A FRAMEWORK FOR ANALYZING MULTIDIMENSIONAL INFRASTRUCTURE SUPPLY CHAIN AND BUSINESS CONTINUITY PLANS TO ENHANCE CITY-LEVEL RESILIENCE

KEYWORDS: CAPACITY BUILDING; CRITICAL INFRASTRUCTURE SUPPLY CHAIN; BUSINESS CONTINUITY PLANS; SOCIAL AND ECONOMIC LOSSES; ZONE OF INFLUENCE; DECISION-SUPPORT SYSTEM

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March 24th 2017

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Introduction

BACKGROUND

- Infrastructure services are critical for disaster response & recovery activities
- Full availability of infrastructure services in need will lead to faster recovery

Which community can recovery more quickly?

Hurricane, Buras LA

Tornado, Gifford IL

1) Environmental Protection Agency (2005), http://archive.epa.gov/katrina/web/html/
2) The News-Gazette (2013), http://www.news-gazette.com/news/local/2014-03-20/federal-funds-help-gifford-water-plant-tower.html

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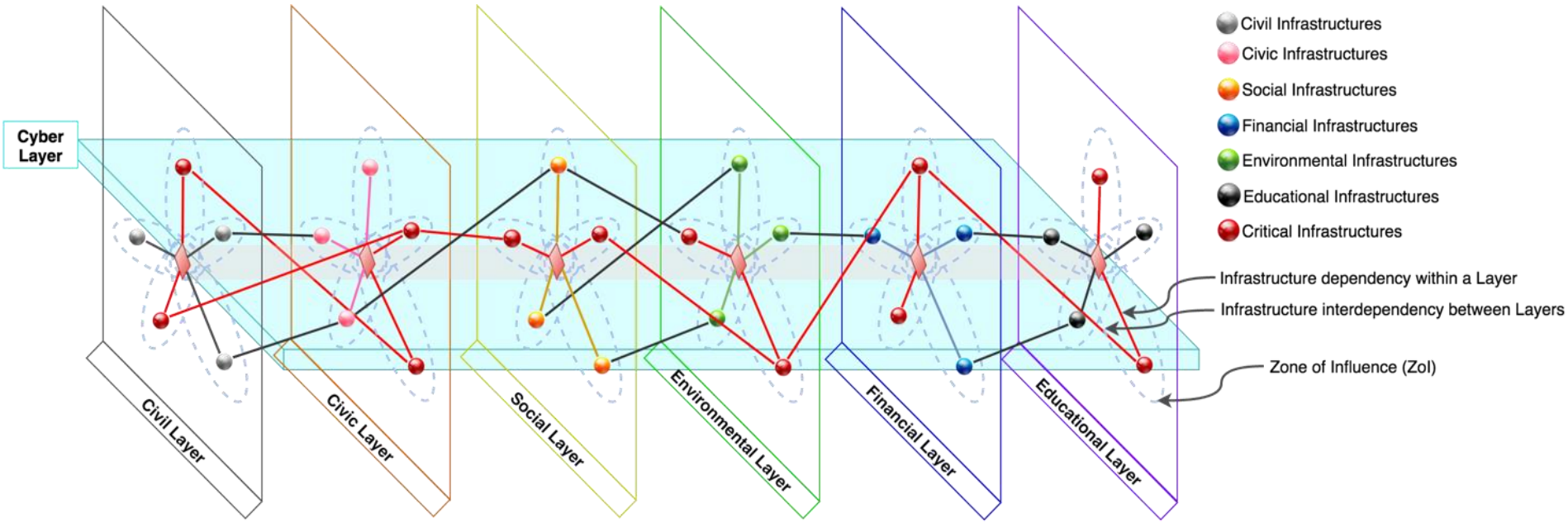
Introduction

BACKGROUND

- Multidimensional infrastructure layers and multi-tier service provision
- Seven principal layers



Civil	Civic	Social	Financial	Environmental	Educational
Utility Systems	Emergency Agencies	NGOs	Disaster Funds	Mangroves	Training
Water, Gas, Electricity	Schools, Hospitals	Religious Centers	Insurance	Debris Site	Programs
Transportation Systems	Police, Governance	Households	Donor Funds	Forests	Feedback Mechanisms

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Introduction

NEEDS & OBJECTIVES

UNDERSTAND

- Nature of interrelationship between infrastructures and cities/communities
- Nature of infrastructure interdependency

