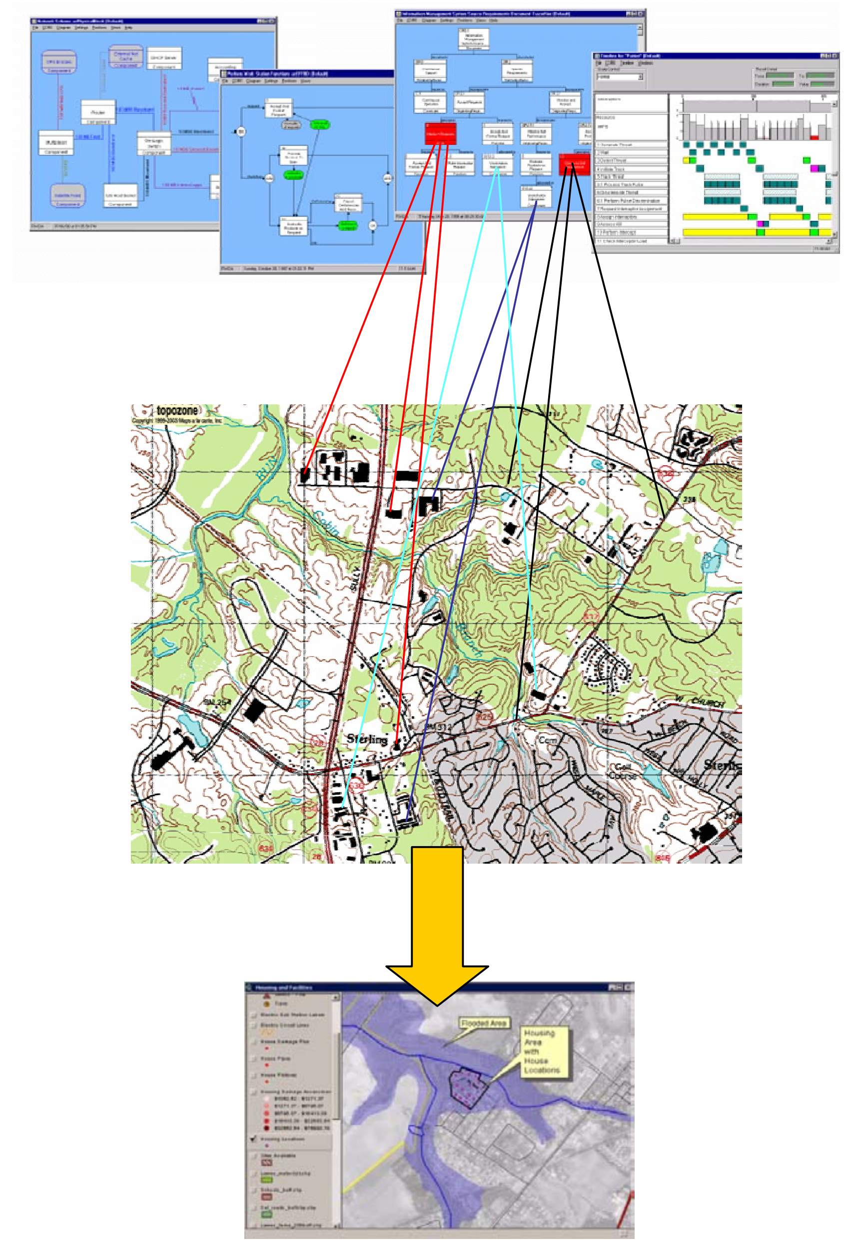
Allocation of Functional Behavior to Geo-Information for Improved Disaster Planning and Management



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Motivation

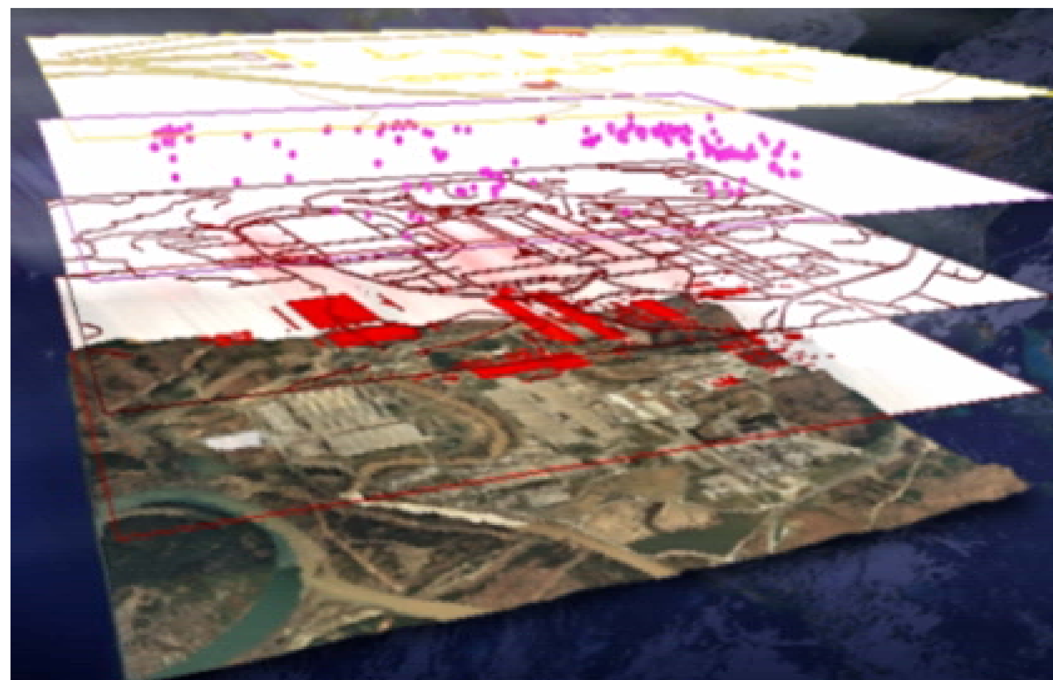
- US Federal Emergency Management Agency (FEMA) 9-11 and 2003/2004 Hurricane Season Lessons Learned:
  - Inability to rapidly acquire, share, and manage the massive amount of data needed to address major disasters
  - Many cities and most rural regions have not yet enriched GIS layer support to a level needed to manage crisis events
  - Current core national infrastructure data collection efforts lack the fidelity for detailed local disaster modeling

