Macro Level Analysis of the Impacts of Sea-level Rise on Pavements Structural Capacity

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And
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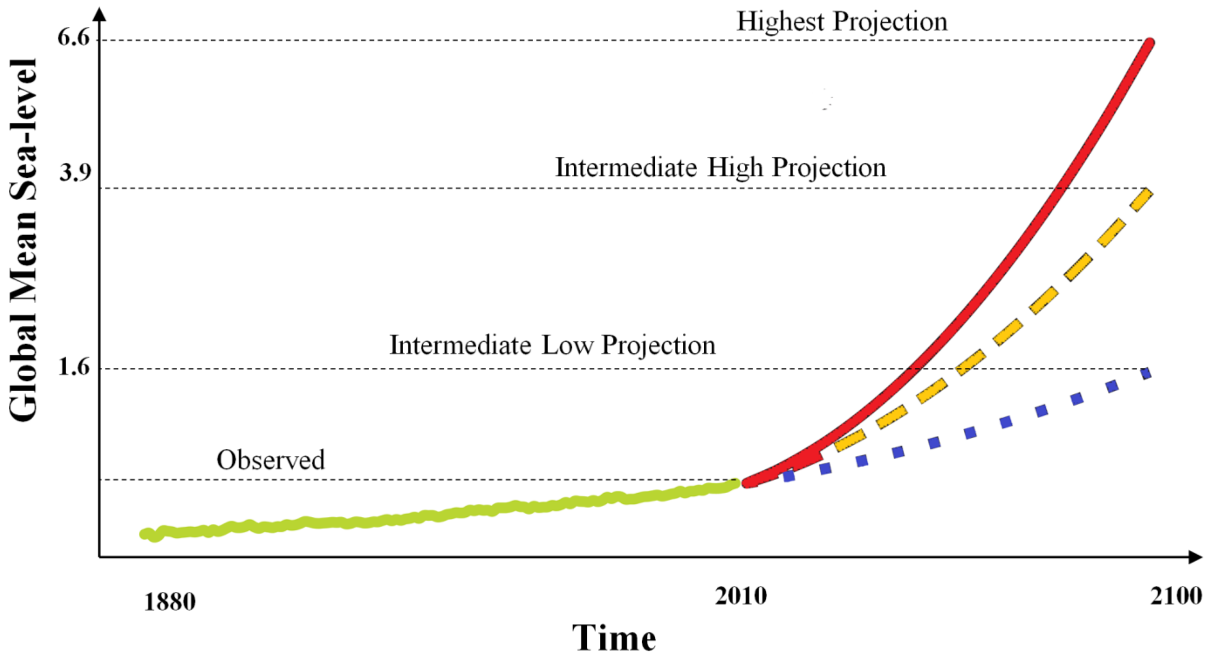
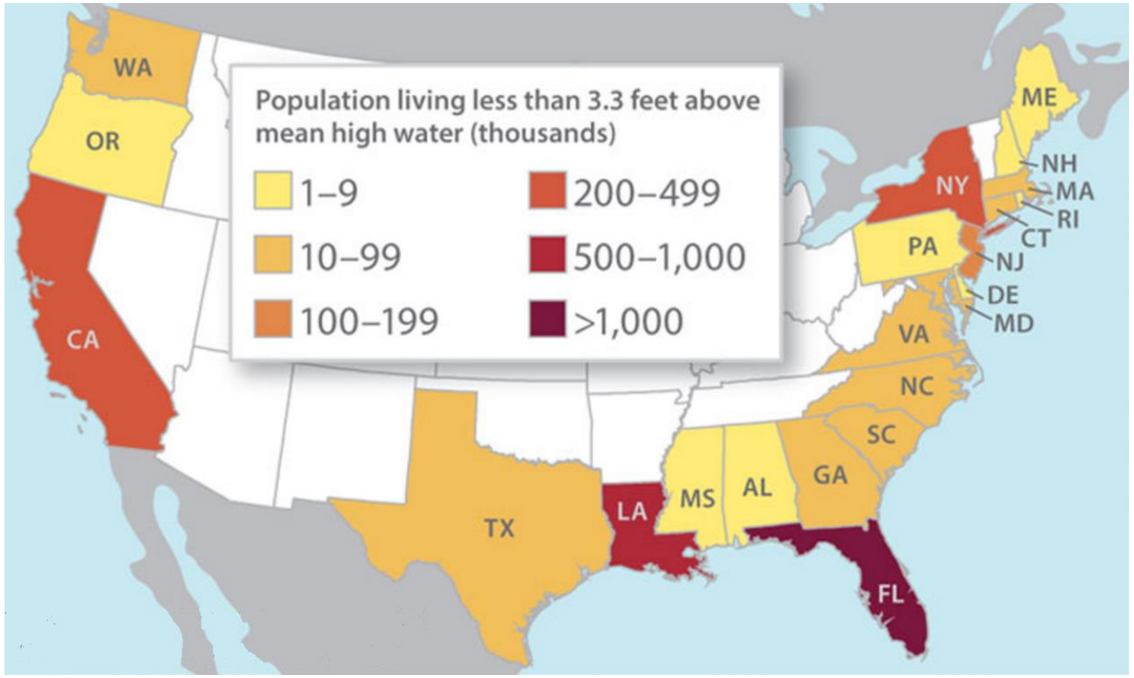
1 Problem Statement

Sea-level is rising due to climate change which will increasingly affect densely populated communities in low-lying coastal regions (IPCC 2014).



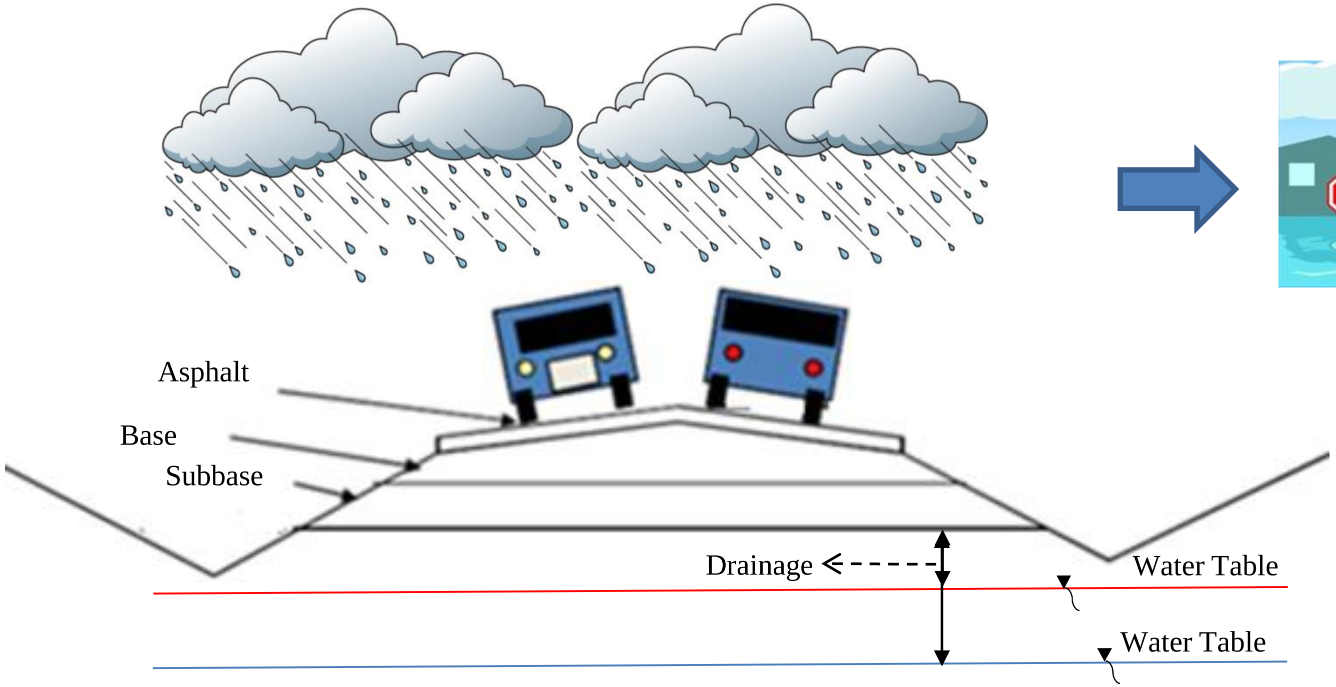
(Climate Central 2011)



(NOAA 2015)

1 Problem Statement

Loss of Functionality & Performance of Roadway Infrastructure is one of the most remarkable impacts of sea-level rise (SLR) (Compact 2012).



1 Problem Statement

Adaptation means anticipating the adverse effects of climate change and taking appropriate action to prevent or minimize the damage they can cause (IPCC 2014).

More frequent M&R

Roadway Damage

Traffic disruption

Economic Impact

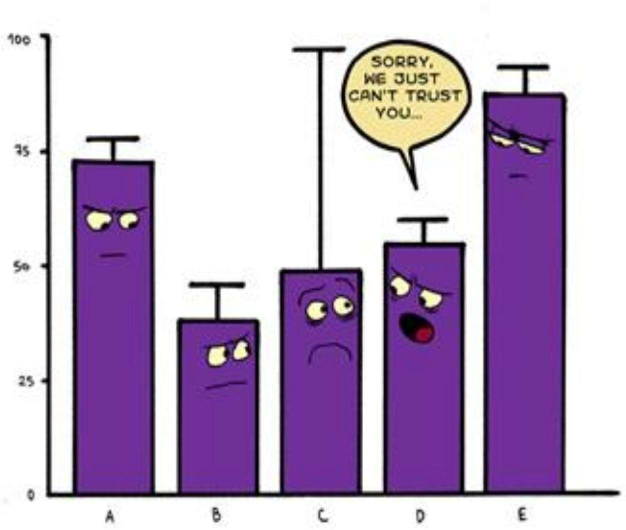
Environmental Impact

Social Impact

"If we don't adapt to sea level rise, the consequences will be quite dramatic through the 21st century" *(Climate Central 2014)*

1 Problem Statement

Effective adaptation to SLR requires an understanding of the long-term impacts of SLR and adaptation on roadway infrastructure.



Uncertainty in the Magnitude and Frequency of SLR

Adaptive Behavior of Social Actors

Complexity of Evaluating Impacts of SLR

1 Problem Statement

<u>The existing approaches for evaluating the impacts of SLR do not consider the evolving conditions of roadway networks.</u>

Assess the impacts based on the existing conditions of assets.

Asset conditions will evolve due to deterioration and dynamic decision making of social actors.