IDENTIFY

- Which are most critical and vulnerable infrastructure services
- Where these infrastructure services will be interrupted
- Level of needs for these infrastructure services

DEVELOP

Mitigation strategies to;

- Minimize areas of infrastructure service disruption
- Allocate available infrastructure services

Prior Research Works

INTERRELATIONSHIP BETWEEN INFRASTRUCTURES AND ASSOCIATED COMMUNITIES

- Criticality Assessment
  - Step 1: Activity Analysis
  - Step 2: Infrastructure Analysis (Zone of Influence)
  - Step 3: Assistance Level of Infrastructure
  - Step 4: Calculation of Relative Level of Criticality

Activity | Social / Economic Contribution | Alternatives | Assistance Level of Infrastructure

Activity	Normalized Weight of Social Contribution (NwSc)	Normalized Weight of Economic Contribution (NwEc)	Alternatives of Infrastructure	Assistance Level (AL) of Infrastructure											
				Utility Group				Frontline Group	Transportation Group						
				Electricity	Gas	Water Supply	Sewer	Levee Section	3rd Ave SE	8th Ave SE	12th Ave SE	I-380 E19A	1st Ave E	8th Ave Bridge	12th Ave Bridge
Commuting	0.16	0.28	3rd Ave SE					1.00	0.32						
			8th Ave SE							1.00					
			12th Ave SE								1.00				
			8th Ave Bridge											0.16	
			12th Ave Bridge												0.16
			I-380Exit19A									0.07			
Local Business	0.16	0.28	Electricity	1.00				1.00							
			Gas		1.00										
			Water Supply			1.00									
			Sewer				1.00								
Shopping	0.25	0.11	8th Ave SE					1.00		0.50					
			1st Ave E										1.00		
Medical Service	0.16	0.28	8th Ave SE					1.00		1.00					
			12th Ave SE								0.50				
Livelihood	0.28	0.06	Electricity	1.00				1.00							
			Gas		1.00										
			Water Supply			1.00									
			Sewer				1.00								
Portion of Social and Economic Contribution	0.64 (PSC: Portion of Social Contribution)	0.36 (PEC: Portion of Economic Contribution)													
Relative Level of Criticality				0.40	0.40	0.40	0.40	1.00	0.06	0.50	0.30	0.01	0.20	0.03	0.03

Level of Criticality

1) Oh, E. H., Deshmukh, A., and Hastak, M. (2013). "Criticality Assessment of Lifeline Infrastructure for Enhancing Disaster Response." Natural Hazards Review, American Society of Civil Engineers, 14(2), 98–107.

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Prior Research Works

INTERRELATIONSHIP AMONG INFRASTRUCTURES (INFRASTRUCTURE INTERDEPENDENCY)

- Quantifying interdependencies among infrastructures:
  - Ratio of causing vs affected by failure
  - Duration of service disruption

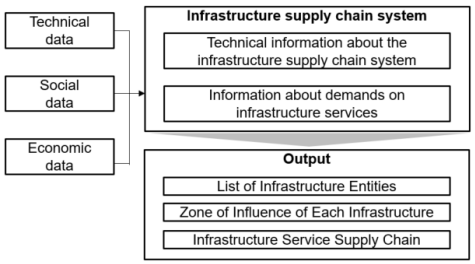
Affected Infrastructure	T(i)/T(e)
Transit-electrified rail (NYC)	1.3
Traffic Signals (NYC)	2.6
Water Supply (Cleveland, OH)	2.0
Water Supply (Detroit, MI)	3.0
NOTE: T(e) is the electric power outage duration and T(i) is the affected infrastructure outage duration Total power outage duration = 42 ~ 72 hours	

1) *Rae Zimmerman, "Decision-making and the Vulnerability of Critical Infrastructure," Proceedings of IEEE International Conference on Systems, Man and Cybernetics, edited by W. Thissen, P. Wieringa, M. Pantic, and M. Ludema, The Hague, The Netherlands: Delft University of Technology, 2004.*
2) *Rae Zimmerman and Carlos E. Restrepo, "The Next Step: Quantifying Infrastructure Interdependencies to Improve Security," International Journal of Critical Infrastructures, 215-230, 2006.*

