# SysML Strategies to Characterize and Analyze Systems of Systems

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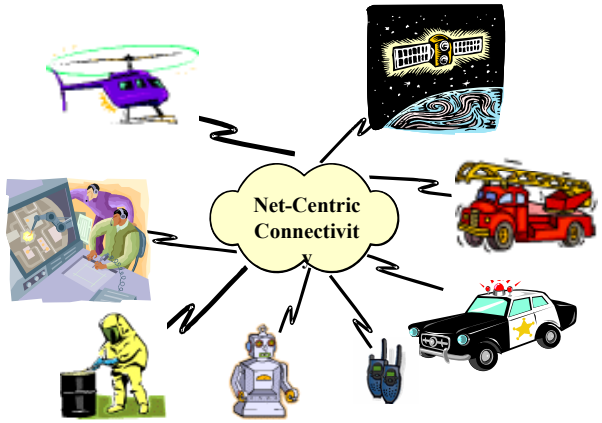
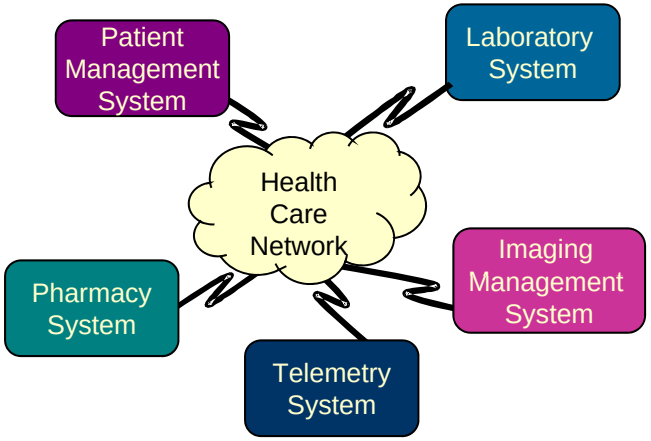
# Overview

- SoS context and key challenges
- SoSE strategies
- SoS example
  - Regional Area Crisis Management SoS (RACRS)
  - RACRS SysML models to support SoSE
- Acknowledgements
- References

# What is a "System of Systems"?

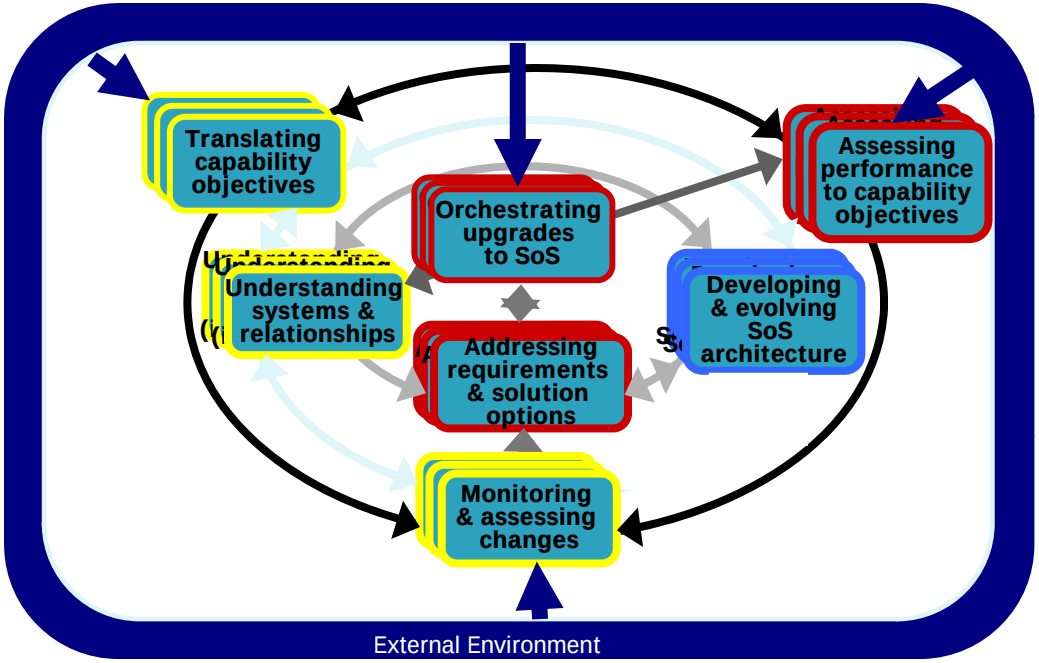
- Very large systems using a framework or architecture to integrate constituent systems (CSs)
- Exhibits emergent behavior not otherwise achievable by CSs
- SoS CSs
  - Independently developed and managed
  - New or existing systems in various stages of development/evolution
  - May include a significant number of COTS products
  - Have their own purpose
  - Can dynamically come and go from SoS
- Typical domains
  - *Military/Crisis Response:* Dynamic communications infrastructure
  - *Business:* Enterprise-wide and cross-enterprise integrations




*Based on Mark Maier's SoS definition [Maier, 1998]*

# SoSE Activities and Management Strategies




SoSE Guidebook view based on interviews and analysis of 18 DoD SoSs in various stages:

- Communications systems
- Command and control systems
- Integrated combat systems
- Ballistic missile defense systems
- Intelligence information systems
- Space-related systems

- Types of SoS governance
  - Virtual [Maier, 1998]

    Lacks a central management authority /clear SoS purpose
  - Collaborative [Maier, 1998]