What Spatial Models of Hazards Give Us

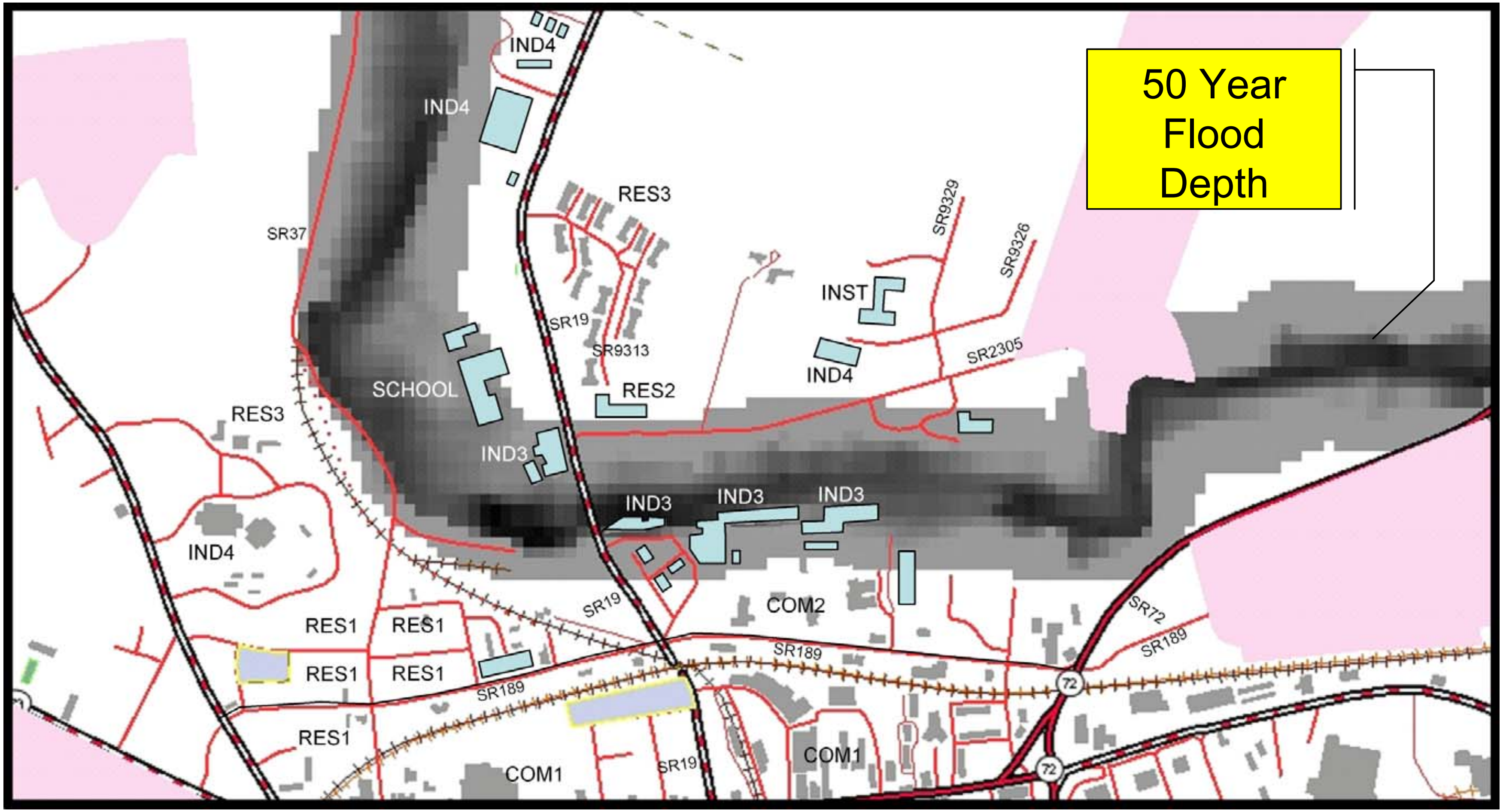
- Primitive Topology
  - Position
  - Dimension
  - Orientation
  - Curvature
- Derived Topology
  - Connectivity
  - Adjacency
  - Containment
  - Intersection
  - Co-linearity
  - Tangency
  - Proximity
  - Slope
  - Aspect
- Given or Derived Attributes

Attribute + topology-based hazard models:

- School in floodplain
- Pipeline intersect road
- Buildings exposed to wind loads
- Slope too steep for building near fault



Riverine Flood Example



- Feature function is inferred from basic attribute - true when collected
- Systemic vulnerability and damage assessment from parts is difficult
- Functional relationship of features not known
- Were all disaster-relevant features included in the analysis?

Challenges with Geo-information for Disaster Management

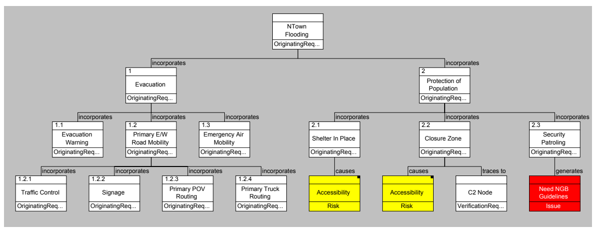
- Geo-information is gathered in a piece-wise, context-neutral fashion
  - The context-variant functional behavior of features is difficult to infer from context neutral attribution
- Disaster impact and vulnerability assessment is needed at a *systems* vs a *feature* level
- Lifeline infrastructural dependency modeling requires a systems approach
- Data capture, management, and analysis need a *systematic* approach

Systems Engineering Design Approach

- Relate attributed spatial features to purposeful system perspectives - designs
- Subject purposeful system perspectives to physics-based hazard modelling to determine effects of hazards on *systems* vs *features*
- Make data collection, management, and analysis more systematic, requirements-driven

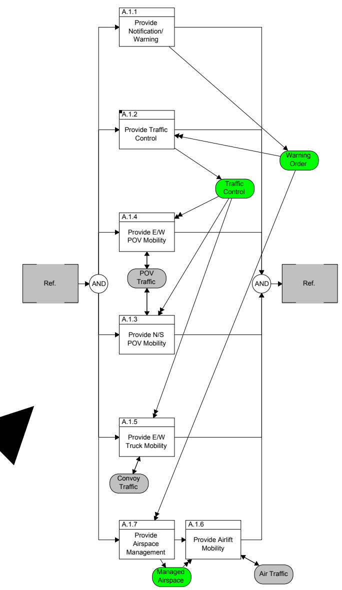
Systems Engineering Design Modelling

Requirements View



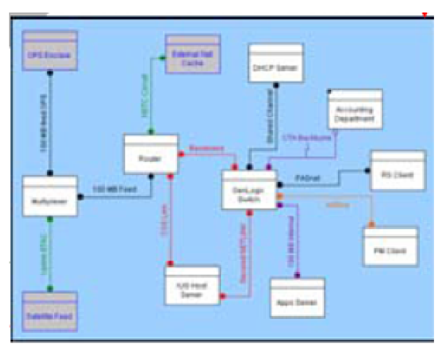
Requirements Trace to Functional Behavior