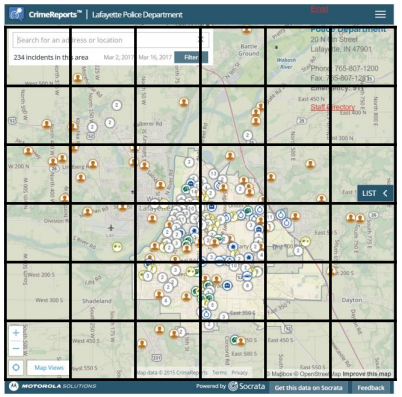
Proposed Multidim'l. Infrastructure Framework

OVERVIEW

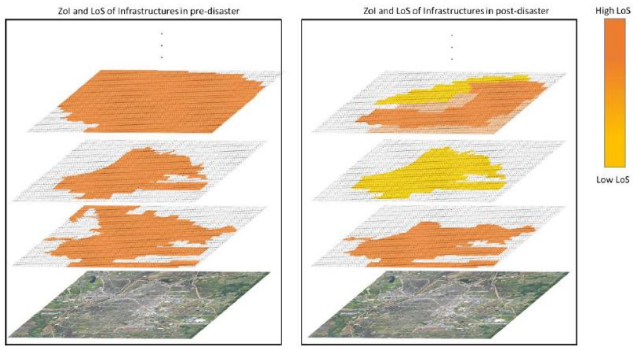
Step 1: Data Collection



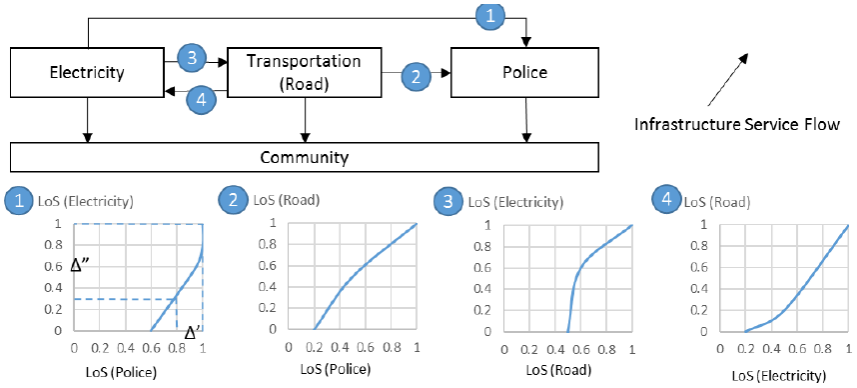
Step 2: Assessment of Infra. Demands and Service Supply Chain



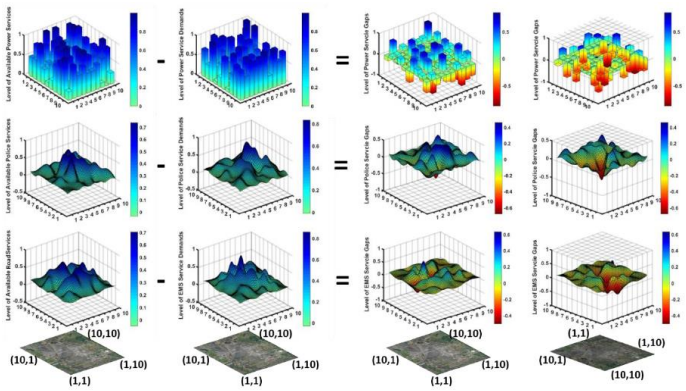
Step 3: Mapping Zone of Influence and Estimate Level of Service