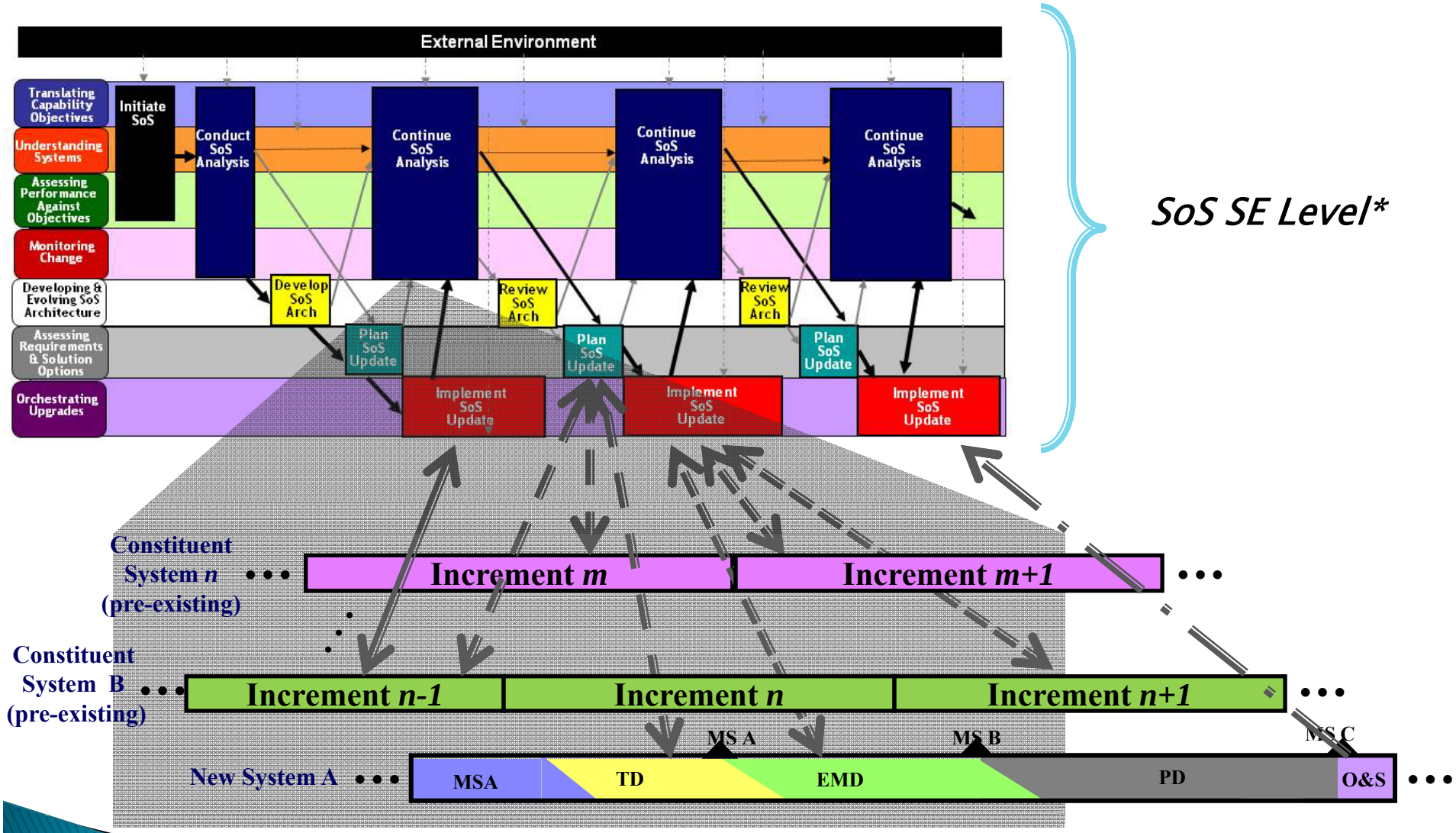
    CS engineering teams work together, but no one in charge
  - Acknowledged [Dahmann, 2008]

    Recognized objectives, designated manager supported by an SoSE team
  - Directed [Maier, 2008]

    SoS centrally managed by a government, corporate, or Lead System Integrator organization

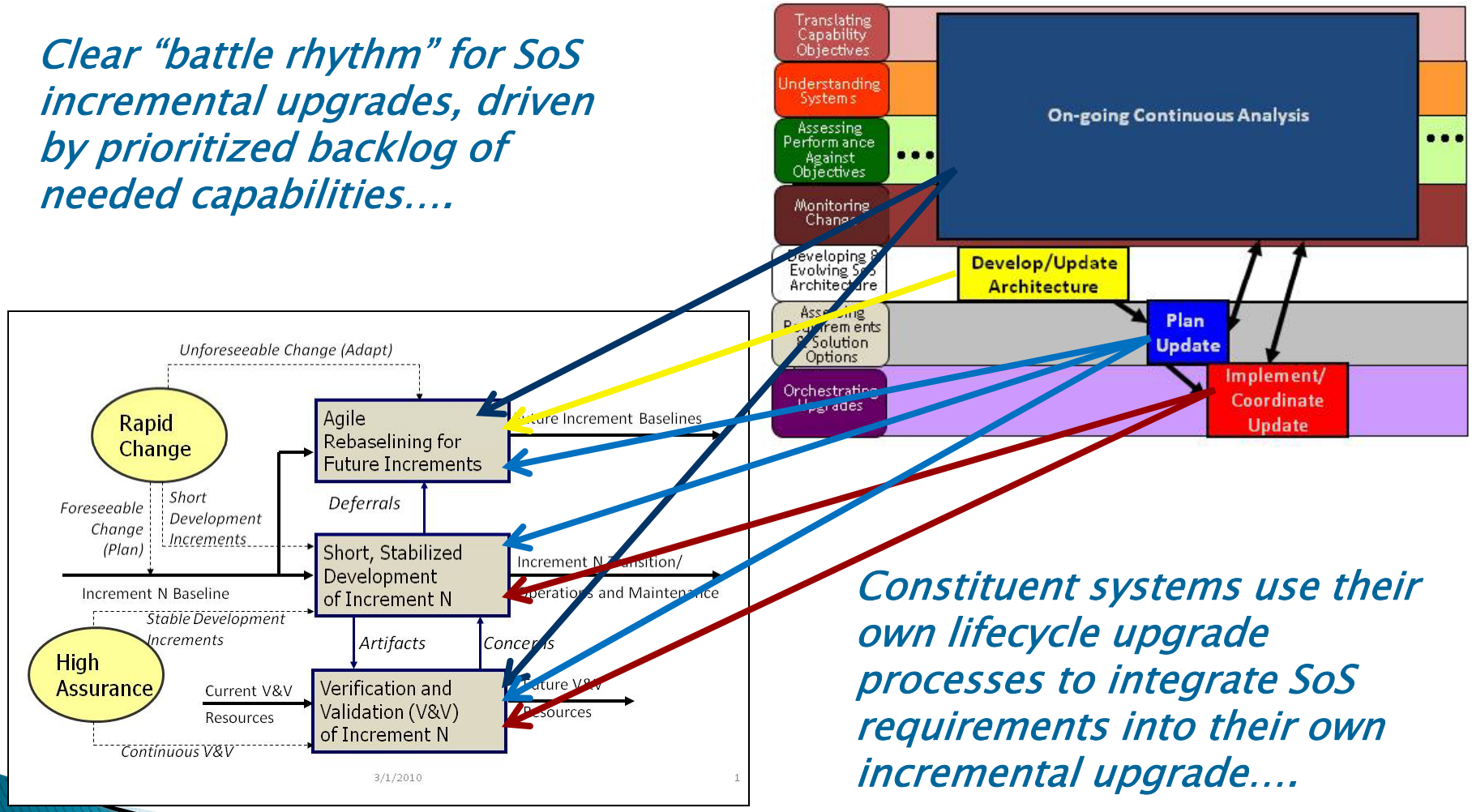
Key SoSE challenges reflected by core elements and governance…