2 Research Objective

To provide a better understanding of sea-level rise adaptation by answering the following important questions:

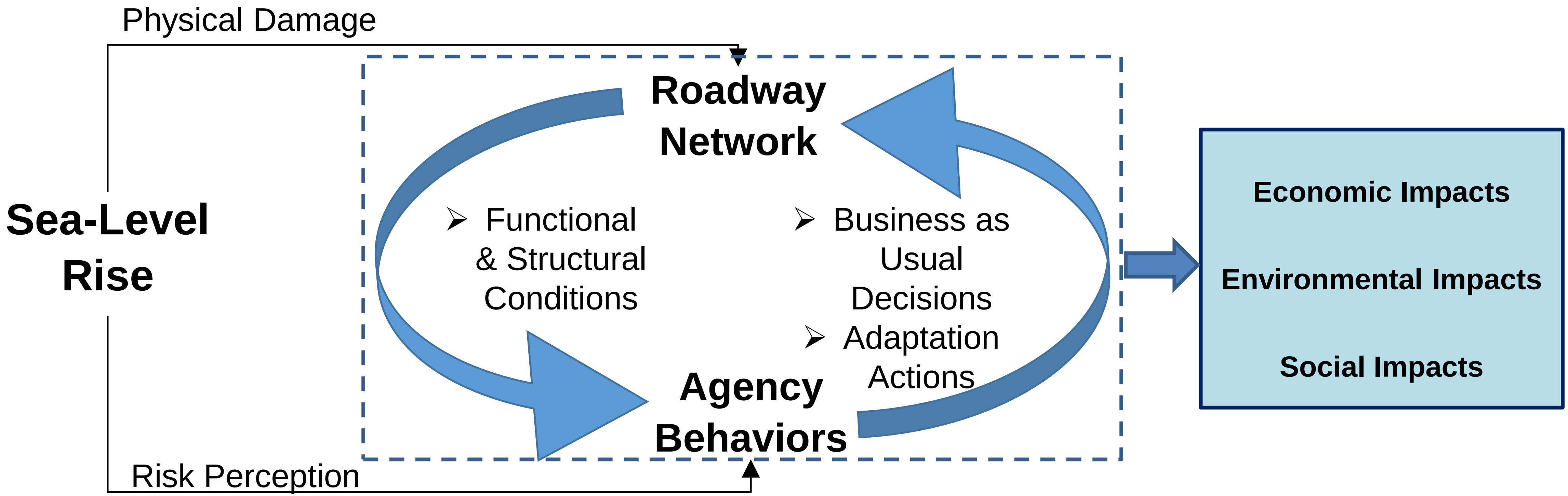
Question #1
- What are the long-term impacts of SLR on economic, environmental, and social performance of roadway infrastructure systems?

Question #2
- What adaptation strategies can mitigate the long-term impacts of SLR on roadway infrastructure?

Question #3
- What adaptation planning approach is more effective for dealing with the SLR uncertainty?

3 Research Framework

SLR affects the economic, environmental, and social performance of roadway infrastructure by influencing the interactions between agency and network.



4 Research Hypotheses

This research tests the following three hypothesis:

Hypothesis 1

- The long-term performance of roadway infrastructure is sensitive to future scenarios of SLR.

Hypothesis 2

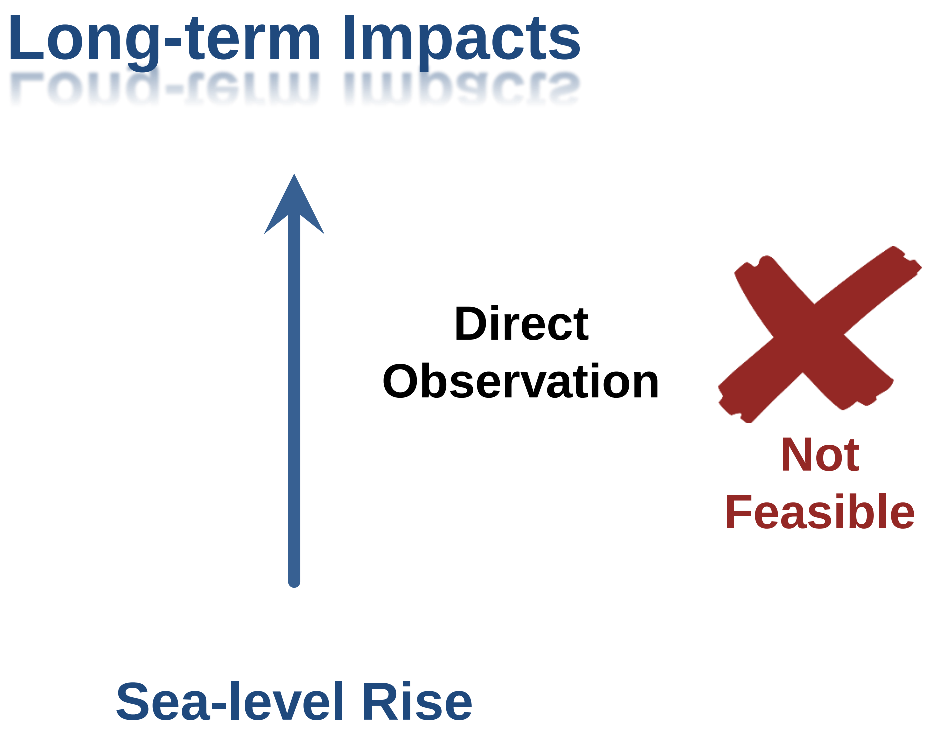
- A set of adaptation actions exist that could mitigate the impacts of SLR on roadway infrastructure across different SLR scenarios.

Hypothesis 3

- An adaptation planning approach based on periodic evaluation of uncertainty reduces SLR impacts on a roadway network.

5 Research Method

A simulation approach is adopted to capture the behaviors and interactions of physical network and agency.



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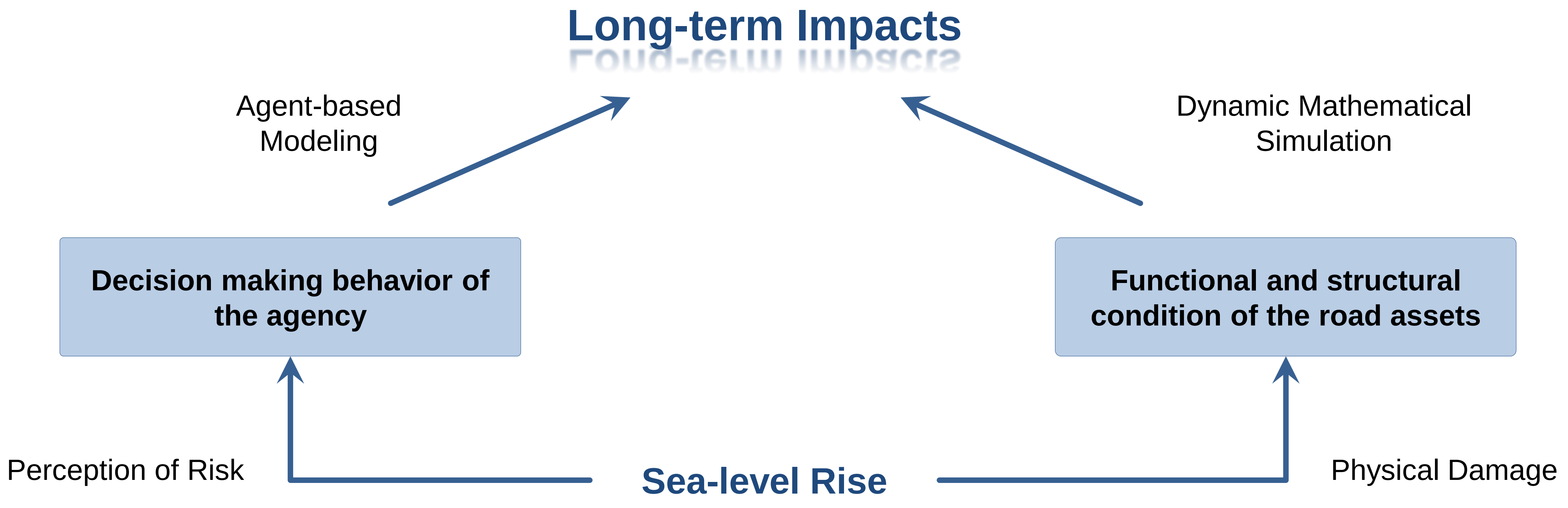
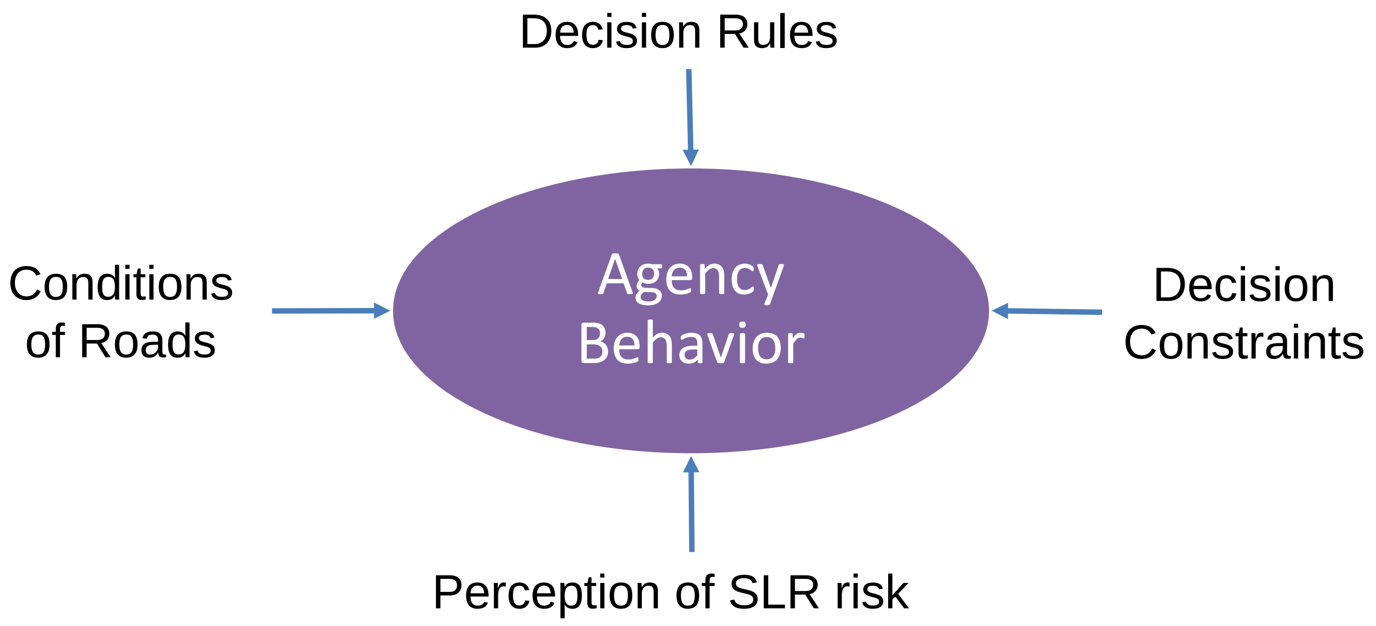


6 Research Design

Design for Testing Hypothesis #1 | Design for Testing Hypothesis #2 | Design for Testing Hypothesis #3

A three step process is followed to test hypothesis 1.