Step 4: Simulation of Infrastructure Service Flows in Post-disaster scenario



Step 5: Gap Assessment to Identify Blind Spots of Infra. Services



Step 6: Development of mitigation strategies

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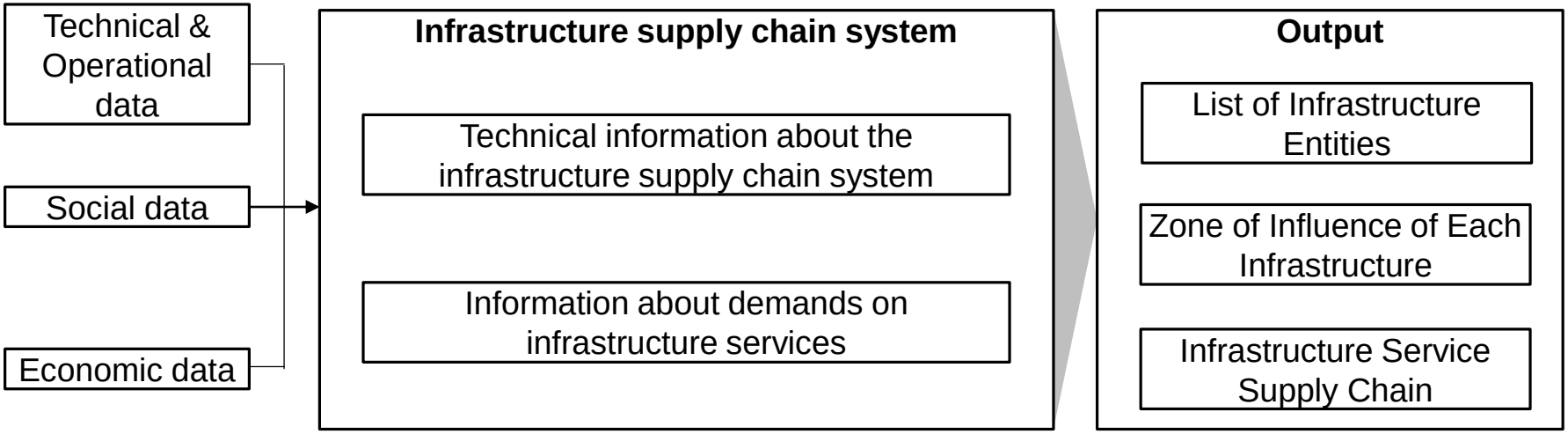
Proposed Multidim'l. Infrastructure Framework

STEP 1: DATA COLLECTION



- Technical and operational data of infrastructures:
  - distances from river, ground slope, earthquake resistant designs, and floor plans etc.
  - key processes and personnel, stockpiles of materials, resources, and contingency plans and decision-making hierarchy etc.
- Social data of associated communities:
  - population, sociodemographic information, educational levels, and religious groups etc.
- Economic data of associated communities:
  - employment, income, major industrial types, and tax reports etc.

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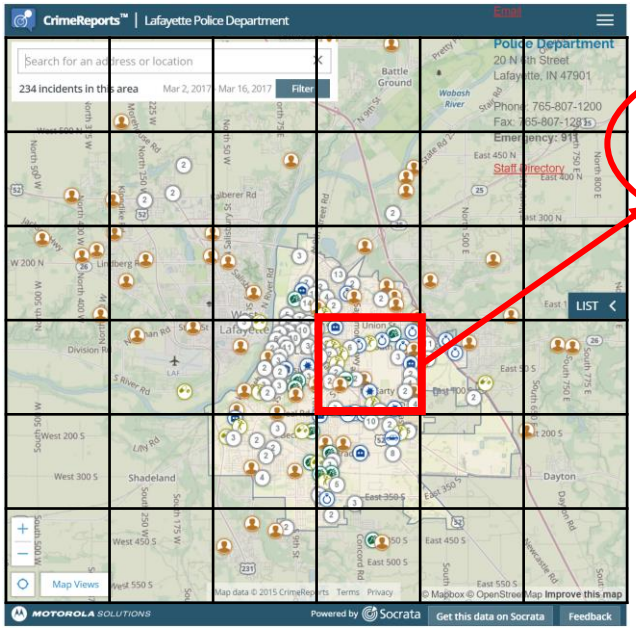
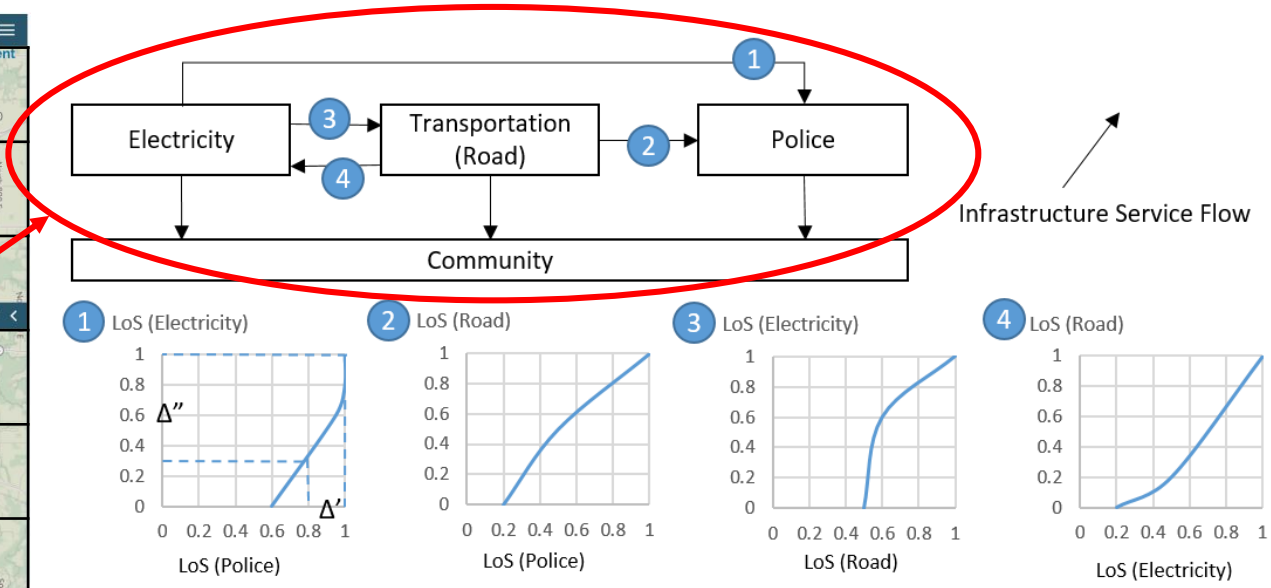
Proposed Multidim'l. Infrastructure Framework