# SoSE Synchronization Challenges



# SoSE Process Strategies: Incremental Commitment Model for SoS

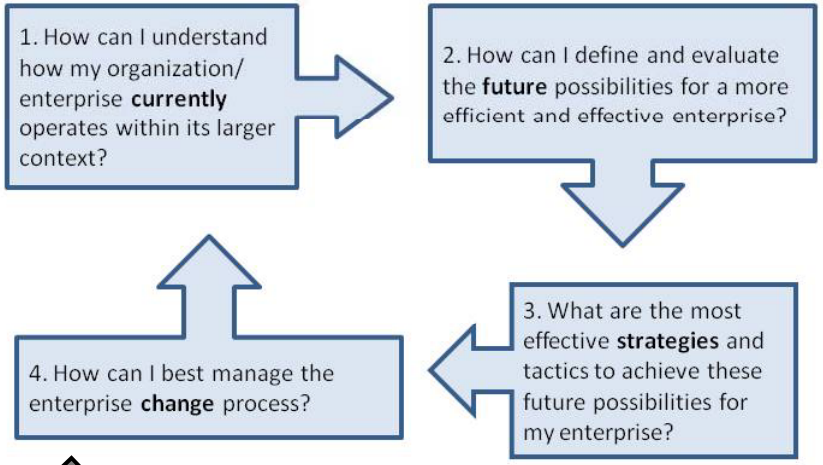
*Clear "battle rhythm" for SoS incremental upgrades, driven by prioritized backlog of needed capabilities….*




*Constituent systems use their own lifecycle upgrade processes to integrate SoS requirements into their own incremental upgrade….*