Functional Behavior View



Requirements Trace To Physical Components

Lacks Geospatial Topology

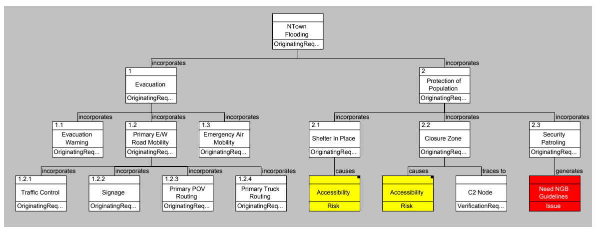


Functional Behavior Allocated to Physical Components

Physical Component View

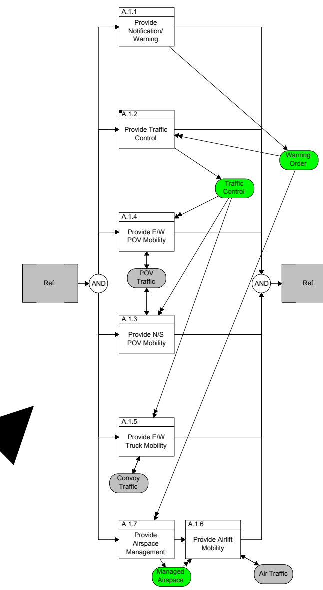
Systems Engineering Design Modelling Using Geo-Information