Step 1: Abstracting Behaviors of Agents



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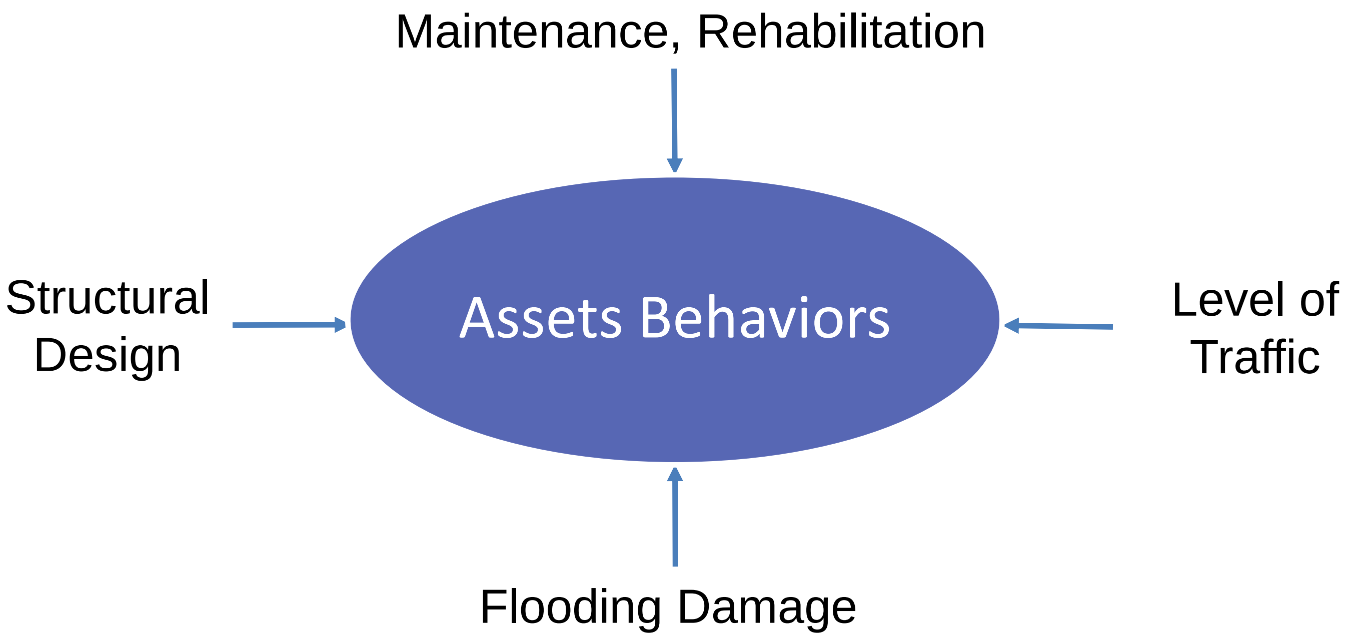
Step 1: Abstracting Behaviors of Agents

Behaviors of Road Assets
- Performance Condition
-Structural Condition



6 Research Design

A three step process is followed to test hypothesis 1.

Step 1: Abstracting Behaviors of Agents

Behaviors of Agency
- Business as Usual Decisions
-Adaptation Actions

Behaviors of Road Assets
- Performance Condition
-Structural Condition

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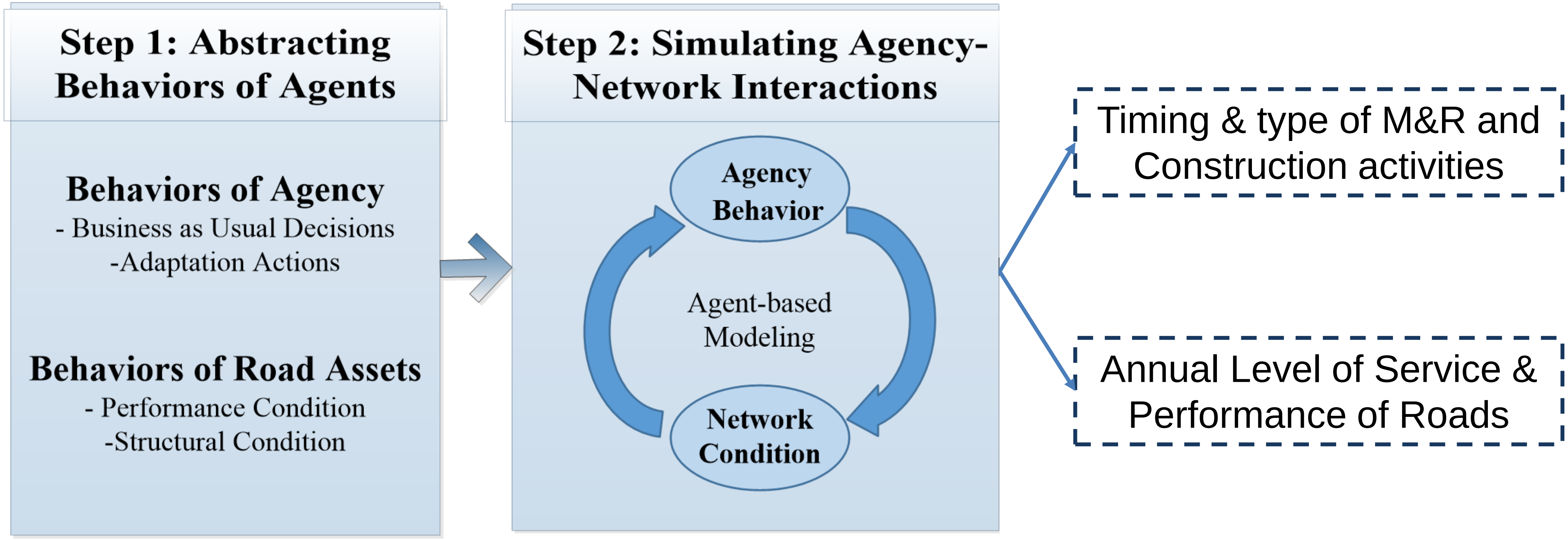

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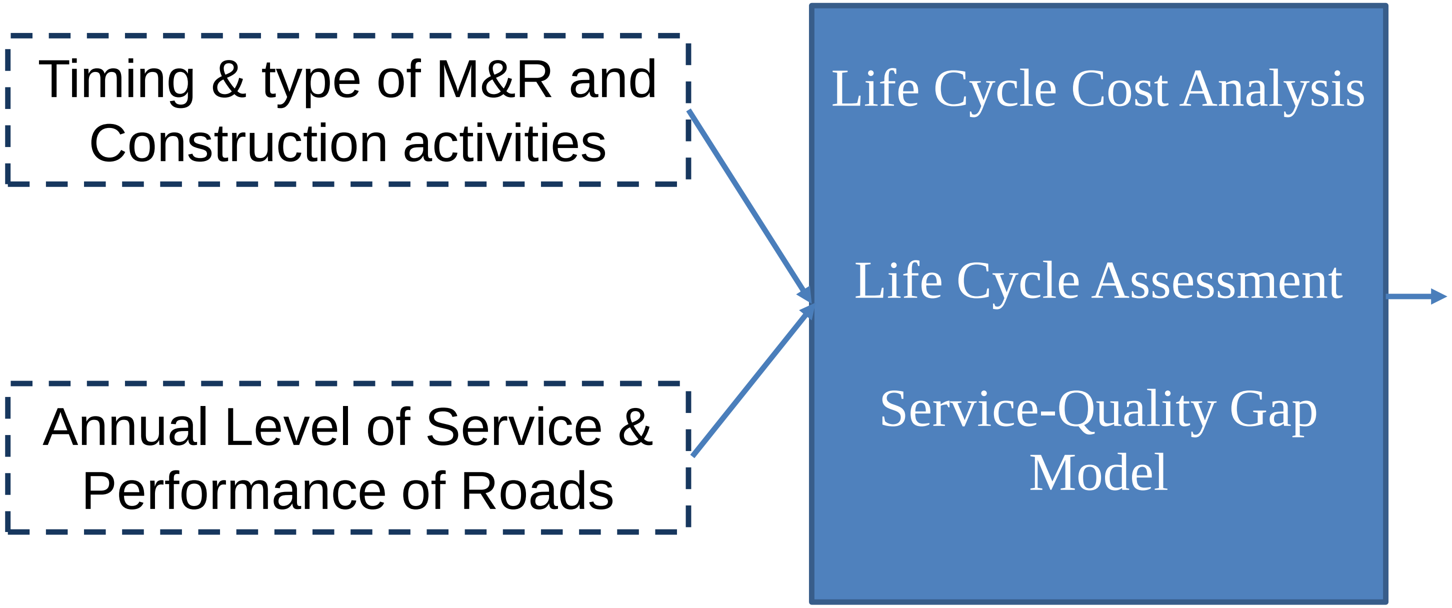

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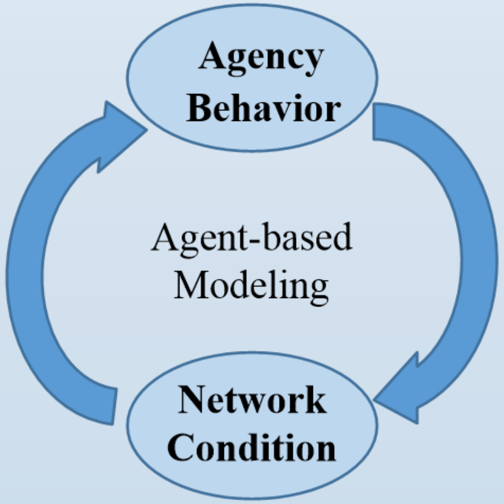
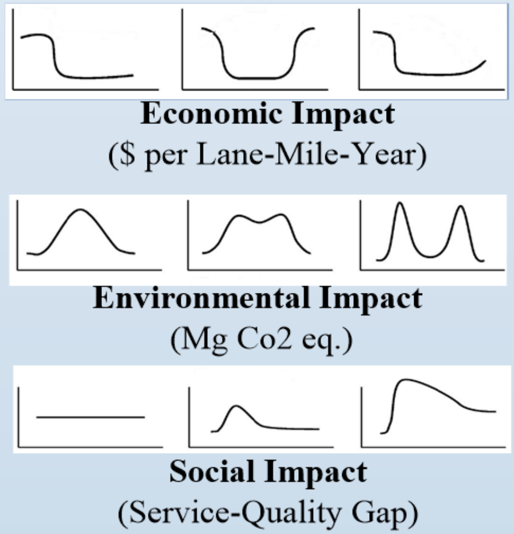
Behaviors of Road Assets
- Performance Condition
-Structural Condition