# SoSE Process Strategies: Lean Enterprise Principles

## SoSE guided by LAI Lean Enterprise 4 Grand Questions



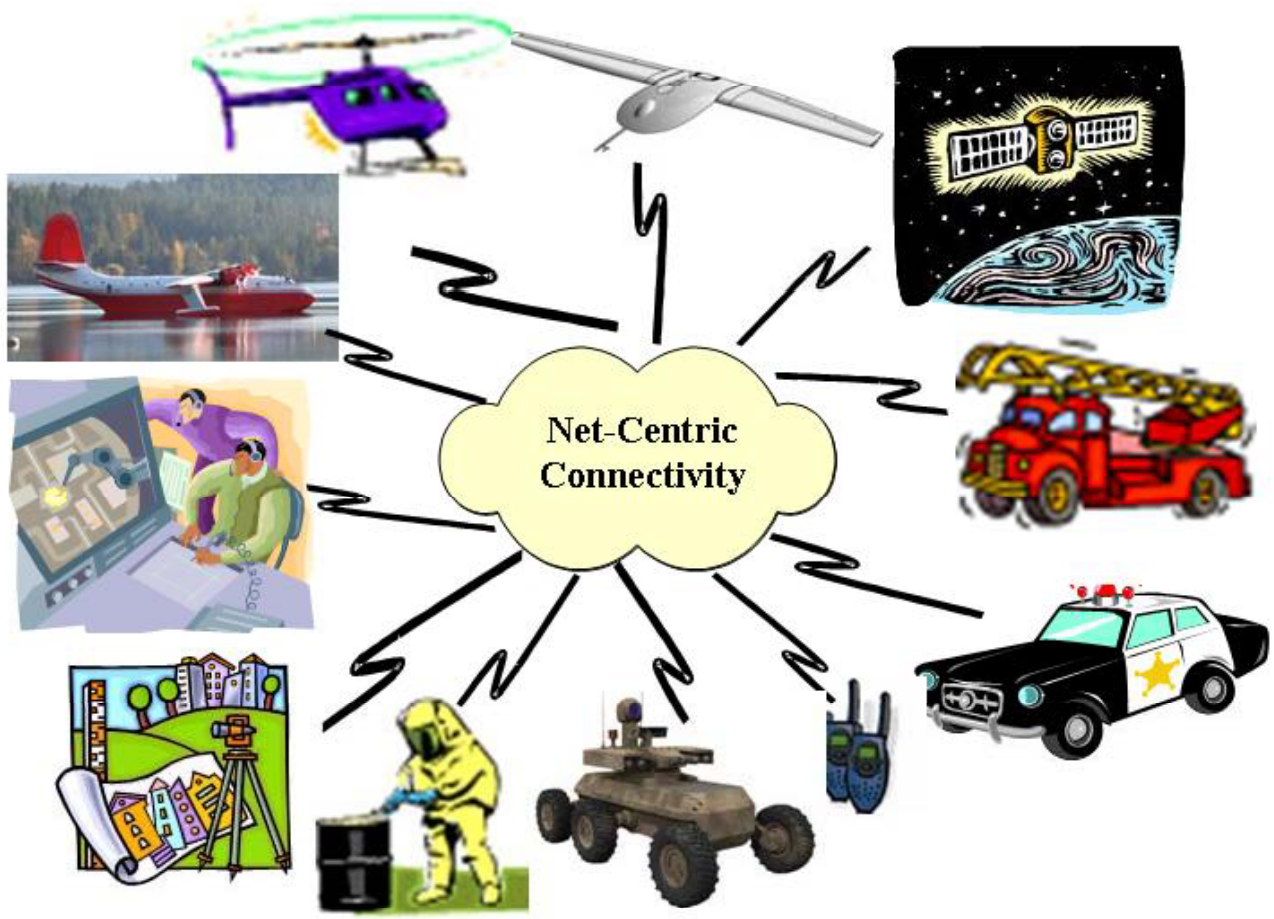

## Lean Enterprise 4 Grand Questions mapped to DoD SoSE case studies….

| SoS ID | Lean Enterprise Grand Questions | | | | Scope of Key Stakeholder Considerations | Number of Constituents |
|---|---|---|---|---|---|---|
| | *Q1: Understand Current* | *Q2: Future Possibilities* | *Q3: Strategies and Tactics for Future* | *Q4: Change Process* | | |
| 1 | X | X | X | Monitor and attempt to guide, but do not manage | Across all DoD services/coalitions | 16 |
| 2 | X | X | X | Work in concert with constituent systems to manage upgrades | Across multiple DoD services and government agencies | 9 |
| 3 | X | X | X | Monitor and attempt to guide, but do not manage | Across all DoD services | 10 |
| [illegible] | [illegible] | [illegible] | Coordinated by larger | Managed from above [illegible] | [illegible] | Many – exact [illegible] |

## Lean Enterprise 4 Grand Questions mapped to SoSE core elements….

| SoSE Core Element | Lean Enterprise Grand Questions | | | | *Stakeholder Considerations* | *Holistic Enterprise View* |
|---|---|---|---|---|---|---|
| | *Q1: Understand Current* | *Q2: Future Possibilities* | *Q3: Strategies and Tactics for Future* | *Q4: Change Process* | | |
| Translating Capability Objectives | | X | | | X | X |
| Understanding Systems and Relationships | X | | | | X | X |
| Assessing Performance to Capability Objectives | X | X | | | X | X |
| Developing and Evolving an SoS Architecture | X | X | X | | | X |
| Monitoring and Assessing Changes | X | | | X | X | X |
| Addressing Requirements and Solution Options | | | X | X | X | X |
| Orchestrating Upgrades to SoS | | | | X | X | X |

# Case Study:
# Regional Area Crisis Response SoS (RACRS)



# Constituent Systems

- *Satellite Imaging System:* Provides images of interest to requestor
- *Fire Department:* Manages the fire response units
- *Police Department/Sheriff's Dept:* Provides safety and crime-fighting support/includes evacuation support and protection from looters
- *Handheld devices:* Provides connectivity to people on the ground (fire fighters, police, sheriff deputies) via voice and video
- *Unmanned ground vehicle (UGV):* Provides
  - On the ground video feeds in situations where it is too dangerous for personnel
  - Clearing of brush/small trees to create fire breaks
- *Hazmat system:* Instrumented gear to help quickly evaluate potentially hazardous situations and well as communications and video capability

# Constituent Systems *(continued)*

- *Regional area Planning and Land Use Data*: Includes building plans and maps for utilities (electricity, water, sewer) and other regional areas of interest
- *Command and Control Center:* Central site to monitor and help coordinate activities/site to support decision makers
- *Aerial water tanker:* State/national asset shared among multiple regional areas
- *News helicopter:* Used to capture video feeds for news programs—includes news events as well as traffic flows, may also be used to monitor for signs of looting
- *Unmanned aerial vehicles (UAVs):* Used for surveillance, lightweight fire retardant drops, and can also be armed to start needed backfires or fire upon looters/rioters

# RACRS Key Features

- Goals:
  - Minimize impacts of area crises
  - Contain potential losses
- Ability to coordinate responses to regional area crises
  - Classify type of crisis
  - Alert appropriate organizations
  - Alert/evacuate public
  - Identify and manage needed resources
    - Fire trucks
    - Airplanes
    - Helicopters
    - Robots/remotely controlled vehicles
    - Medical supplies/special treatment or isolation facilities
- Request and coordinate support from other agencies: state, Federal, or other regional areas
- Strategic partnership with local news stations for live video feeds
- Support crisis management activities in other regions

# RACRS Issues and Risks

- Incompatible interfaces between existing systems
- COTS products available to support interconnectivity, but have not been used at this level (potential scalability issues)
- Police and fire departments currently have on-going projects to integrate the police, fire department, and 911 systems
- Limited local budgets to modify other existing systems
- Little or no modifications expected for related State and Federal systems but expectations that these will evolve
  - Potential impacts with interfaces to other regional area systems
- Federal funds available if system implemented within the next 5 years
- Both County Board of Supervisors and City Council need to approve plans and budgets
- Citizen privacy and security issues
- Potential overlapping authorities during crises: local, state, and Federal