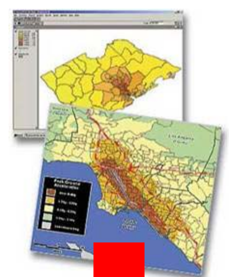
Requirements View



Requirements Trace to Functional Behavior

Functional Behavior View

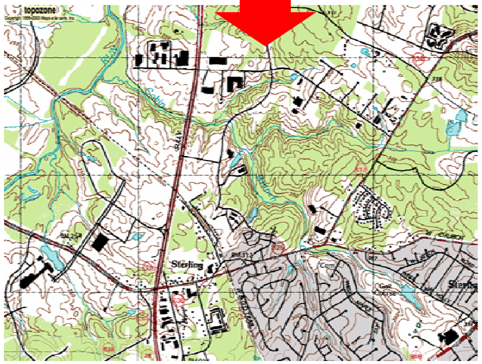




Hazard Models

Requirements Trace To Geo-Information

Functional Behavior Allocated to Geo-Information

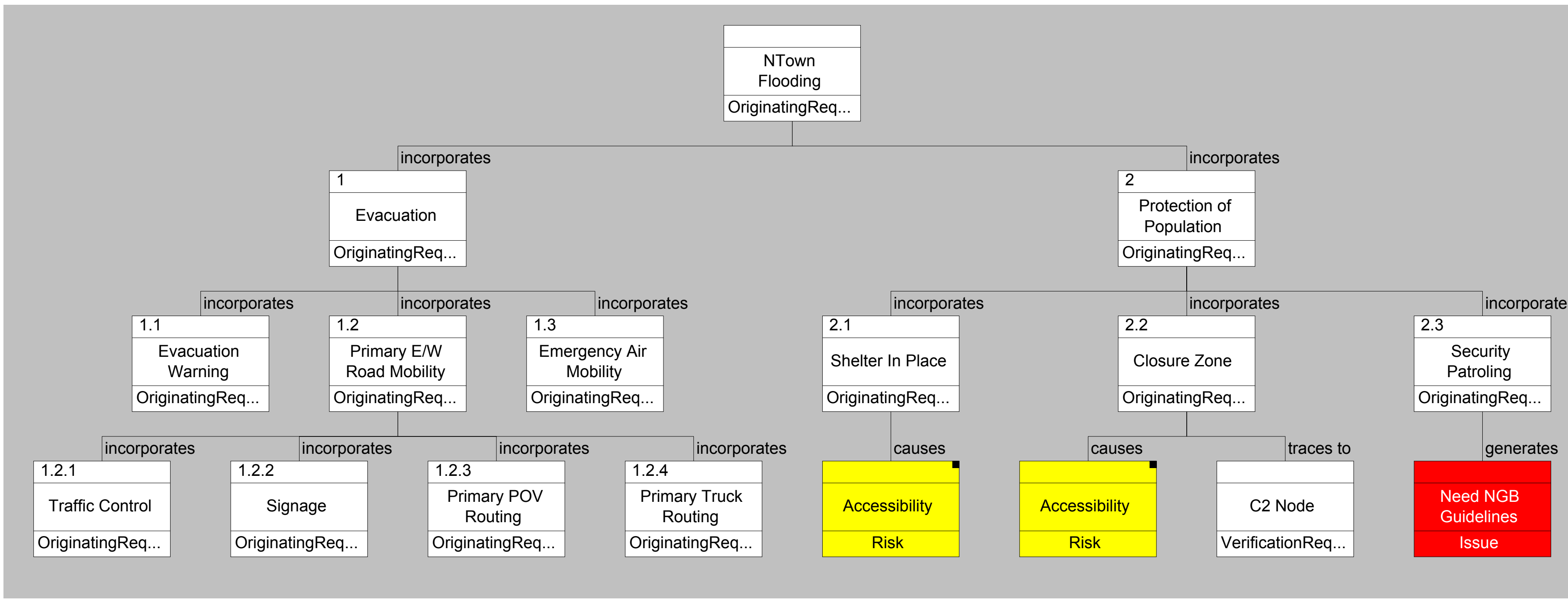


GeoSpatial View

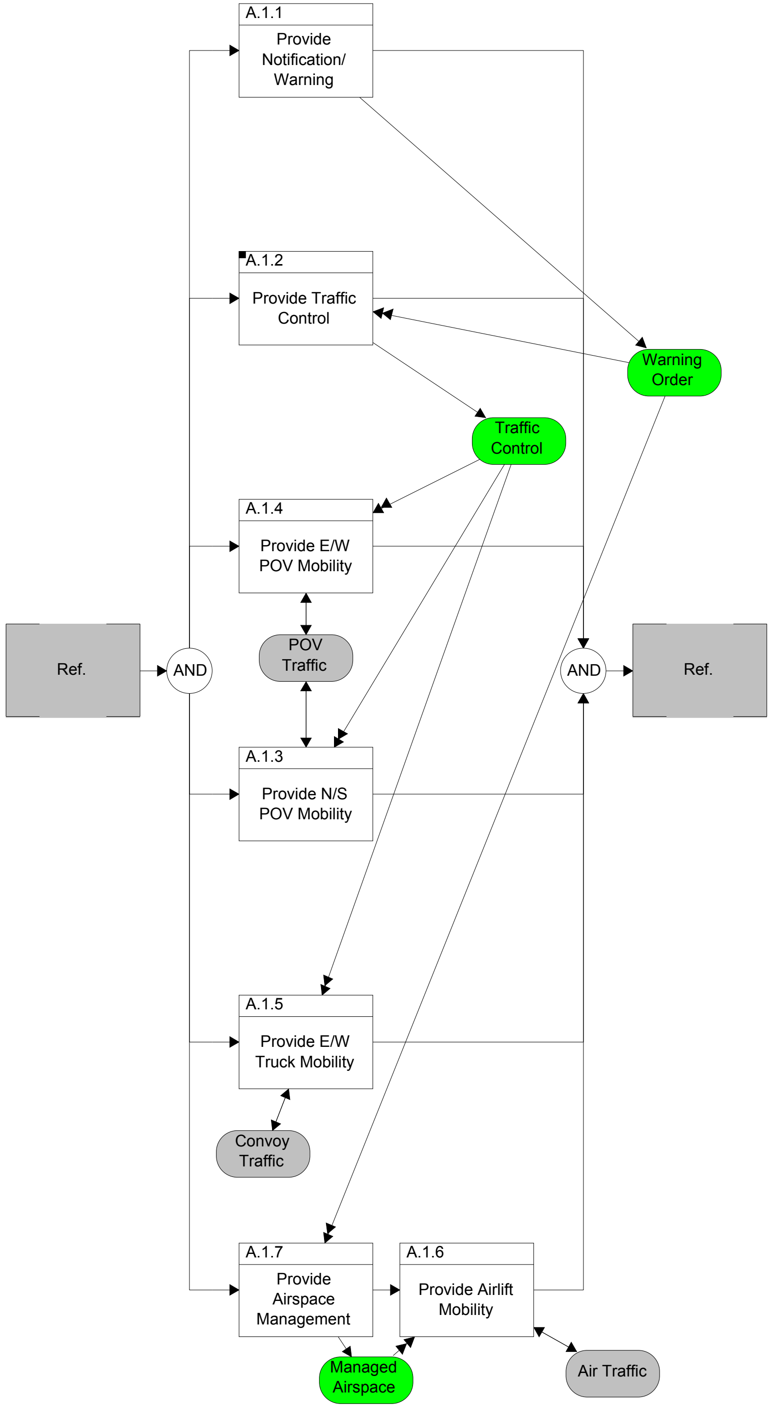
Working the Linkages

- Establish community design objectives
- Model the functional behavior of systems that seek to achieve these objectives
- Allocate this understanding to features in the physical world as represented by a GIS
- Model the effects of key hazards on the geo-information feature population
- Assess the resulting vulnerability of or impact on the affected functions
- Assess the vulnerability of the community design objectives in the disaster context

Design Case: Evacuation
Requirements Tree



- Fairly generic for a particular design like evacuation
- Also a good framework to tie issues and concerns