Step 2: Simulating Agency-Network Interactions



Step 3: Determining Sea-level Rise Impacts

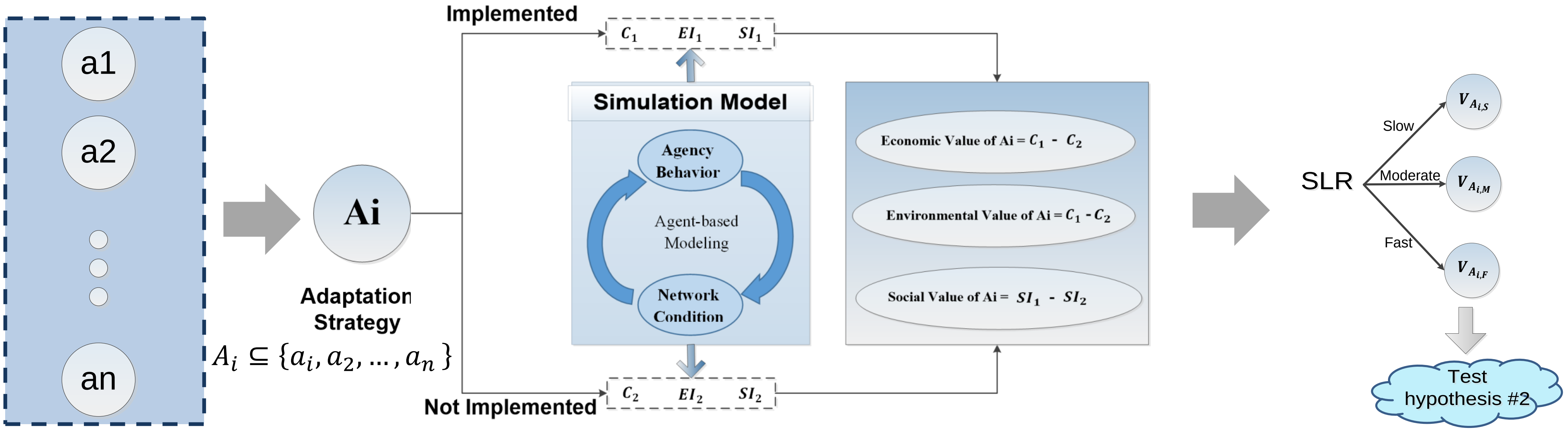


6 Research Design

Design for Testing Hypothesis #1 | **Design for Testing Hypothesis #2** | Design for Testing Hypothesis #3

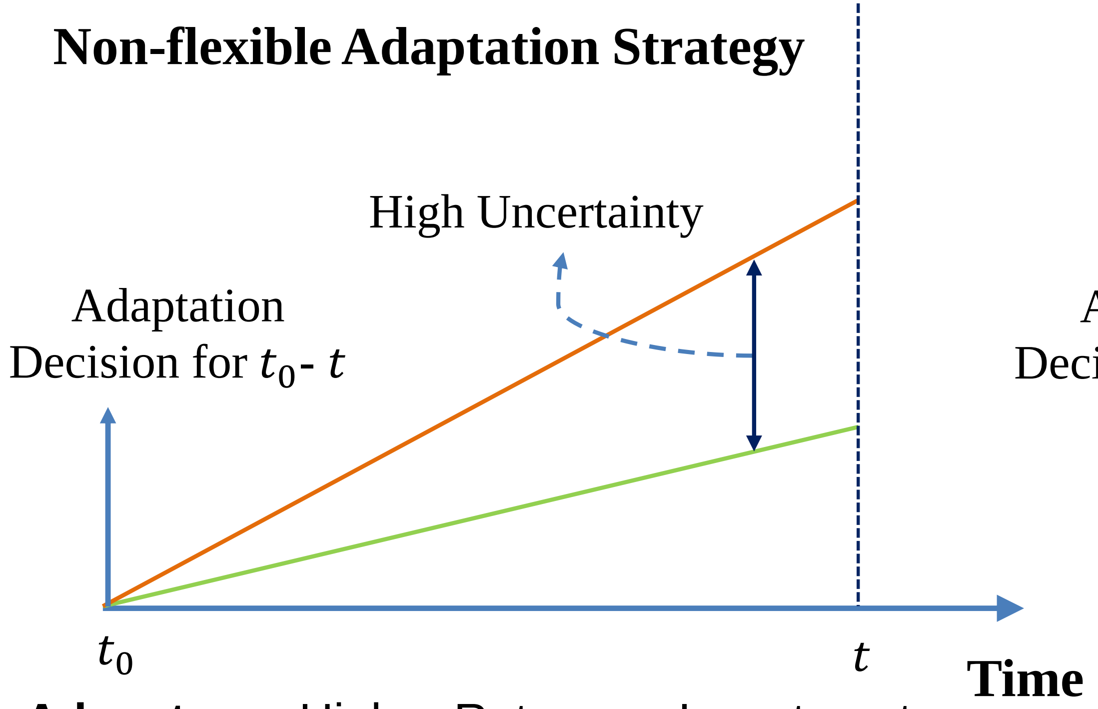
A four step process is followed to test hypothesis 2.

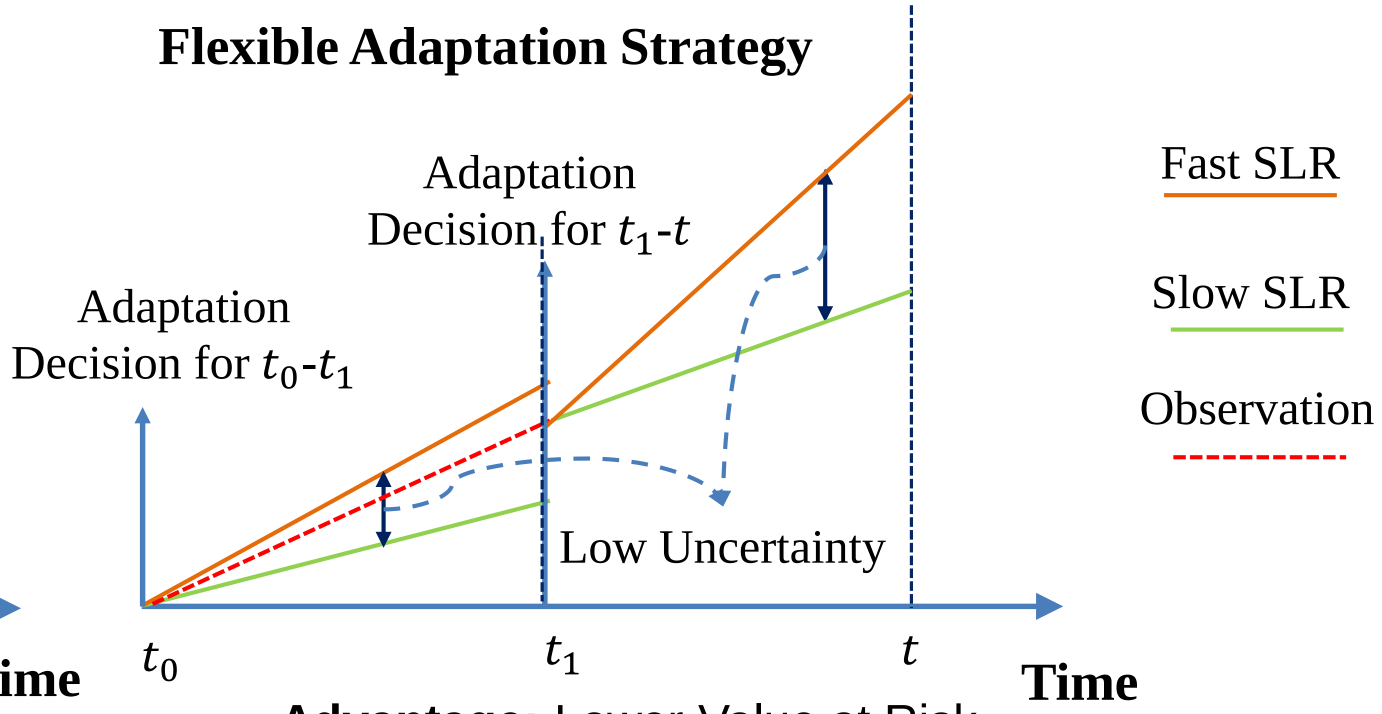
Step 1: Identify Adaptation Action Space → **Step 2: Generate Adaptation Strategies** → **Step 3: Assess the value of Strategies** → **Step 4: Test the Hypothesis 2**



6 Research Design

Design for Testing Hypothesis #1 | Design for Testing Hypothesis #2 | **Design for Testing Hypothesis #3**