# RACRS Desired Characteristics

- Integrate existing legacy systems together using a net-centric architecture that includes wireless, mobile networks for mobile units and existing networks for fixed Control Center connectivity
- Must work across coastal plain, intermediate mountain range, and low-lying desert area on far side of mountain range
- As part of this effort, the city and county planning and land use organizations would like to replace their location tracking systems with a new system that is based on city/county records and not the more general purpose map programs/ databases typically provide by Geographic Information System (GIS) vendors
- No other new system components planned for the early versions of this SoS
- Build on existing connectivity
  - Some sort of connectivity exists between
    - City police, sheriff's, 911, and ambulance systems
    - Jail information system and state and Federal agencies
  - Most other system components are relatively closed, independent systems

# Elements to Think About

- Key mission scenarios
  - Fires
  - Earthquake in Southern California
  - Hazardous material spill on freeway during rush hour
- Feature, service, or crisis priorities—how to define early increments
- Candidate architecture(s) and increment definitions: What can be defined as "independent projects"? How does this impact cost and schedule?
- What elements require early simulation/prototyping/evaluation?
- Risk management: What key risks should be addressed first?
- Where to be agile? Where to be plan-driven?
- Types of oversight for various types of component system providers
  - Strategic partners
  - Vendors
  - Suppliers
  - Developers
- What additional assumptions/constraints are there?

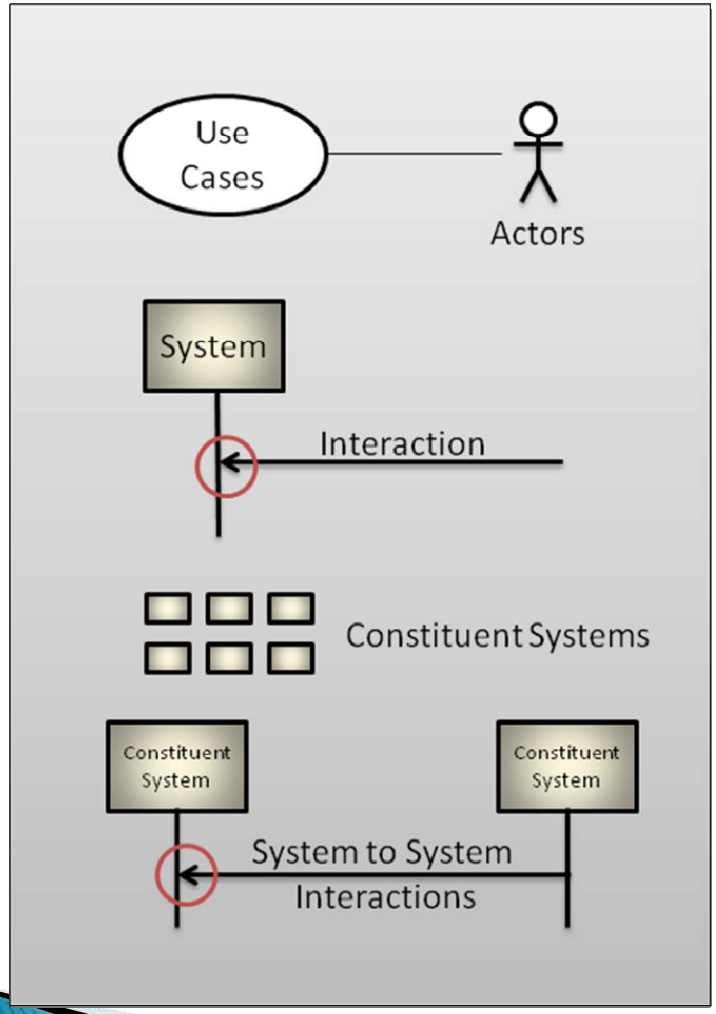
# Desired SoS Engineering Modeling Support

- Understand CSs and their relationships
  - SoS architecture and capabilities
  - CS functional capabilities
  - Interfaces and protocols
  - Data elements, precision, and rates
- Develop and evolve an SoS architecture
  - Understand current architecture
  - Develop target architecture to guide SoS evolution

# Desired SoS Engineering Modeling Support *(continued)*

- Assess CS changes
  - Impact to SoS architecture and capabilities
- Address new requirements and options
  - Implementation and transition strategies for desired capability
  - Impact to constituent systems

# Overview of SysML Model Capabilities with Respect to SoSE




Understanding the user perspective

Understanding how the single system fits in the SoS environment

Understanding the key constituent systems in the SoS environment and what their single system capabilities are