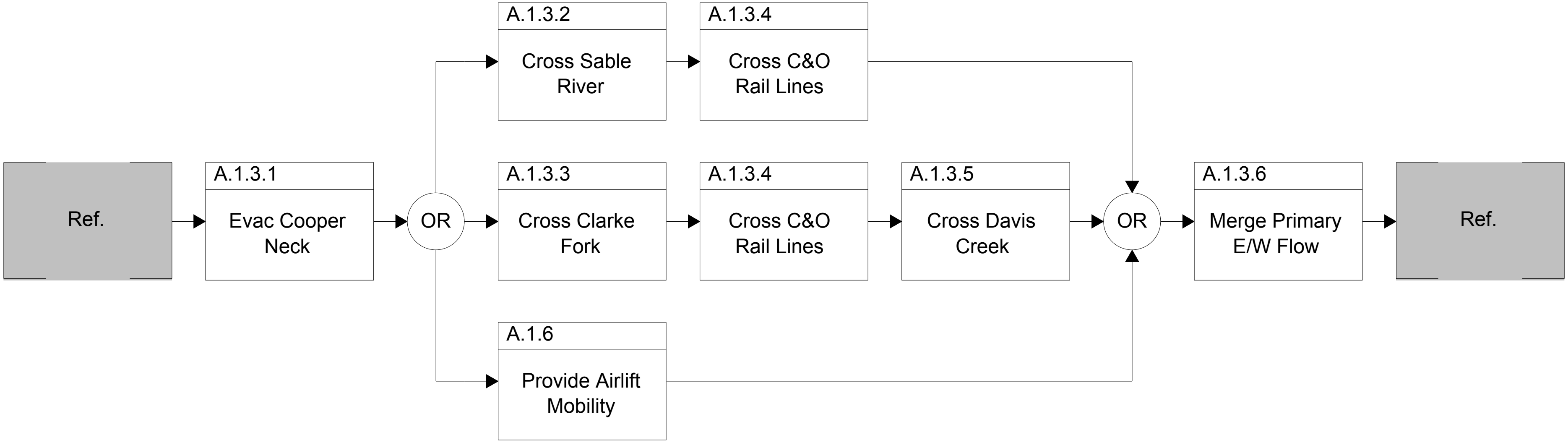


Top-Level Functional View of Evacuation

- Generic at higher levels

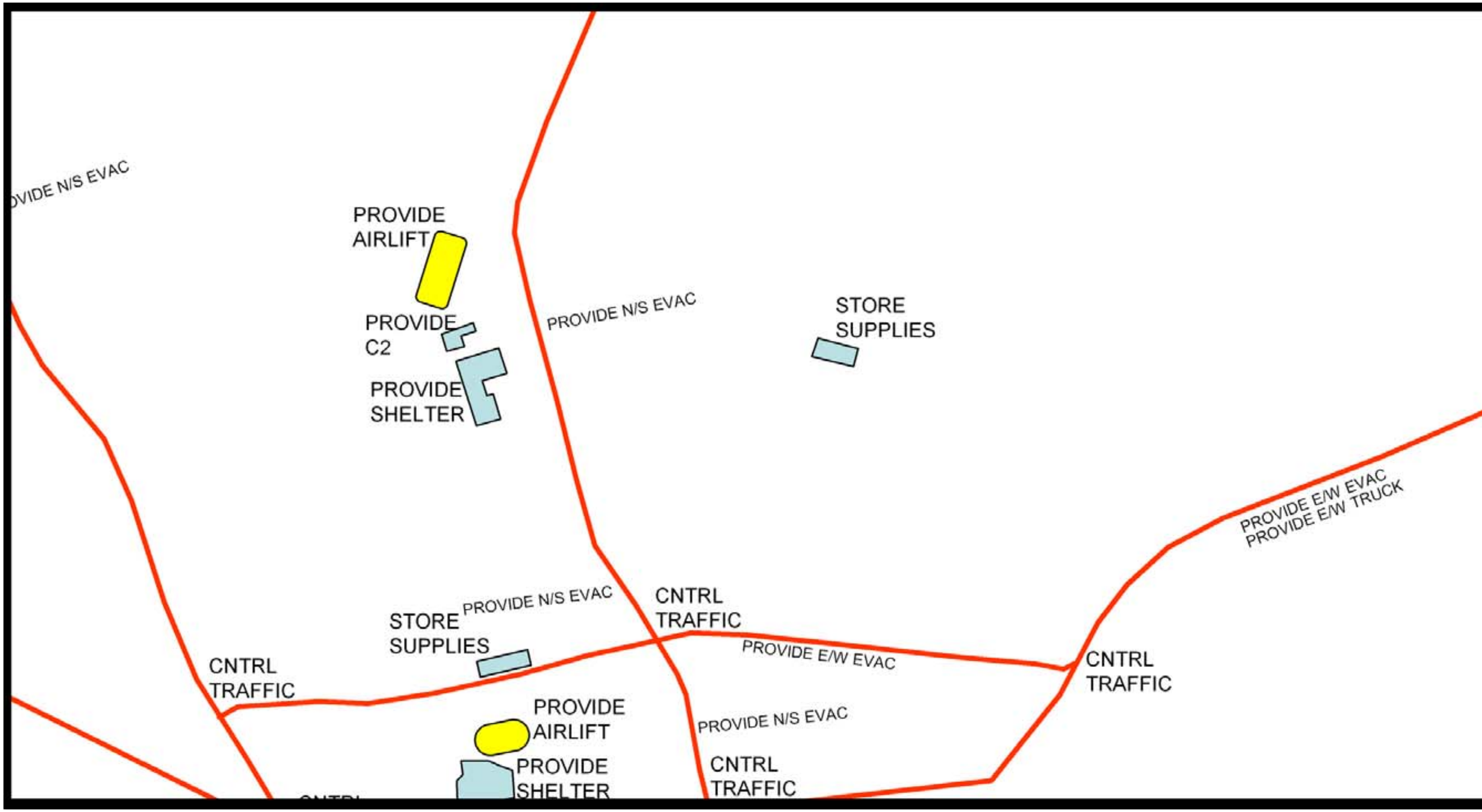
Functional View of Evacuation

Third Level of Functional Decomposition: Provide N/S Mobility



- Specific at lower levels yet structured, hierarchical
- Functional interdependencies become visible

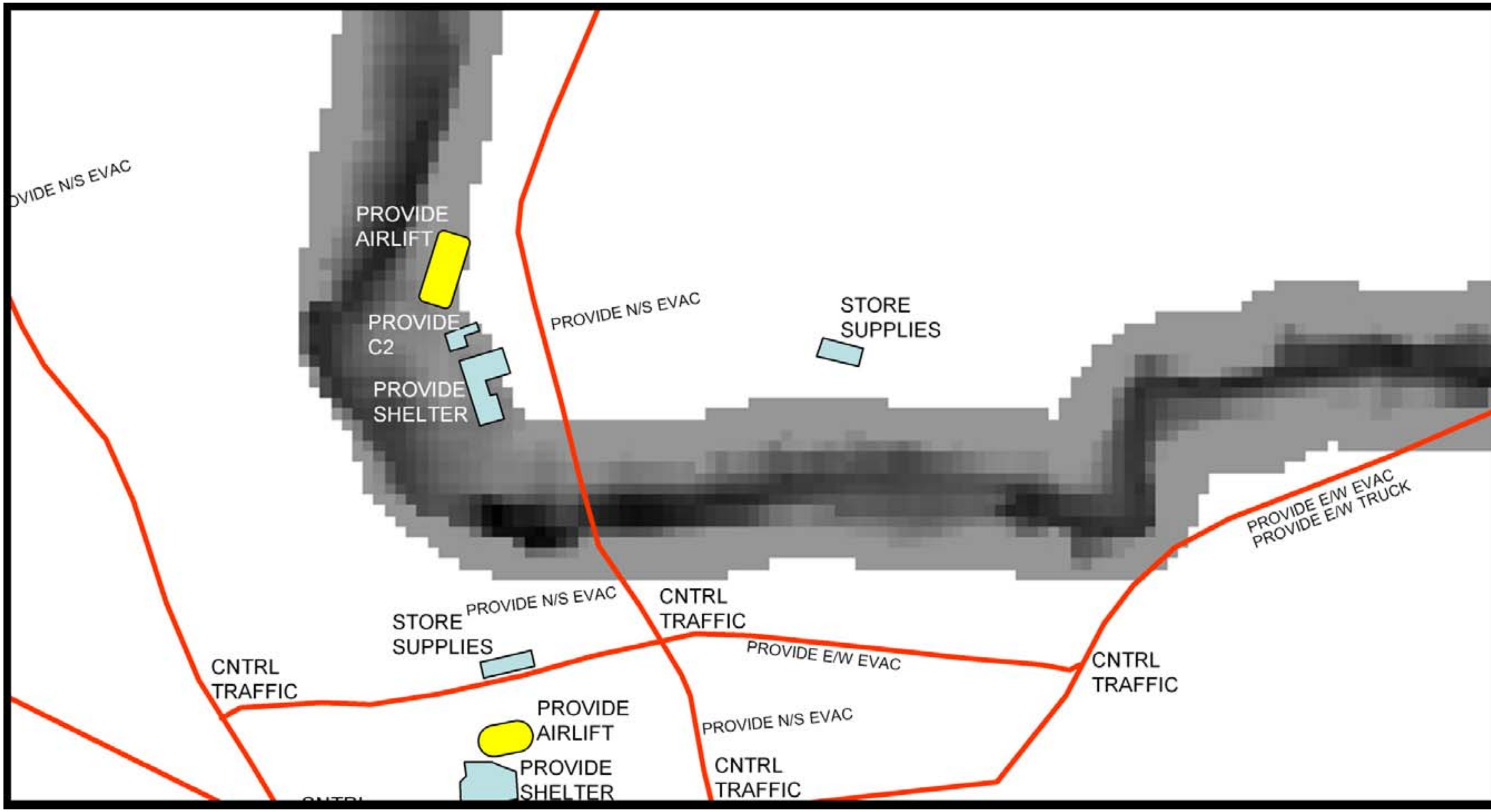
Spatial View of Function



EVACUATION DESIGN

- Function is derived from design goal
- Potentially less data to collect and manage
- Captures functional domain expertise