STEP 2: ASSESSMENT OF INFRASTRUCTURE DEMANDS AND SERVICE SUPPLY CHAIN

Community's Infrastructure demands and default grid cells



Infrastructure's interdependency and its service supply chain



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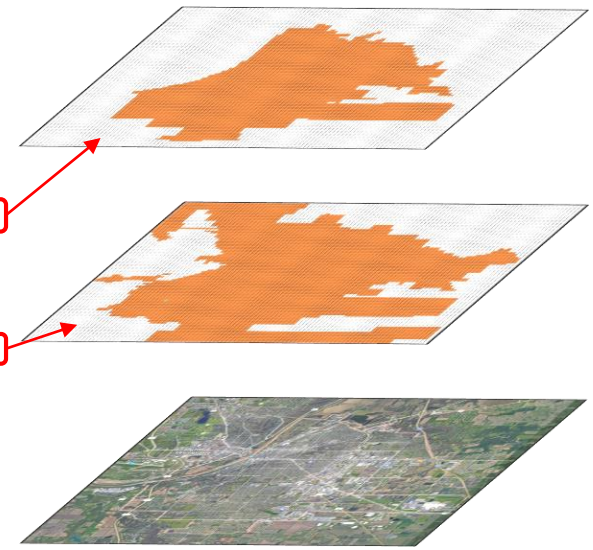
Proposed Multidim'l. Infrastructure Framework

STEP 3: MAPPING ZONE OF INFLUENCE AND ESTIMATE LEVEL OF SERVICE

- Zone of Influence (ZoI) can be varied depending on the attributes of the operational characteristics of infrastructures
- Level of Services (LoS) can be measured in scalable units for pre- and post-disaster conditions.

	Zone of Influence				Possible Service Disruption			
	Critical Condition and Attribute				Service Area		Level of Service (LoS)	
	Physical accessible	Topographic Condition	Jurisdiction boundary	Business territory	Partial loss	Full loss	Measure	e.g.
Wastewater			X		X	X	Scalable	Reduced drainage capacity
Stormwater		X			X	X	Scalable	Reduced drainage capacity
Water				X	X	X	Scalable	Reduced water pressure
Solid Waste				X	X	X	Scalable	Longer service period
Police			X			X	Scalable	Longer response time
Fire Protection and EMS			X			X	Scalable	Longer response time
Libraries	X				X	X	Scalable	Reduced service hour / Partial close
Parks	X				X	X	Scalable	Partially closed
Power				X	X	X	Dichotomous	Service hours
Schools	X		X			X	Scalable	Reduced service hour / Partial close
Telecommunications				X	X	X	Scalable	Service hours
Street Lighting			X		X	X	Dichotomous	Service hours
Urban Forest		X			X	X	Scalable	Reduced recreational area
Ground Transportation			X		X	X	Scalable	Reduced service hour / Partial close
Airports	X			X	X	X	Scalable	Reduced service hour / Partial close