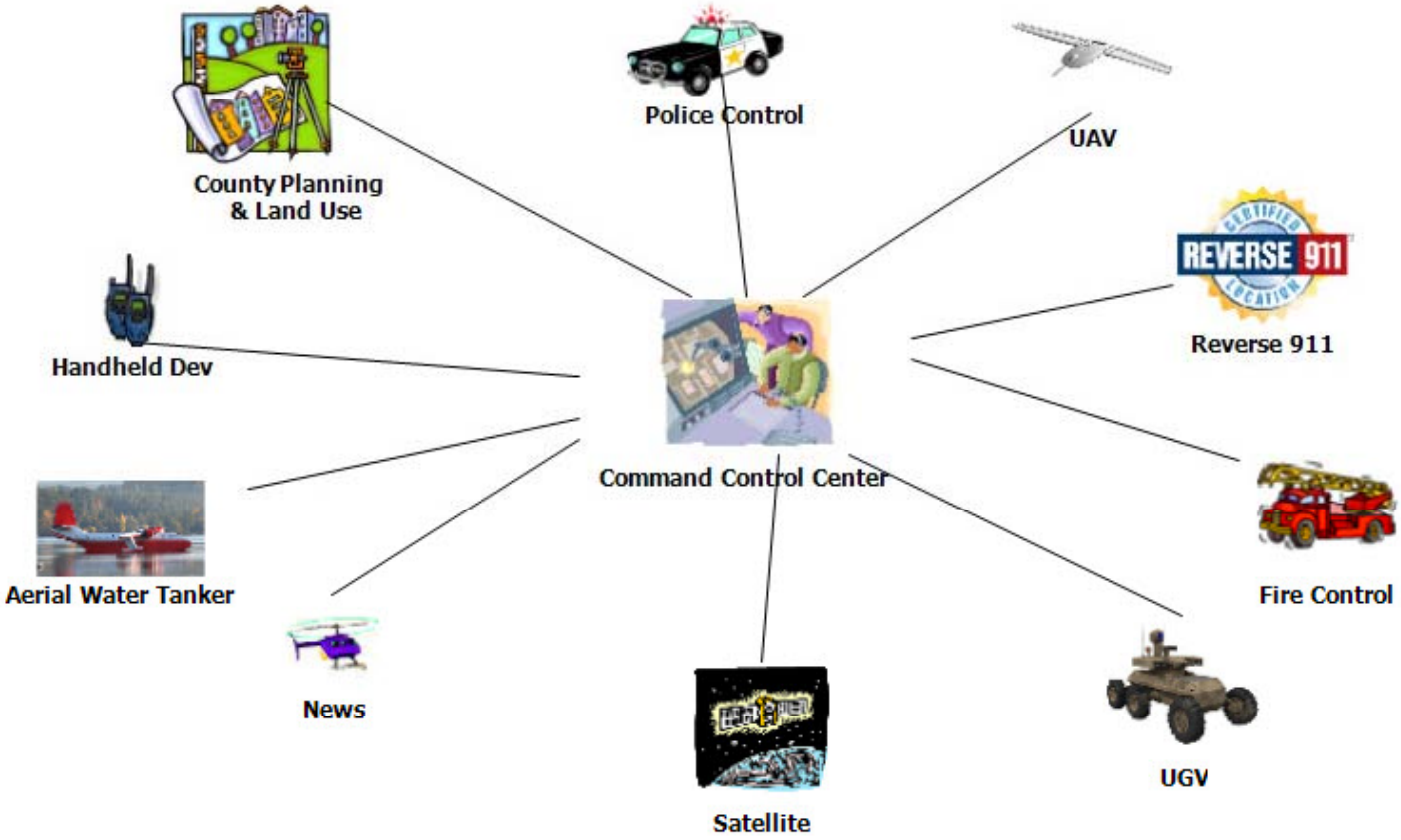
Understanding the interactions between the various constituent systems within the SoS

# SysML Models that Support SoS Engineering Needs

- Object classes
  - Characterize each SoS CS and its capabilities
- Interface classes
  - Describe each CS interface
- Input/output entity classes
  - Express the associated data attributes of each data item transferred over that interface
- Use cases
  - Characterize both CS and SoS capabilities from the different user perspectives
- Sequence diagrams
  - Characterize and analyze the operational flow for an SoS capability

