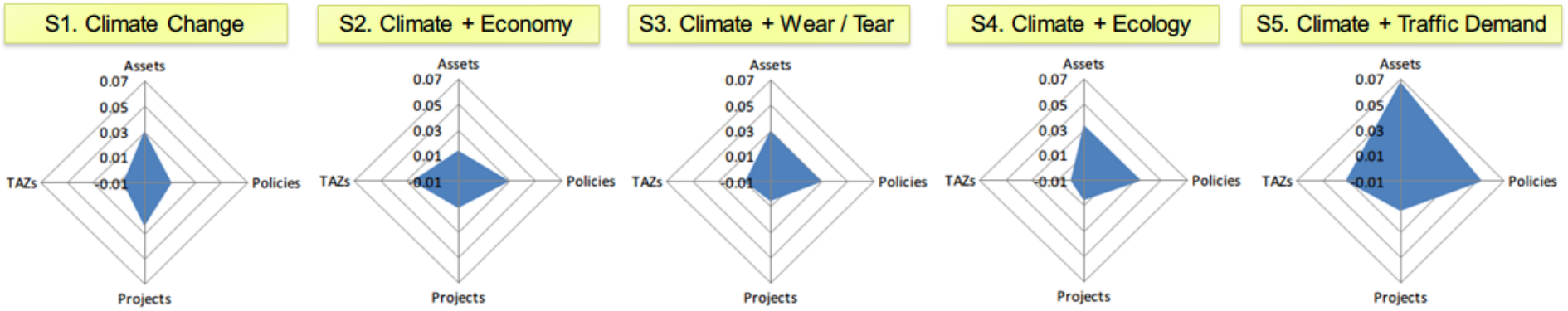
Lessons Learned and Needs (cont.)

Lesson 5. Climate combined with other factors, including *economics*, *ecology*, *travel demands*, *wear and tear*, *land use*, *regulation*, *energy policies*, *technology*, etc.., to influence priority-setting.



Lessons Learned and Needs (cont.)

Lesson 6. The results identified the most influential scenarios for priority-setting. With each update of the long-range plan, our results helped in the allocation of resources.



Most influential scenario for priority-setting: *Sea-level rise* and *storm surge* combined with *increase in traffic demand*

Lessons Learned and Needs (cont.)

Lesson 7. The framework has been effective in education and training of agency officials et al.

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Center for Transportation Studies

Lessons Learned and Needs (cont.)

Lesson 8. The approach is transferable to the nation.

The software workbook tools are provided via a website:

RELATED SITES: FHWA | VDOT | HRPDC | HRTPO

Impact of Climate to Long-Range Transportation Planning

Scenario-Informed Multicriteria Analysis Tool

Virginia Pilot «
Climate Change Vulnerability and Risk Assessment «
FHWA DTFH61-05-D-00019 «

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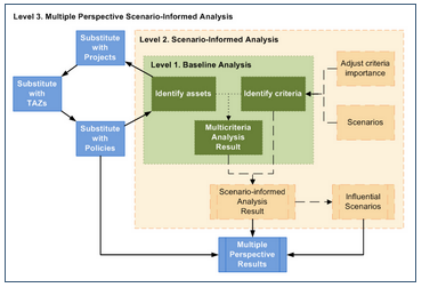

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Lessons Learned and Needs (cont.)

- *Asset* vulnerability is insufficient to address climate change -- must address several planning elements

  Assets, projects, policies, locations (TAZs), other elements…

- Climate change intersects actual decision making in a region's Long Range Transportation Plan

  Time horizon of thirty years or more, updated every four to five years mandated by federal and state laws

- Climate change influences priority-setting both *alone* and in *combination* with other factors