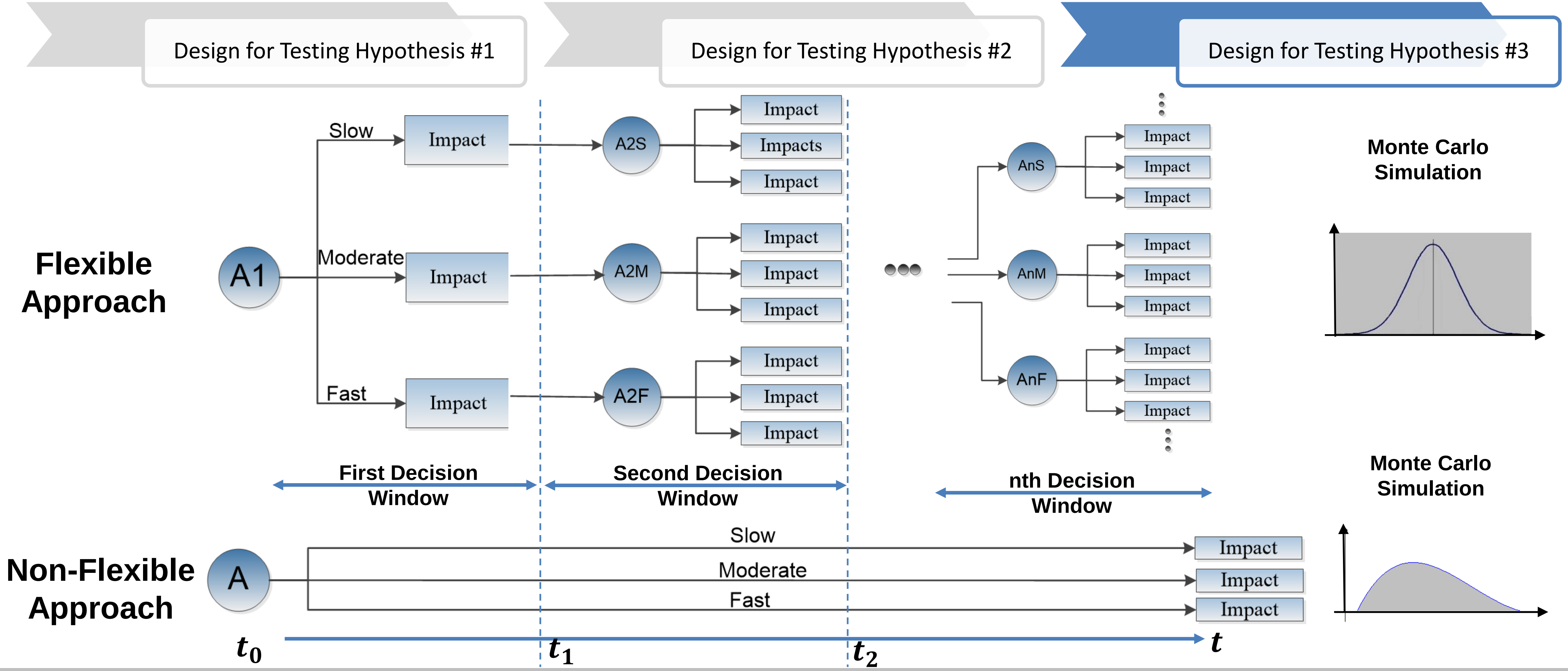
Advantage: Higher Return on Investment

Limitation: Higher Value at Risk

Advantage: Lower Value at Risk

Limitation: Lower Return on Investment

6 Research Design



6 Research Design

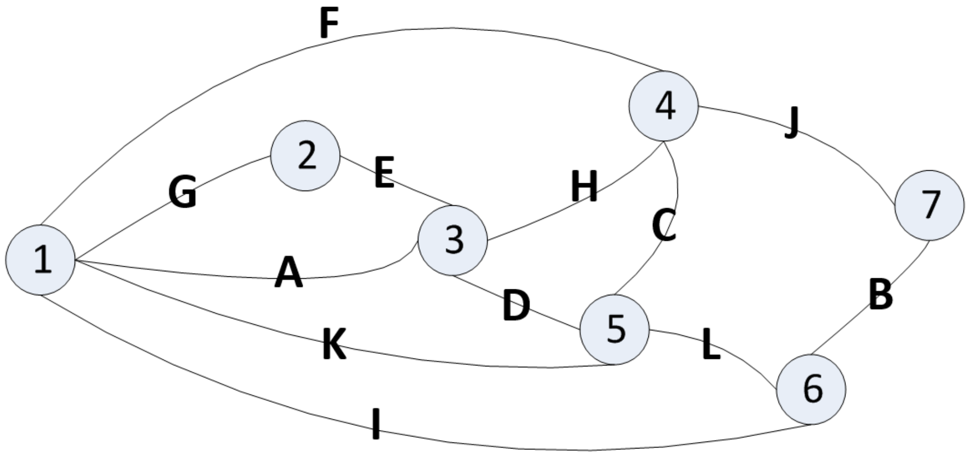
A three step process is followed to test hypothesis 3.

Step 1: Simulate long-term planning strategy → Step 2: Simulate flexible planning strategy → Step 3: Compare the two planning approaches

7 Proof of Concept

A Pavement Network Is Studied to Test Feasibility of the Proposed Research Method.

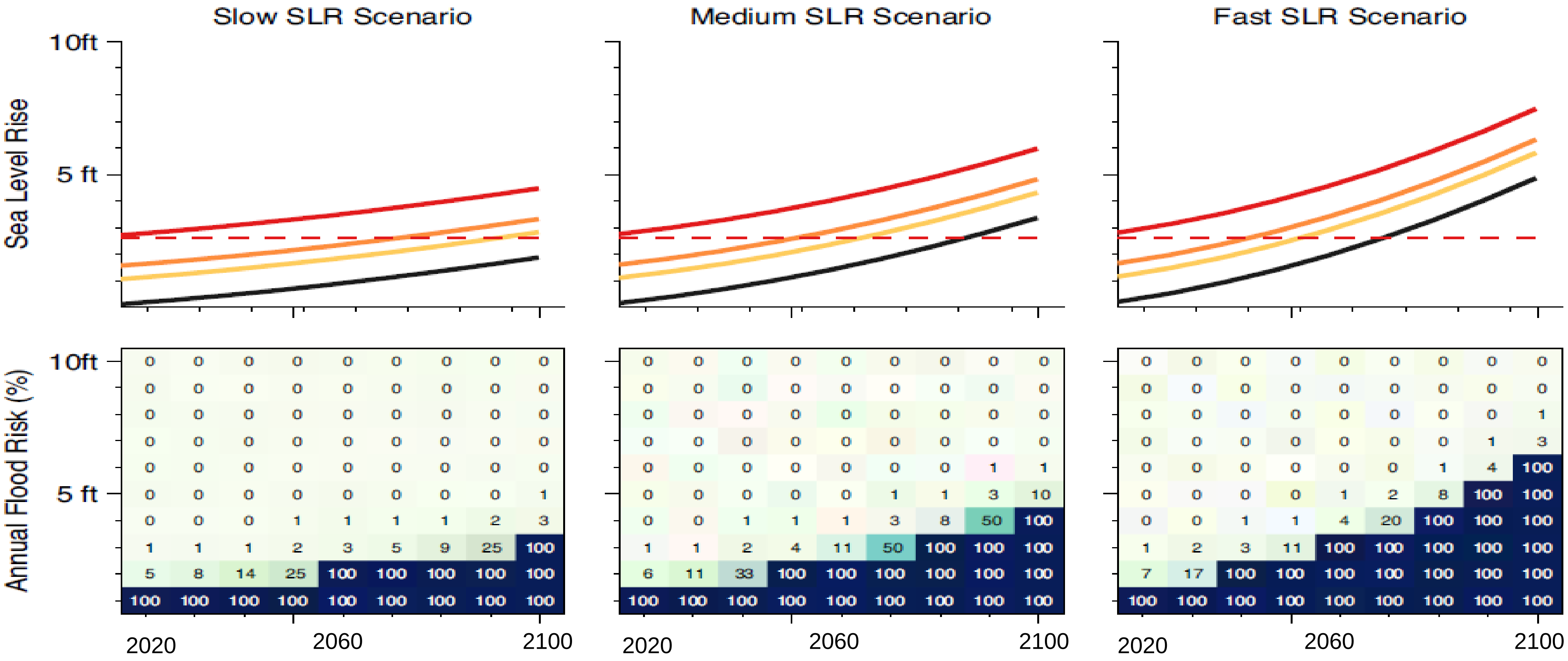
Road Name	Road Type	Pavement Type	Length (Miles)	Width (Yards)	Elevation (Feet)	STR	ESAL/Day (in base year)
A	R	Flex	1.55	12.03	2	3.53	224
B	I	Com	0.50	12.47	3	14.57	1185
C	I	Flex	0.68	13.67	4	4.35	1645
D	I	Flex	0.19	12.47	5	7.22	1756
E	R	Flex	0.43	14.22	4	4.79	864
F	R	JPCP	2.73	13.78	3	11.02	688
G	I	JPCP	0.62	15.53	6	17.72	1142
H	R	JRCP	1.06	17.94	3	13.39	1785
I	R	JRCP	2.80	13.01	3	13.39	1785
J	I	Com	1.37	13.56	4	14.57	1185
K	I	Flex	1.68	12.90	3	5.60	1479
L	I	Flex	0.62	18.15	4	7.71	1756



Source: *The ICMPA7 Investment Analysis and Communication Challenge for Road Assets (Haas 2008)*

7 Proof of Concept

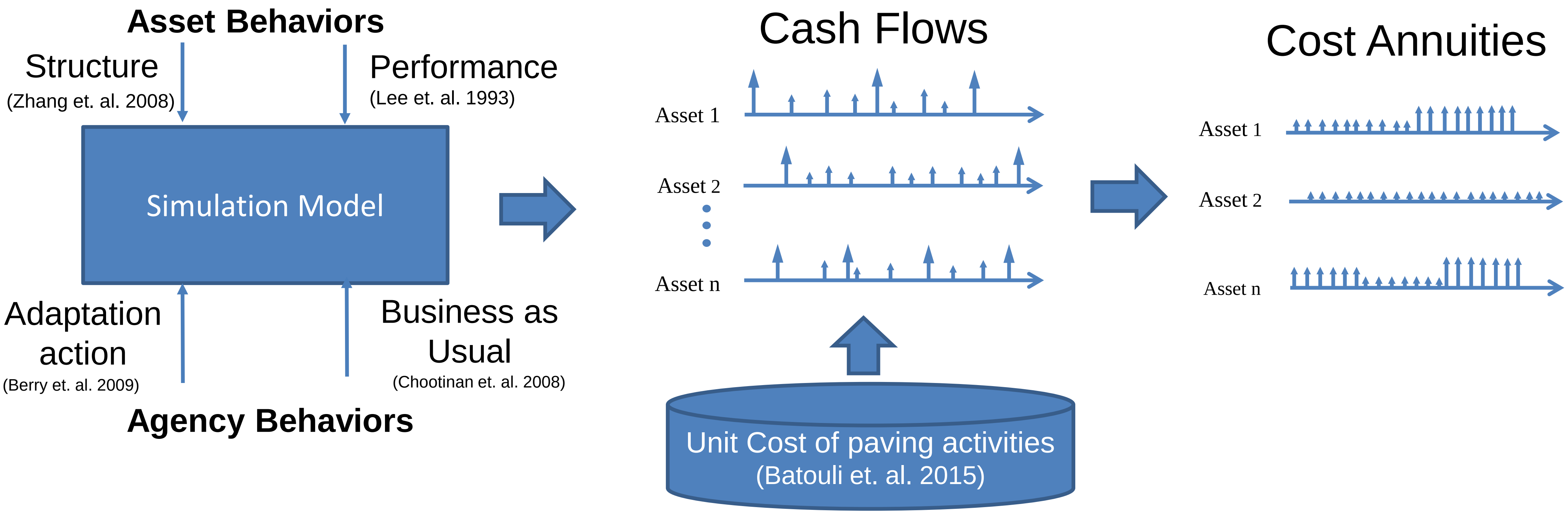
The network is exposed to flood damage caused by sea-level rise scenarios related to Southeast Florida.



(Strauss et al. 2013).