Examples of Zone of Influence (ZoI) and Possible Service Disruption for Multidimensional Infrastructures

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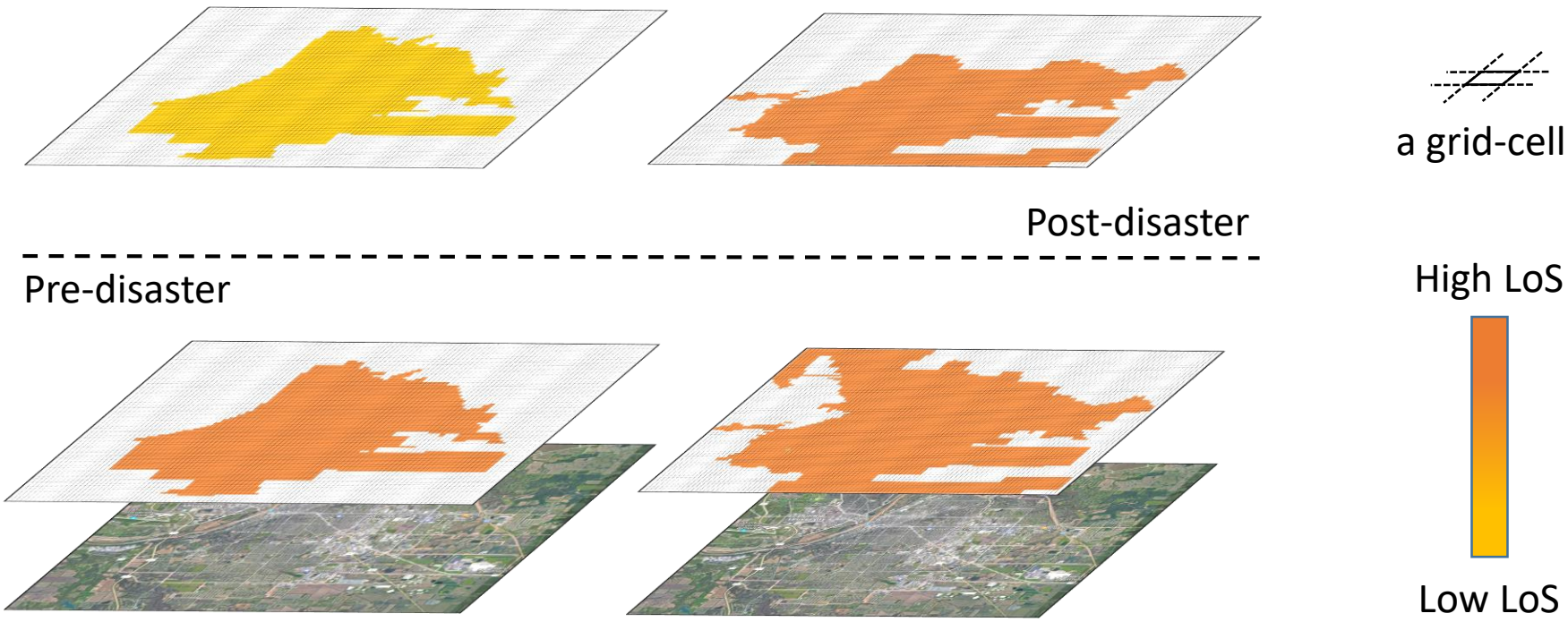
Proposed Multidim'l. Infrastructure Framework

STEP 4: SIMULATION OF INFRASTRUCTURE SERVICE FLOWS IN POST-DISASTER SCENARIOS

- Within a grid-cell: simulate reduced LoS due to reduction in LoS of other interdependent infrastructure
- Between grid-cells: simulate reduced ZoI influenced by neighboring cells