  Travel demand, economic, wear and tear, ecology, technology, others

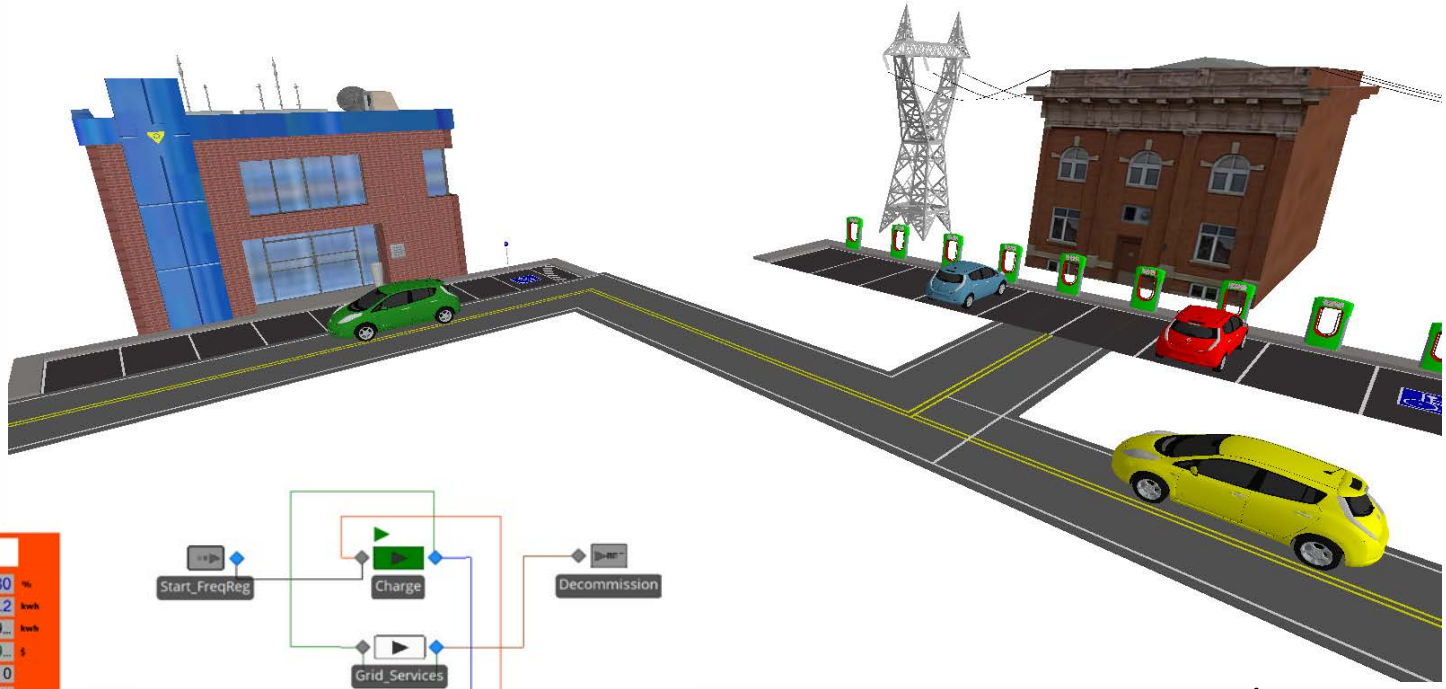
Mobile Grid

V EHICLE

2

G RID

Resilience of Energy, Transportation, and Communications Infrastructures



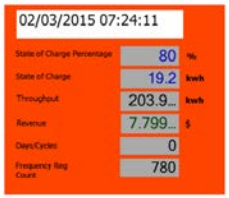
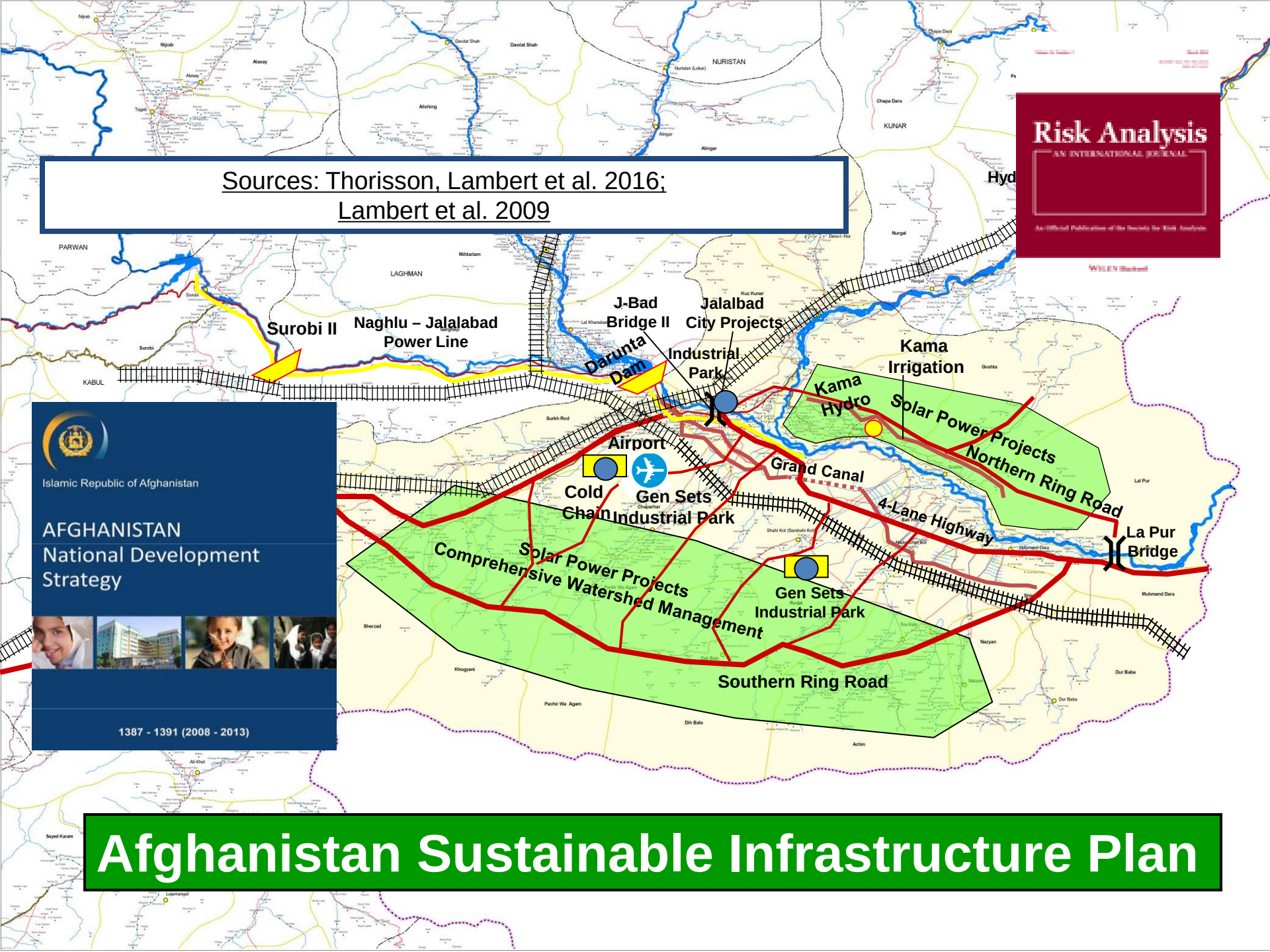