7 Proof of Concept

Proof of Concept for Hypothesis #1 | Proof of Concept for Hypothesis #2 | Proof of Concept for Hypothesis #3



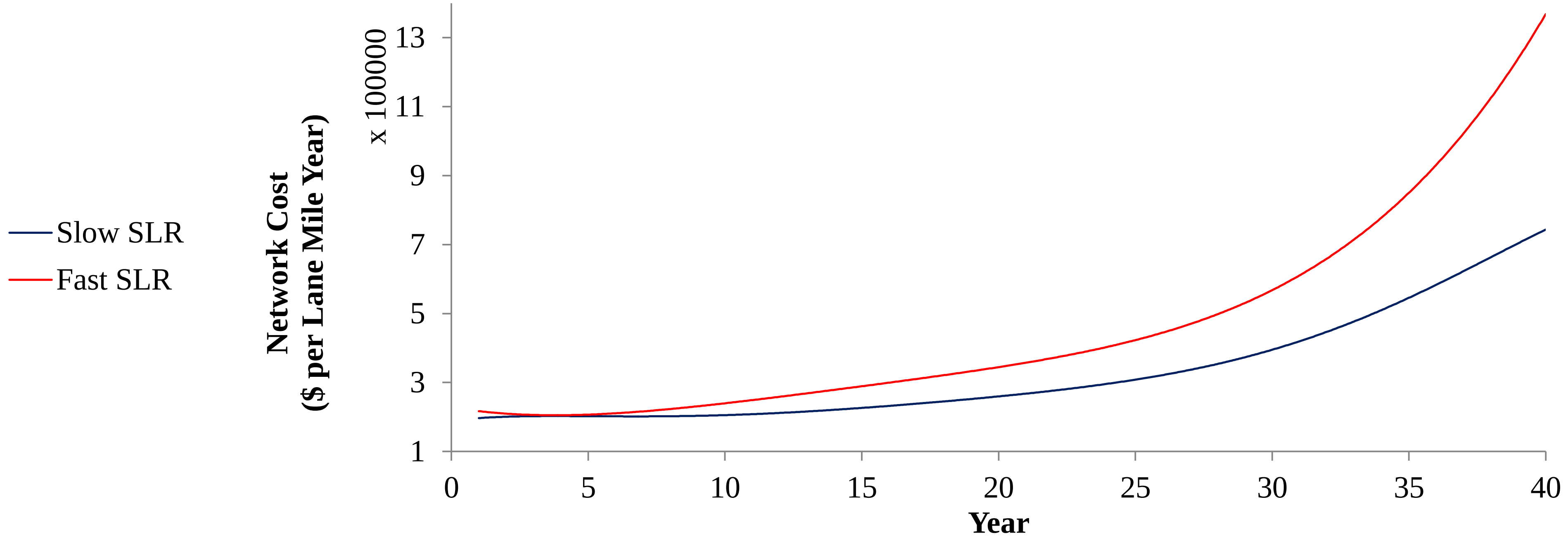
7 Proof of Concept

Proof of Concept for Hypothesis #1

Proof of Concept for Hypothesis #2

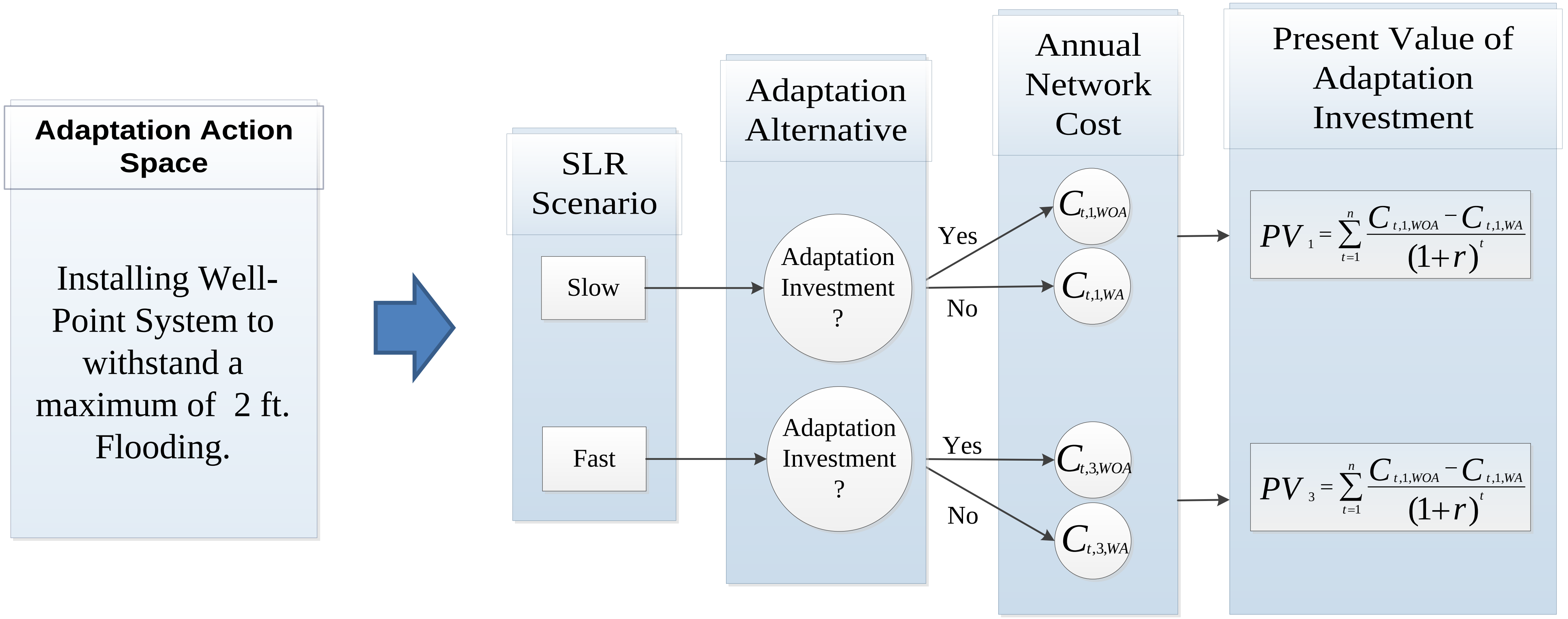
Proof of Concept for Hypothesis #3

The results show potential of the proposed framework and computational model for assessing the long-term costs of SLR on a roadway network respective to first question and hypothesis.



7 Proof of Concept

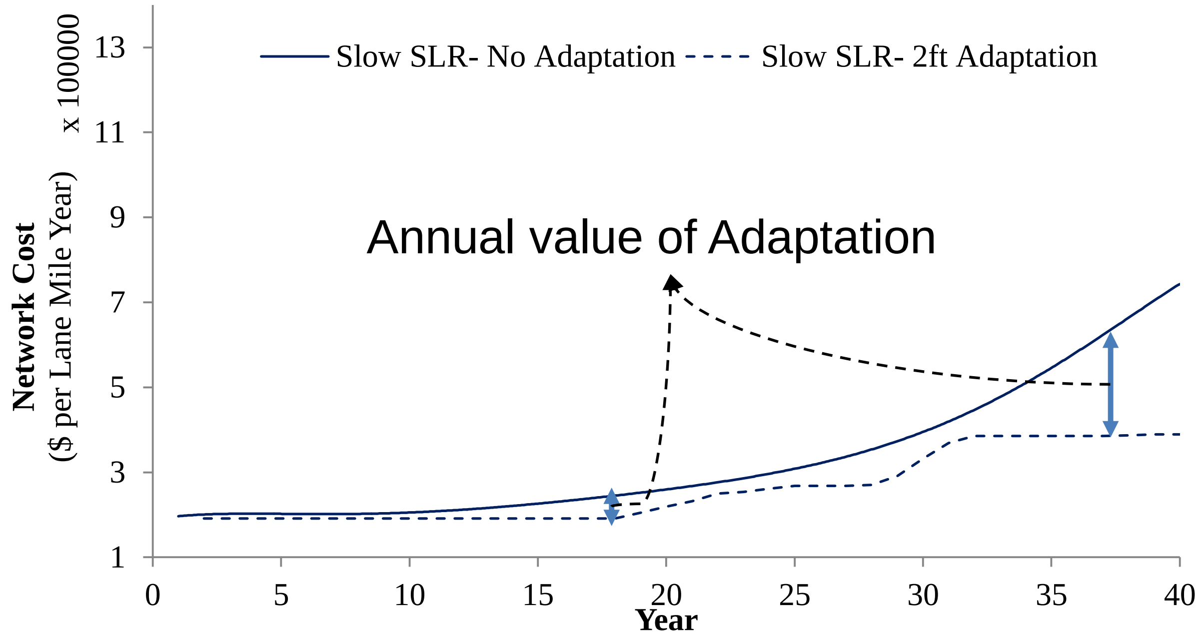
Proof of Concept for Hypothesis #1 | **Proof of Concept for Hypothesis #2** | Proof of Concept for Hypothesis #3

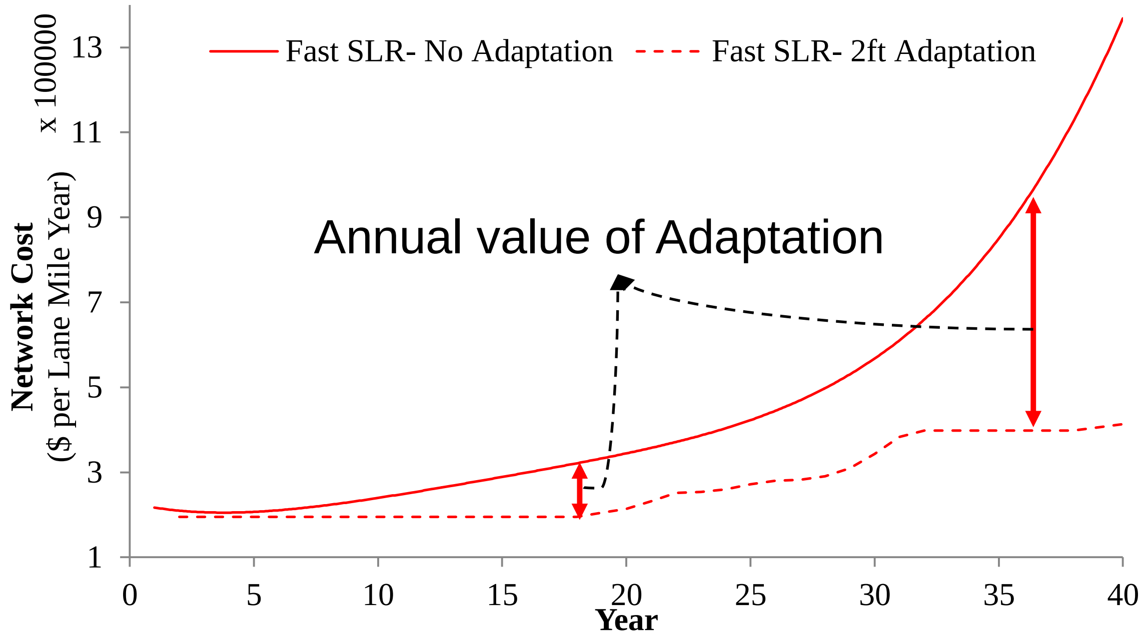


7 Proof of Concept

Proof of Concept for Hypothesis #1 | **Proof of Concept for Hypothesis #2** | Proof of Concept for Hypothesis #3

The results show potential of the proposed framework and computational model for evaluating the impacts of adaptation on network cost respective to second question and hypothesis.