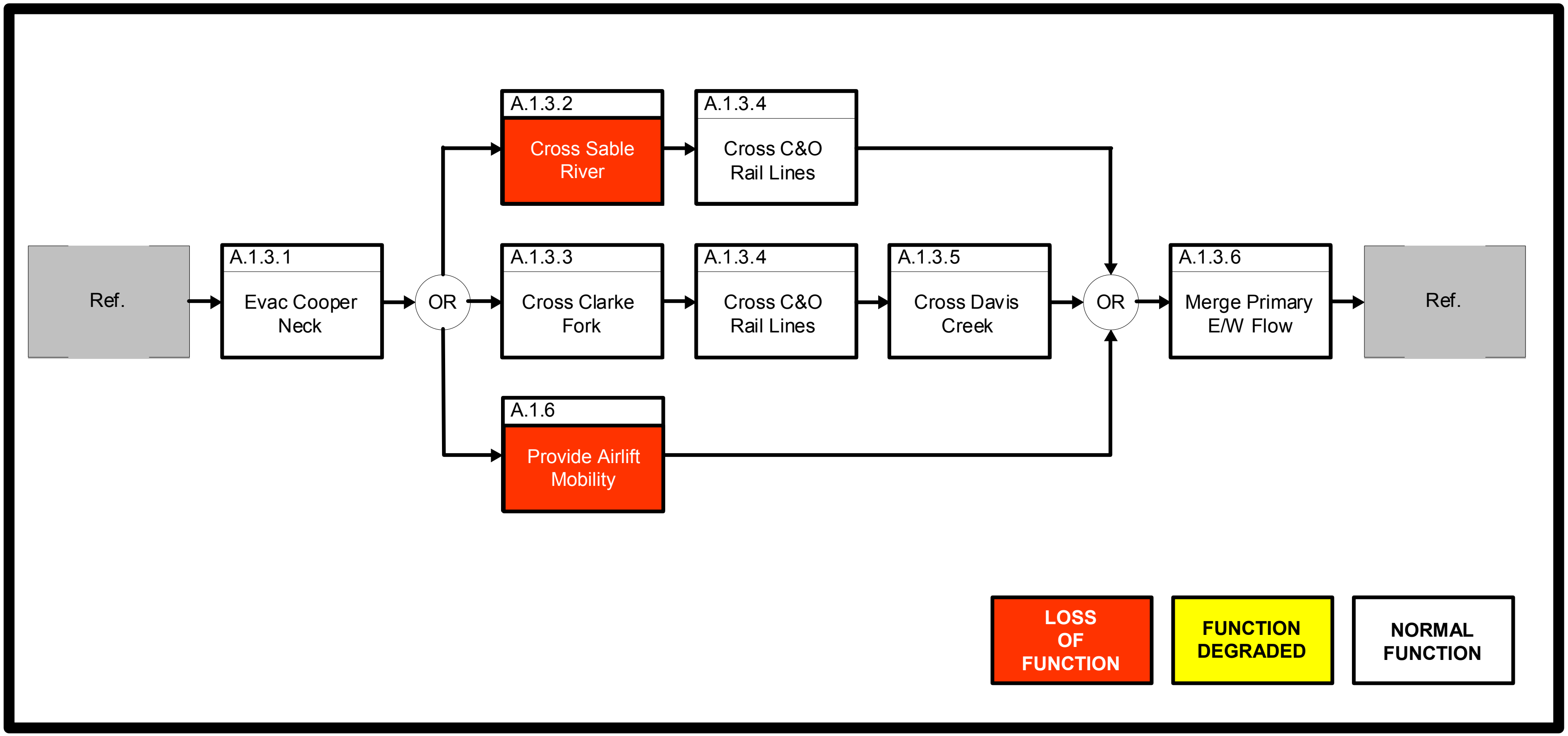
DESIGN GOAL: EVACUATION



- Assessment is at systems level
- Could be used in planning, mitigation, response, and/or recovery stages

Findings
- Provide C2 within floodzone
- Provide Shelter within floodzone
- Provide N/S Evacuation intersect floodzone
- Provide Airlift intersect floodzone

Functional View of Flood



- Functional interdependencies become visible

How this Approach Would Improve Management of Geo-Information

- Focuses feature collection toward those that provide functions relevant to the disaster management process
- Abstracts complex feature behaviors outside the GIS instead of as numerous attribute layers
- Makes the collection of geo-information systematic and more complete

Current Research Issues

- Portability of Requirements Trees and Functional Models – is there a disaster management functional basis?
- Applicable designs (e.g., evacuation, civil defense, electric power loss resiliency)
- Appropriate scale and complexity of use
- Human/Machine Interface issues – function to feature ties in models
- Foreword (design → geo) and reverse (geo → design) cases
- Applicability to infrastructure interdependence and the reliability of complex systems