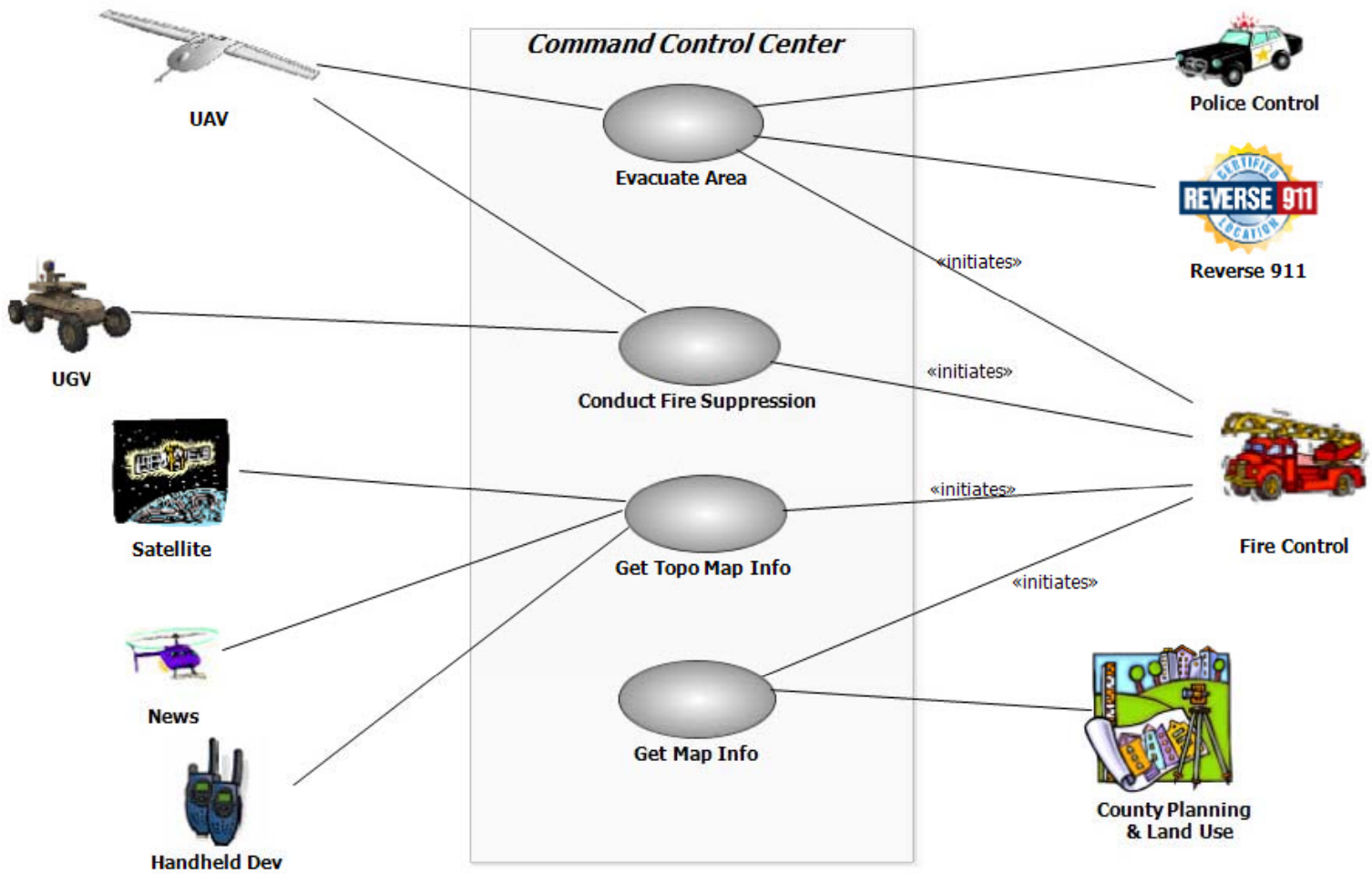
# RACRS Context Diagram

## – From the perspective of the CCC

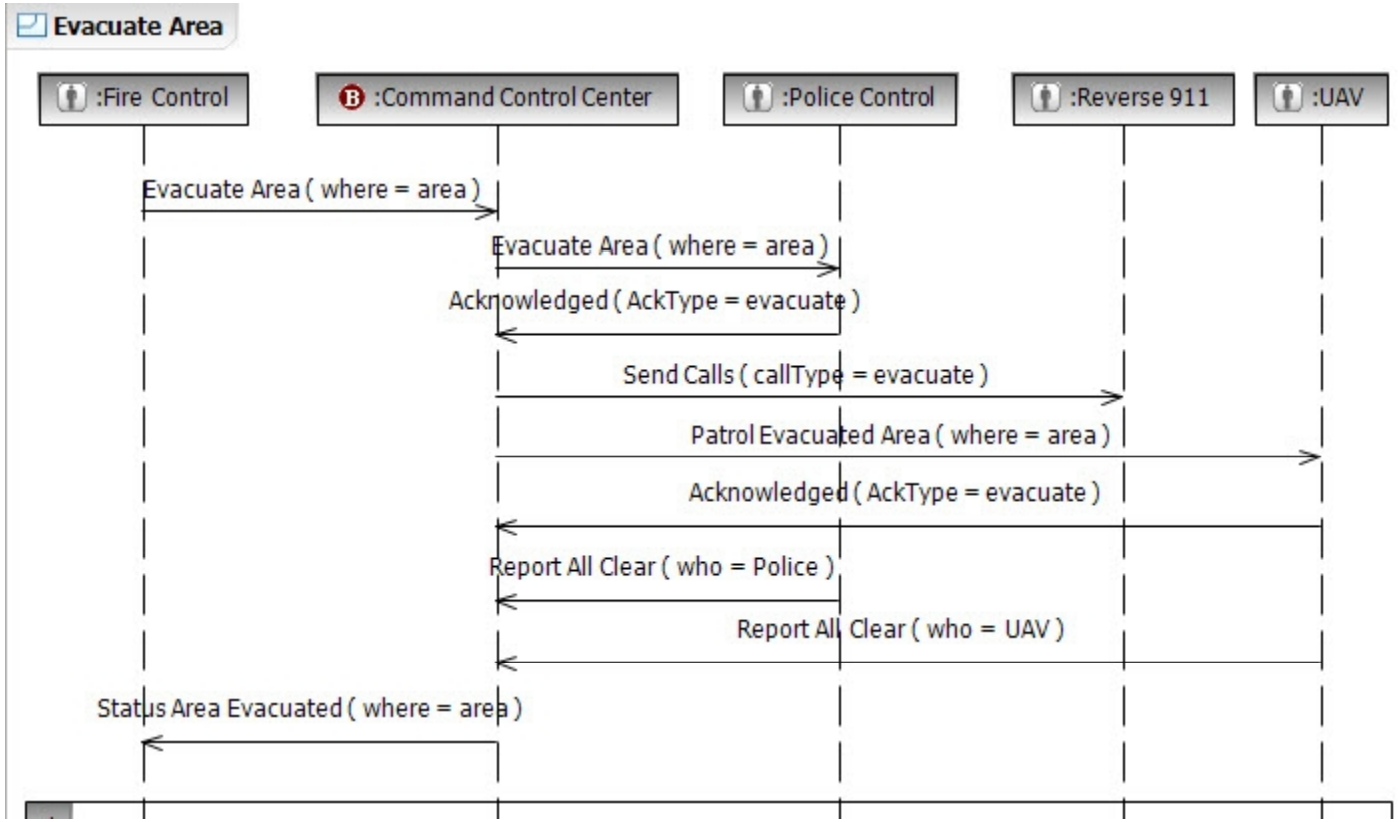



Key “boundary object” that can be viewed from many perspectives…

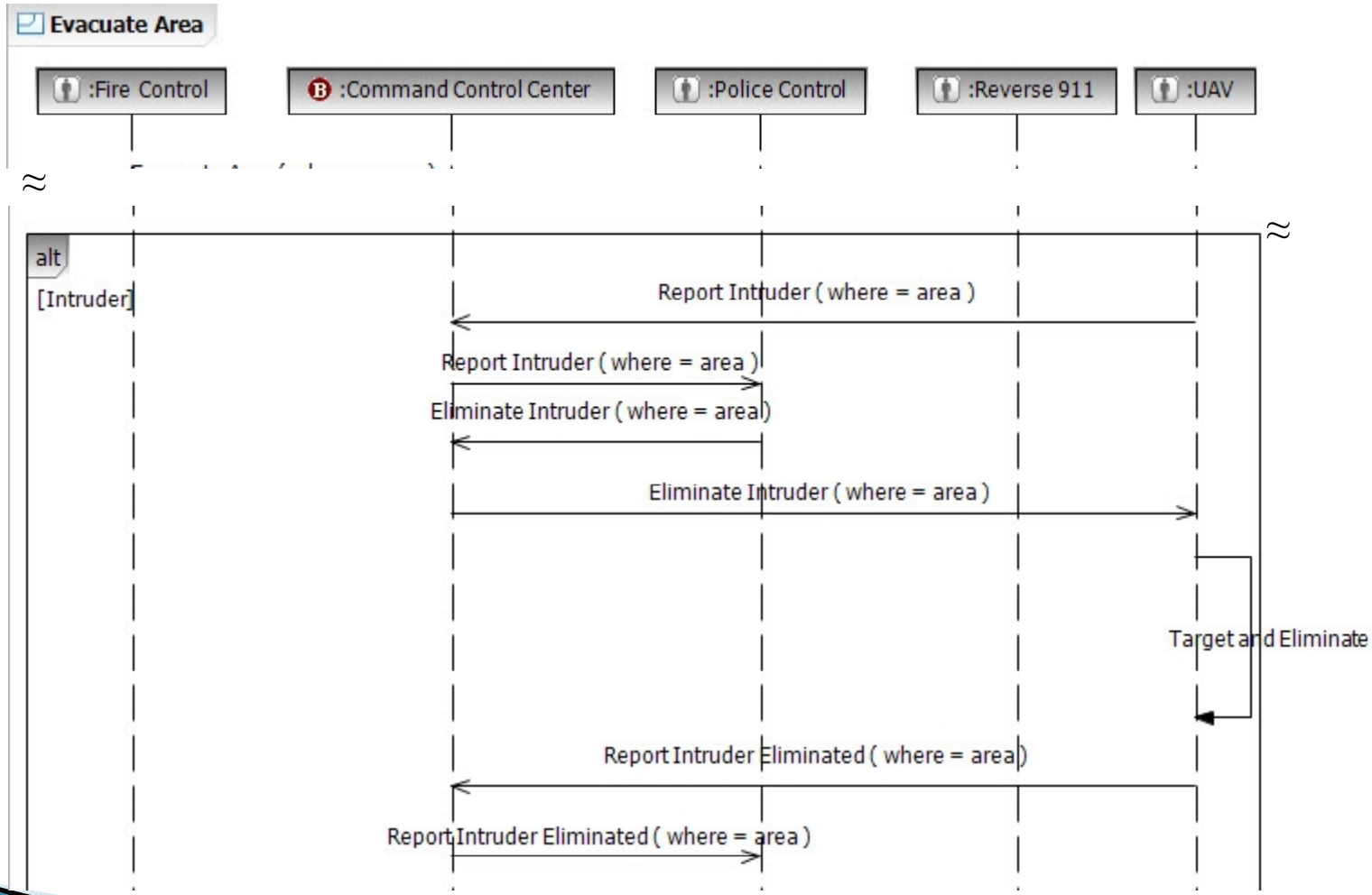