7 Proof of Concept

Proof of Concept for Hypothesis #1
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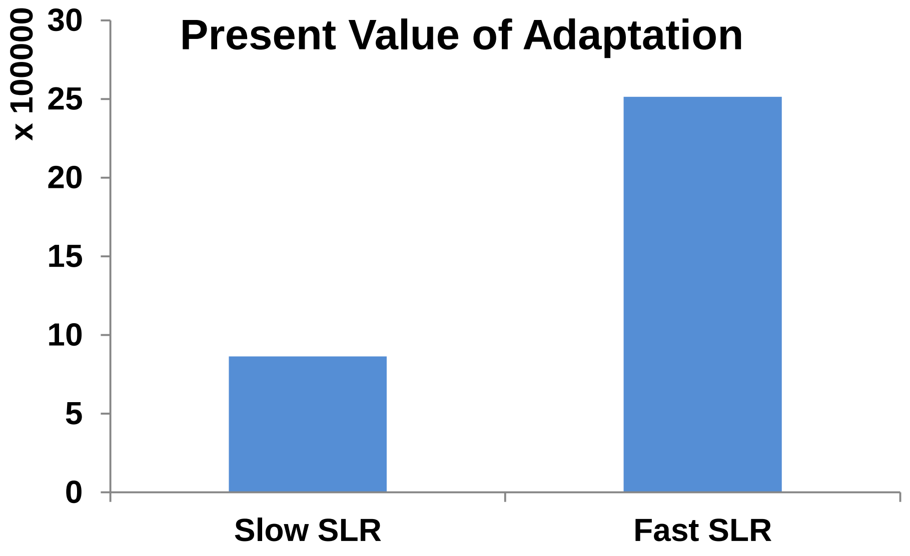
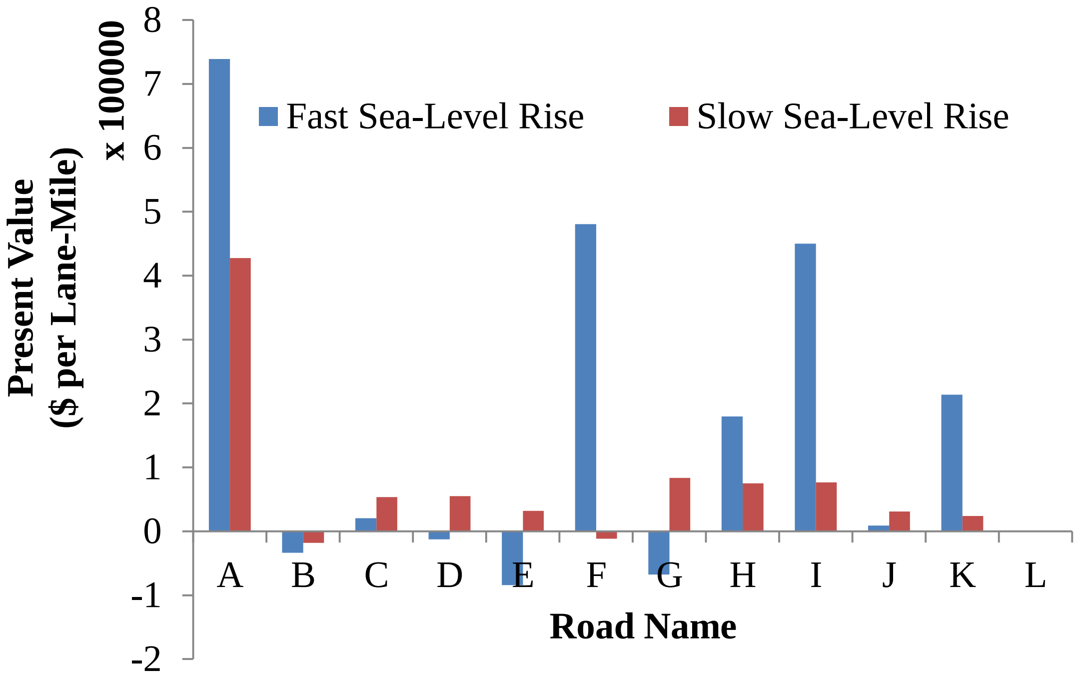




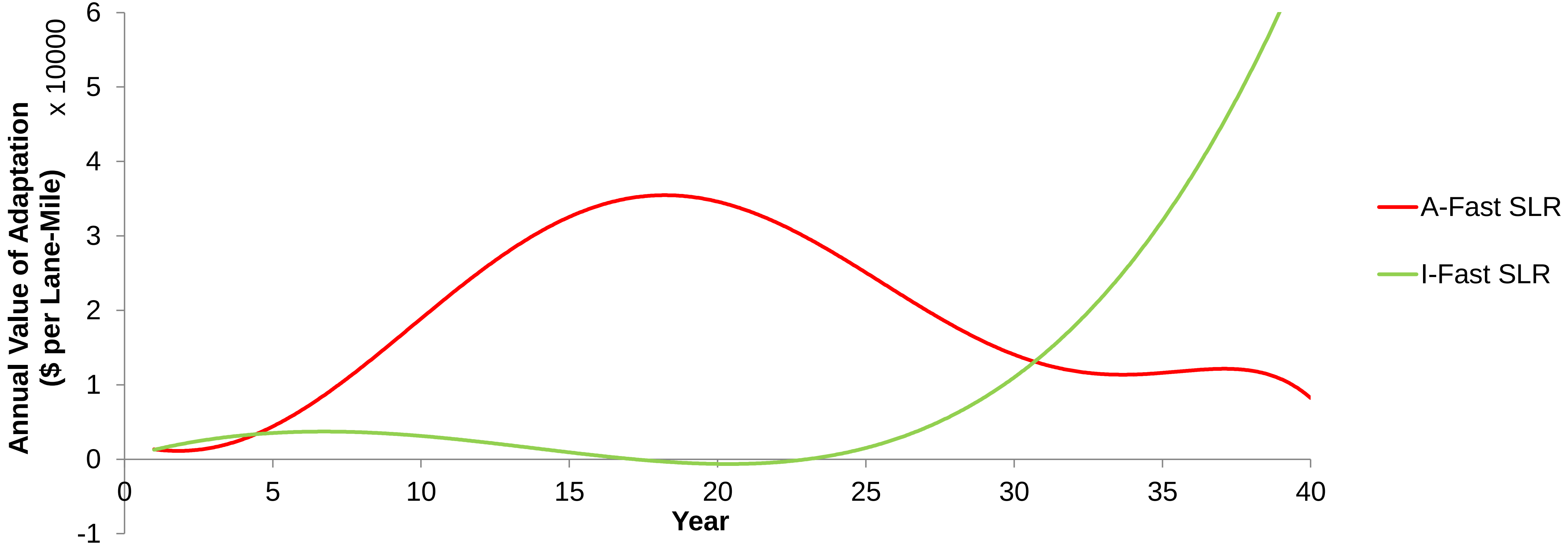
7 Proof of Concept

Proof of Concept for Hypothesis #1

Proof of Concept for Hypothesis #2

Proof of Concept for Hypothesis #3

The results motivated development of hypothesis 3.



7 Proof of Concept

- **Additional stormwater systems**
  - Useful in short term
  - Requires means to discharge the added stormwater
- **Well point systems**
  - More permeant solution
  - A series of pump stations may be required (Typical dewatering systems are confined to areas less than 500 feet long)
  - The cost could exceed $1 million per lane mile (the cost has the potential to double)

7 Proof of Concept

- **Exfiltration trenches or French drains**
  - will cease to work as they become submerged so this technology will be abandoned.
- **Elevating the road**
  - Solves the problem at root
  - Huge impact on adjacent properties
  - Exceed the cost of new roads.

7 Proof of Concept

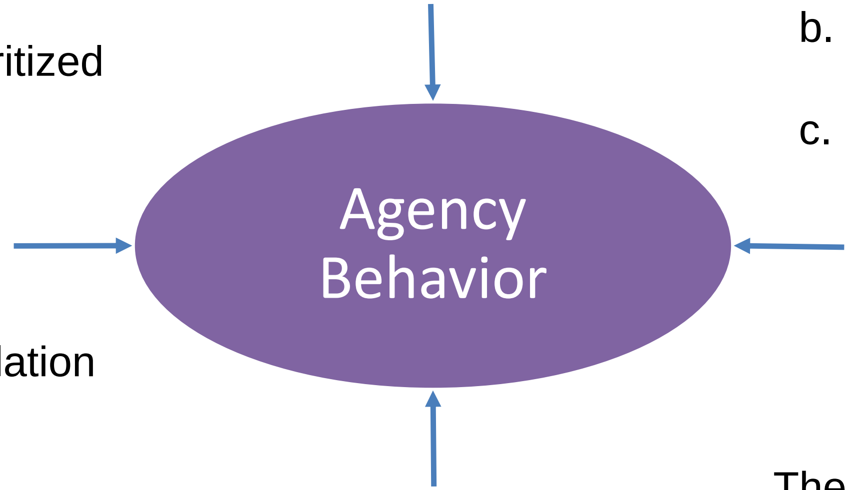
The agency behaviors are modeled using action charts in a Java based programming platform.

a. PSR< M&R is considered
b. M&R is applied only if it restores performance to PSR>4
c. Roads with lower PSR are prioritized for M&R funding

Decision Rules

a. Annual M&R budget=$300K
b. Urban and rural roads are irremediable with PSR values of 2.2 and 2, respectively
c. No link could be left failed

Conditions of Roads



Decision Constraints

PSR values are taken from the simulation model.