Example of change in LoS

Example of change in ZoI

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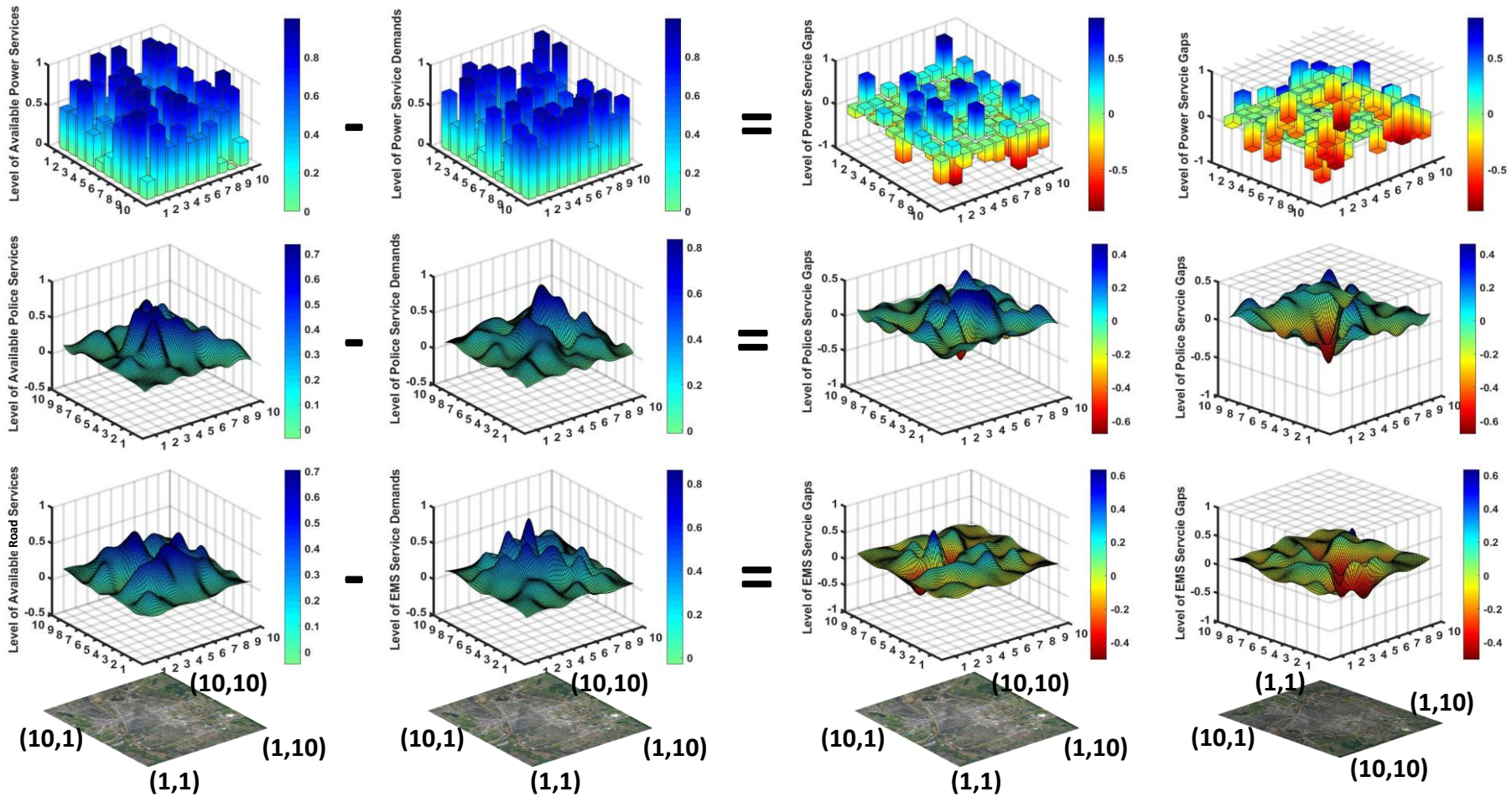
Proposed Multidim'l. Infrastructure Framework

STEP 5: GAP ASSESSMENT TO IDENTIFY BLIND SPOTS OF INFRASTRUCTURE SERVICES

Available LoS - Service Demands = Service Gaps (Left: high angle, Right: low angle)



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Conclusion and Future Research

- To help develop mitigation strategies to minimize areas of infrastructure service disruption, and to allocate available infrastructure services, we develop a framework to
  - Understand nature of interrelationship between infrastructures and cities/communities & nature of infrastructure interdependency;
  - Evaluate available infrastructure gaps which tell potential blind spots of infrastructure services in post-disaster situation;

- Uncertainties of quantifying ZoI and LoS of interdependent infrastructures
- Trade-off between accuracy of gap analysis based on number of infrastructures and grid-cells & effectiveness when applied to reality
- The Four Phases of Emergency Management:
  - Mitigation, preparedness, response, and recovery

Thank you

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