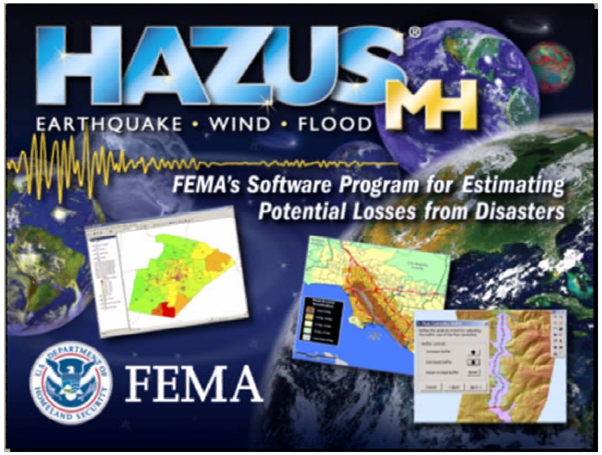
Tools Used

CORE®

Vitech corporation

ArcGIS™

Professional GIS for the Desktop



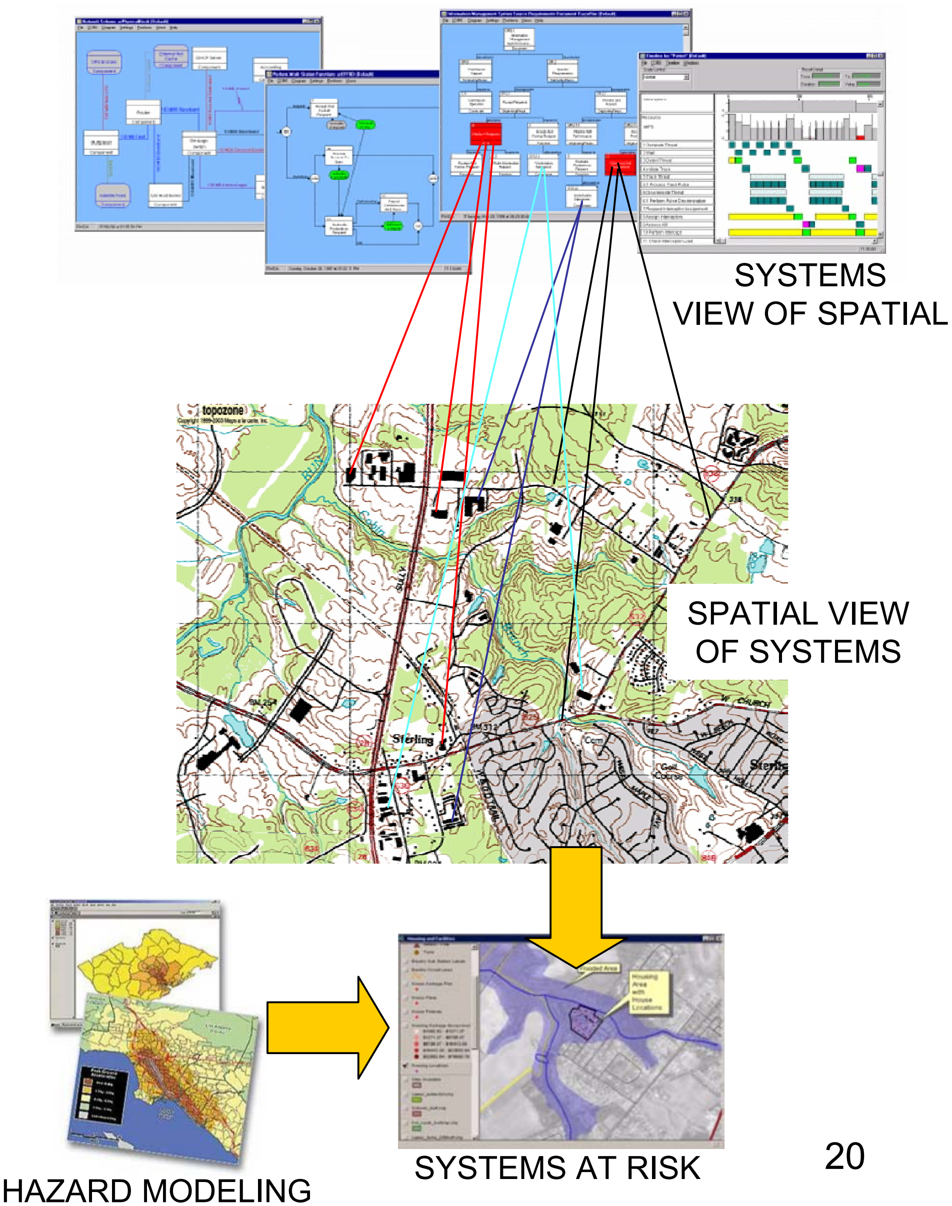
HAZUS Models

	Earthquake Ground Motion Ground Failure	Flood Frequency Depth Discharge Velocity	Hurricane Winds Pressure | Missile | Rain
Direct Damage			
General Building Stock	✓	✓	✓
Essential Facilities	✓	✓	✓
High Potential Loss Facilities	✓	✓	✓
Transportation Facilities	✓	✓	
Lifelines	✓	✓	
Induced Damage			
Fire Following	✓		
Hazardous Materials Sites	✓	✓	✓
Debris Generation	✓	✓	✓
Direct Losses			
Cost of Repairs/Replacement	✓	✓	✓
Income Loss	✓	✓	✓
Crop Damage		✓	
Casualties	✓		
Shelter and Recovery Needs	✓	✓	✓
Indirect Losses			
Supply Shortages	✓	✓	
Sales Decline	✓	✓	
Opportunity Costs	✓	✓	
Economic Loss	✓	✓	

From: FEMA 2004

Summary

- Systems engineering modeling techniques together with spatial analysis techniques to address vulnerability of critical infrastructure to natural hazards
  - Systems Engineering methods model mapping of infrastructural function to requirements and to the physical domain
  - Spatial methods model the topology of the physical domain and its exposure to natural and man-made hazards



Backup

Infrastructure Reliability

- Reliability and vulnerability of complex systems (such as critical infrastructure) is very difficult to determine
  - Dependent failures often hard to assess as they are linked and/or cascading
  - Need to develop risk contexts
  - Need to understand effects of migration of risk due to management activities

Gas → Electricity → Water

Functional Modeling

Approach used to model any man-made system by identifying the designer defined overall goal it must achieve and the designer/user defined functions it must perform.

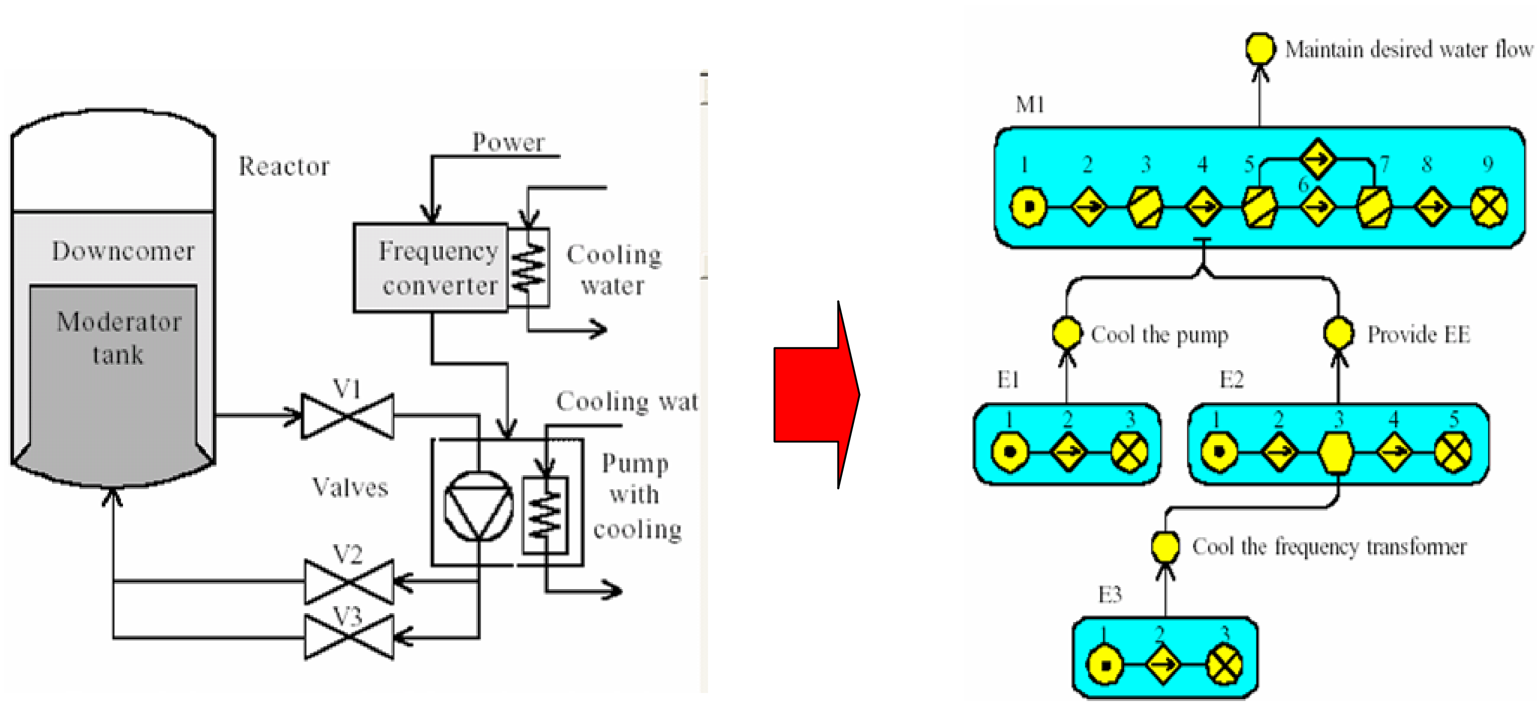
Must answer:

- *Why was the system designed in the first place?*
  - Clarifies the intention(s) of the designer of the system and hence the overall goal the system must achieve.
  - answer leads to:
- *What is the system supposed to do in order to achieve the goal?*
  - Clarifies the functions the system must perform, and it at the same time leads us to:
- *How must different parts of the system's physical structure interact in order to realize the functions?*