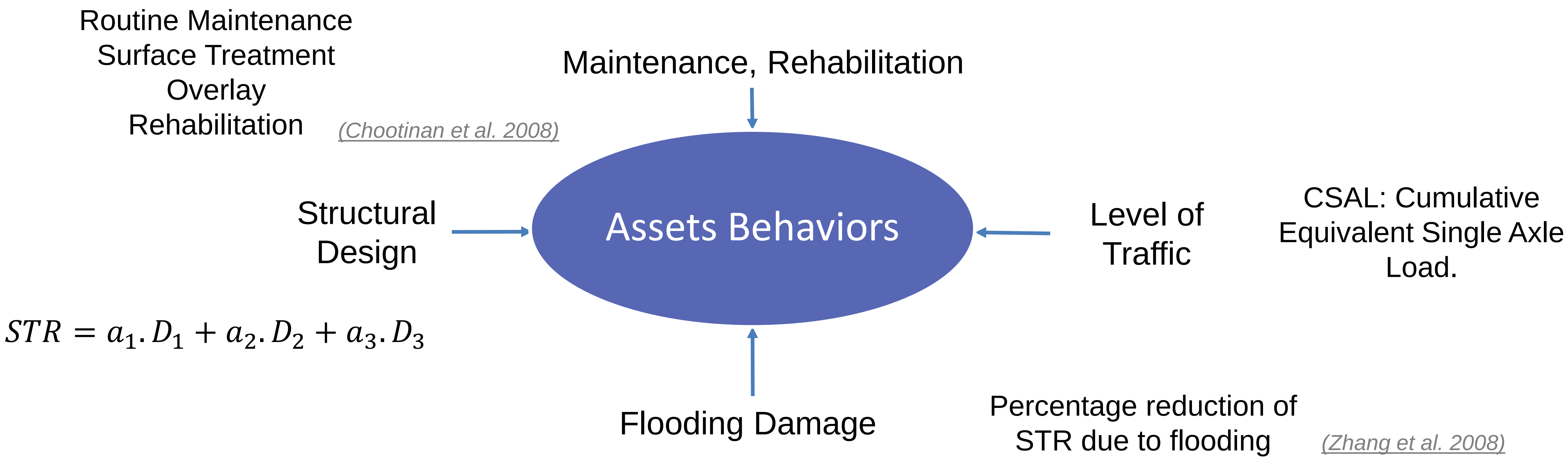
Perception of SLR risk

The flooding risk respective to Southeast Florida as projected in Strauss et al. (2013).

7 Proof of Concept

Proof of Concept for Hypothesis #1 | Proof of Concept for Hypothesis #2 | Proof of Concept for Hypothesis #3

The behaviors of road assets are extracted from literature.



7 Proof of Concept

Proof of Concept for Hypothesis #1 | Proof of Concept for Hypothesis #2 | Proof of Concept for Hypothesis #3

A simplified performance prediction model is used to simulate the performance conditions of road assets..

$$PSR_j = PSR_i - A.F * a * STR^b * Age_j^{\ c} * CESAL_j^{\ d} + MR_j$$

- PSR_i: Initial PSR
- $A.F$: Adjustment factor for climate zone
- STR: Existing Pavement Structure
- $CESAL_j$: Cumulative 18-kip Equivalent Single-axle loads
- MR_j: Performance Improvement due to M&R activities

(Lee *et al.* 1993)

8 Future Steps

The research plan includes four major tasks:

Data Collection from Case Study
- Interviews with agency personnel & review documents
- Existing published data

Computation Model
- Develop Computational Model
- Verification and Validation

Simulation Experiments
- Design experiments
- Conduct Simulation Experiments

Theoretical Constructs
- Test Hypotheses using Monte Carlo simulation
- Theoretical Constructs Validation

8 Future Steps

A Sub-portion of the roadway network in the City of Miami beach will be studied.

8 Future Steps

Different methods will be used to collect required data sources.

SLR Risk and Potential Damage

Frequency and intensity of flooding, Extent of damage due roads due to flooding

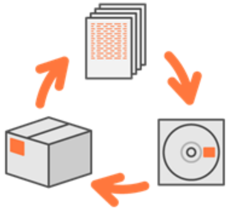
Impact Assessment Inventories

Unit cost and environmental impacts of construction, M&R, and use of roads, User expectation of the level of service

Existing published data

Interviews with agency personnel

Review of agency's documents



Agency's Asset Management System

Network Characteristics

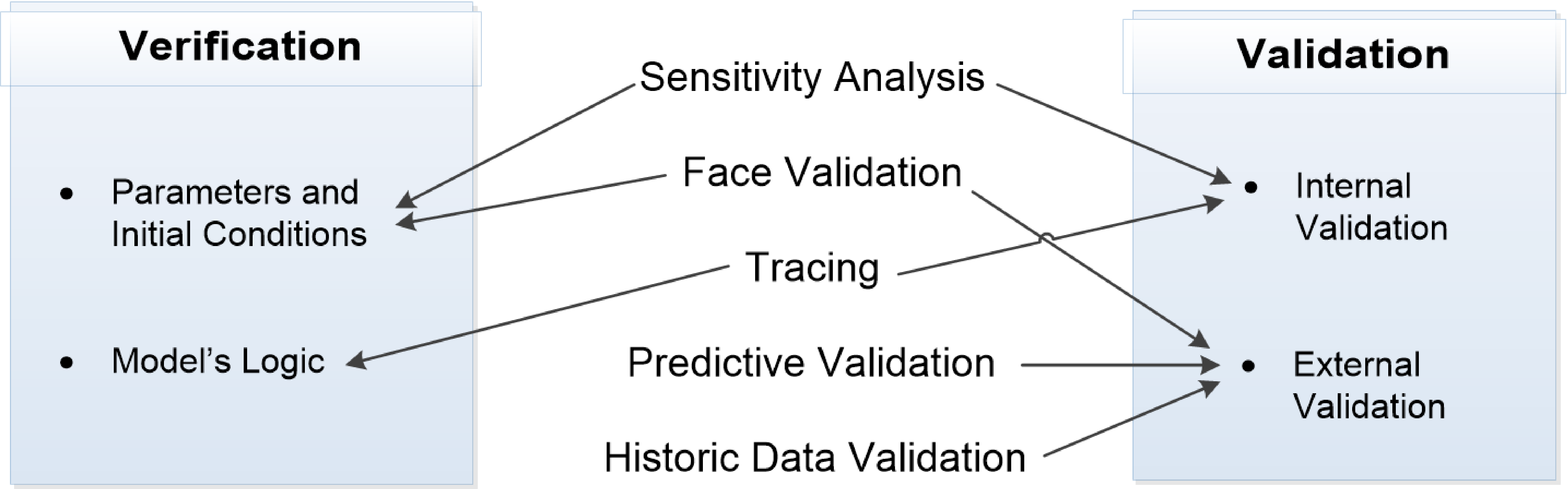
Age, Type of pavement, Structural design, Level of traffic, History of M&R,...

Agency Decision Making

Budget, Decision rules for M&R funding, Strategies for adaptation to SLR

8 Future Steps

The simulation model will be verified and validated to ensure the completeness, consistency, coherence, and correctness of the model and its outcomes.



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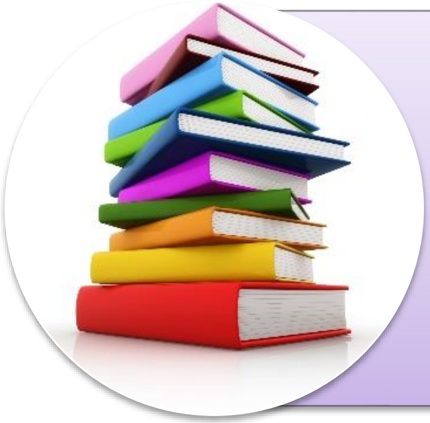
Expected Contributions



Theoretical Contribution

- Create theoretical constructs required for assessing long-term impacts of SLR on roadway infrastructure and evaluate adaptation strategies
- Capture dynamic interactions of social systems and physical networks as related to assessment of SLR impacts and adaptation
- Contribute to the development of the theory of sustainable & resilient infrastructure

Practical Implication

- Enable assessing the long-term impacts of SLR on the environmental, economic and social performance of roadway infrastructure.
- More informed decision-making for adaptive design, operation, and management of roadway infrastructure.

References

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Publications out of Dissertation

❑ Conference Publication:

1.**Batouli, M**., & Mostafavi, A. (2015). Assessment of network-level environmental sustainability in infrastructure systems using service and performance adjusted life cycle analysis, ICSC15 – The Canadian Society for Civil Engineering's 5th International/11th Construction Specialty Conference

2.**Batouli, M**., Swei, O. A., Zhu, J., Gregory, J., Kirchain, R., & Mostafavi, A. (2015, June). A Simulation Framework for Network Level Cost Analysis in Infrastructure Systems. In International Workshop on Computing in Civil Engineering.

3.**Batouli, M**., Mostafavi, A. (2014). A hybrid simulation framework for integrated infrastructure management, Winter Simulation Conference 2014.

4.**Batouli, M.**, Mostafavi, A. (2015) A Simulation Framework for Sustainability Assessment in Evolving Socio-Technical Infrastructure Systems, Accepted for CONVR 2015

5.**Batouli, M.**, Mostafavi, A. (2016) Assessment of Sea-Level Rise Adaptation in Coastal Infrastructure Systems: Robust Decision-Making under Uncertainty, Submitted to Construction Research Congress 2016

Other Publications in FIU

❑ Journal Publication:

[1] **Batouli, S. M**., Zhu, Y., Nar, M., & D'Souza, N. A. (2014). Environmental Performance of Kenaf-fiber Reinforced Polyurethane: a Life Cycle Assessment Approach. Journal of Cleaner Production, 66, 164-173**.**

❑ Conference Publication:

1.Orgut, R. E., Zhu, J., **Batouli, M**., Mostafavi, A., & Jaselskis, E. J. (2015). A review of the current knowledge and practice related to project progress and performance assessment, The Canadian Society for Civil Engineering's 5th International/11th Construction Specialty Conference

2.**Batouli, S. M.**, Zhu, Y. (2013). Comparative Life-Cycle Assessment Study of Kenaf Fiber-Based and Glass Fiber-Based Structural Insulation Panels. In ICCREM 2013@Construction and Operation in the Context of Sustainability (pp. 377-388). ASCE.

3.**Batouli, S. M.**, & Zhu, Y. (2014). A Framework for Assessing Environmental Implications of an Urban Area, Construction Research Congress 2014

4.**Batouli, S. M.**, & Zhu, Y. (2014). Using Accrual Accounting Life Cycle Assessment as an Indicator of Urban Sustainability, International Conference on Computing in Civil and Building Engineering 2014

5. Orgut, R. E., **Batouli, M.,** Zhu, J., Mostafavi, A., & Jaselskis, E. J. (2016) Metrics that Matter: Evaluation of Best Practices for Project Progress Measurement, Performance Assessment, and Forecasting, Submitted to Construction Research Congress 2016






THANK YOU!