FIGURE 3
EXAMPLE OF SIMIO SIMULATION OUTPUT

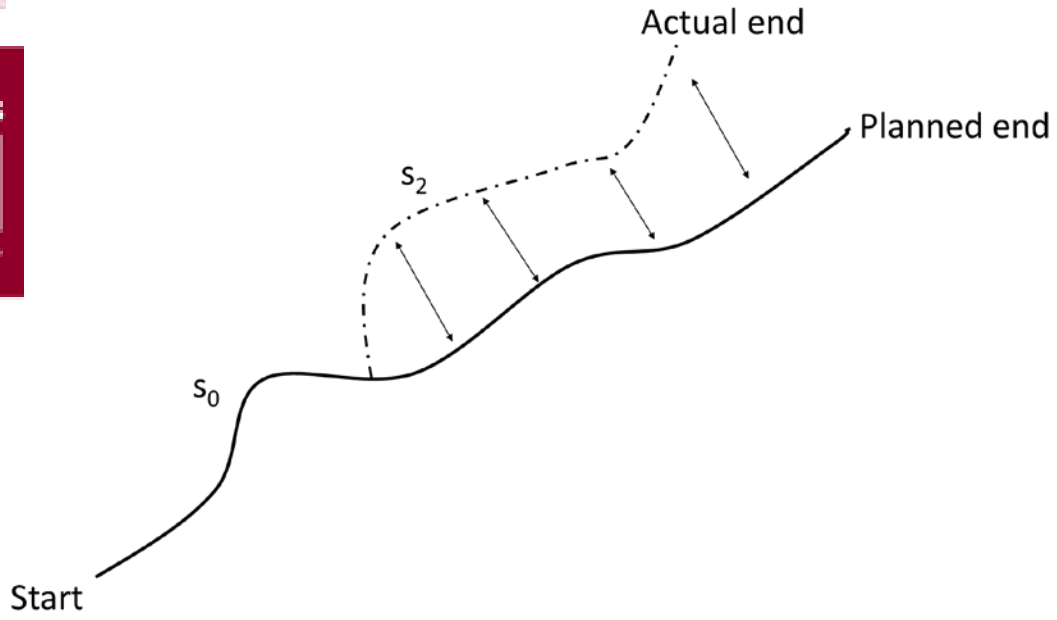
FIGURE 2
SIMIO MODEL OF INTEGRATED GRID AND LOGISTICS SERVICES

Best Paper Award, 2015 IEEE Systems and Information Engineering Design Symposium



Afghanistan Sustainable Infrastructure Plan

Disruptions inform *resilience*, an evolution of priorities in time.



c)

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www.virginia.edu/crmes/fhwa_climate