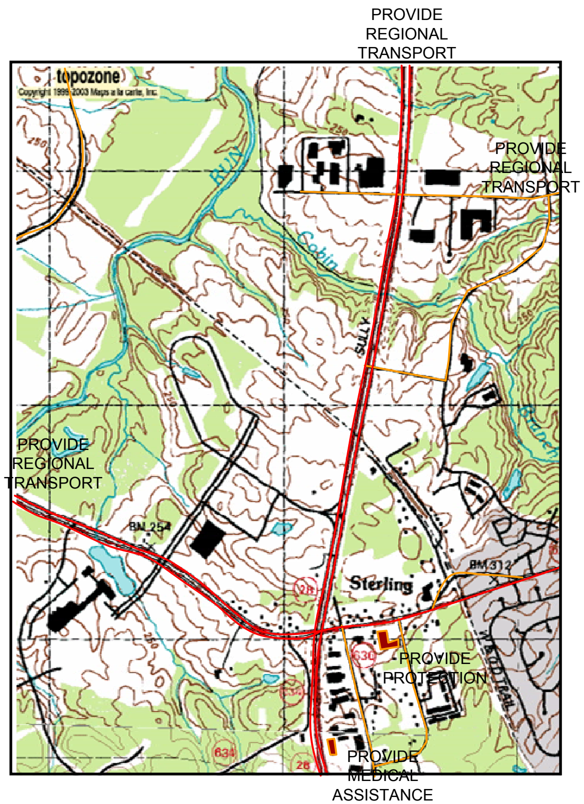
From Modarres, 2003

Multi-Level Flow Models

- Context derived from functional understanding of complex system elements and interdependencies toward design goals
  - From Lind & Larson, 2000; and Modarres 2003



Useful Even Without Hazard Model



DESIGN GOAL: EP RESILIENCE

Case: Functional elements operate in a spatial context

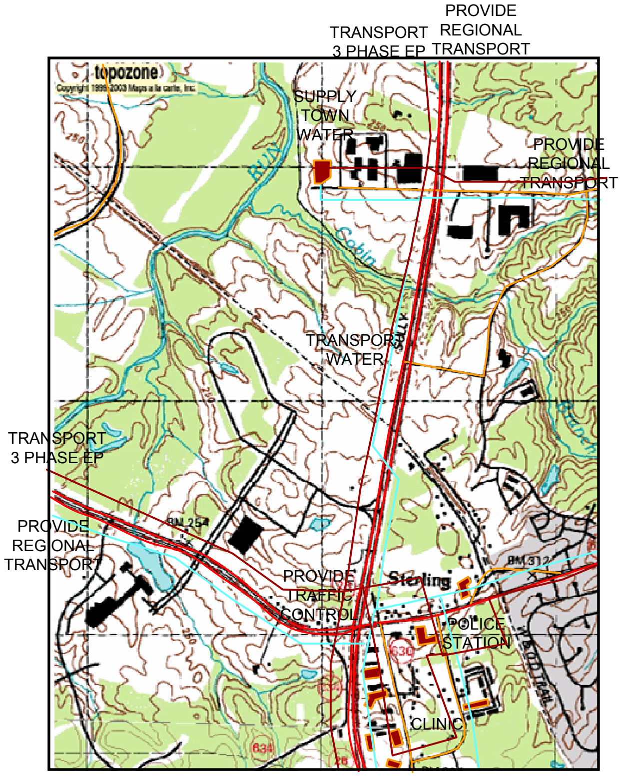
Findings

• "Provide Regional Transport" intersect "Provide Region Transport" needs EP Backup for EP resilient traffic control

• Useful for resilience investments

Example

DESIGN GOAL: INFRASTRUCTURE RESILIENCE



Case: Functional interdependence between EP and water pressure

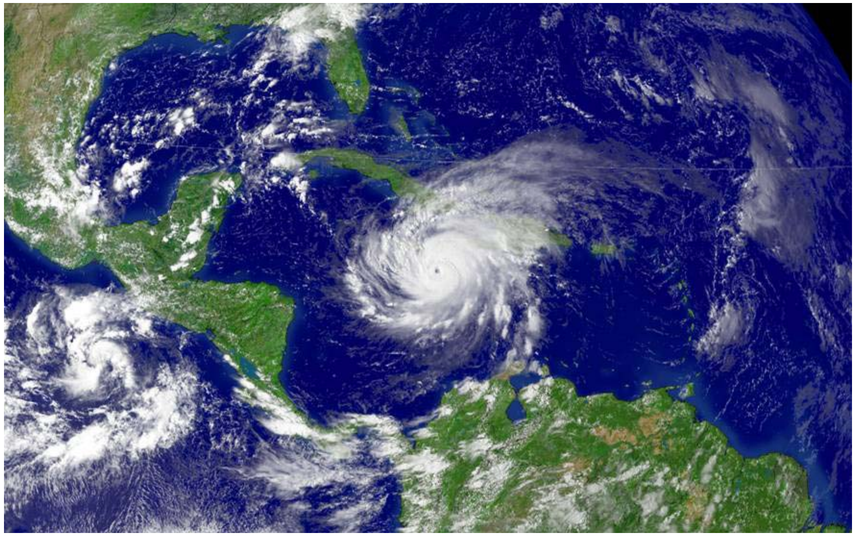
Findings

- Identification of new failure mode:
  Clinic <depend> water <depend> EP
- Structure of infrastructure elements for reliability models

- Function is derived from design goal
- Interdependence is derived from MFM and Goal Tree

Case 1: Environmental Risk to Infrastructure

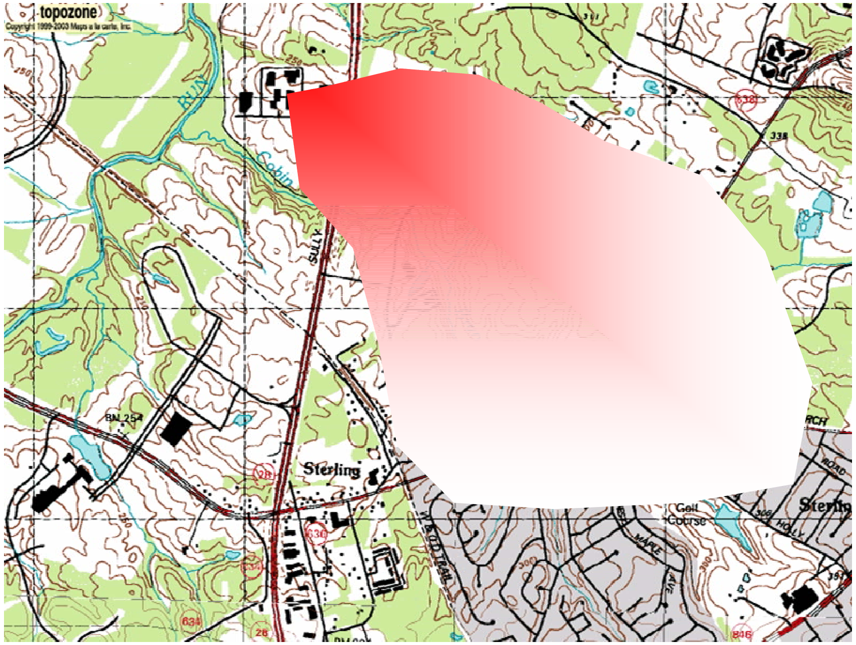
- Topical
- Unclassified
- Well studied/modeled
- Groundtruth exists



Hurricane/flooding, coastal community

Case 2: Human Risk to Infrastructure

- Topical
- Unclassified if kept generic
- Models exist for certain phenomenology (e.g., toxic plume dispersal)



Toxic/radioactive plume, suburban setting