# Scenarios: CCC Use Cases



# Evacuate Area Sequence Diagram

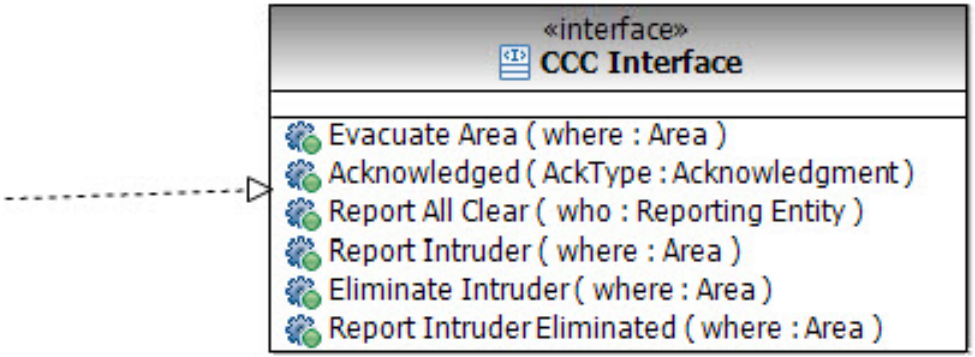


# Evacuate Area Alternate Sequence for Intruder "Management"

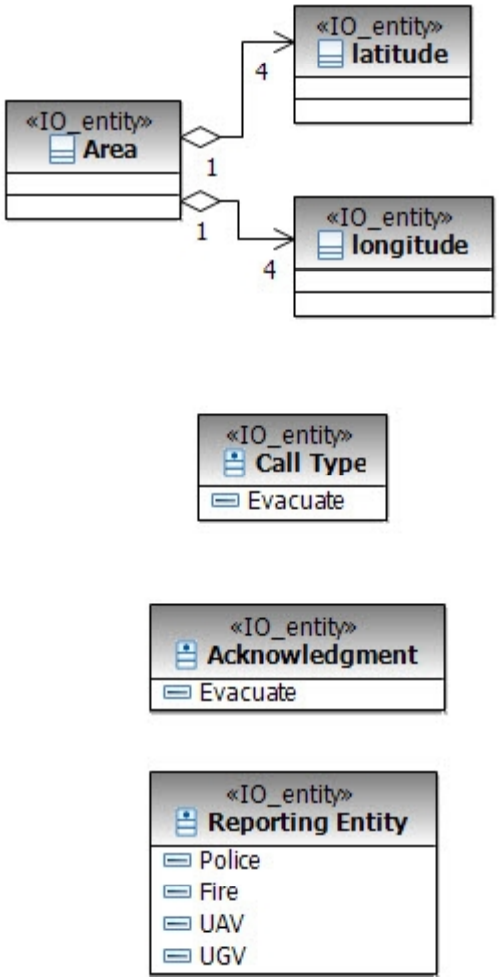


# CCC Interface Class

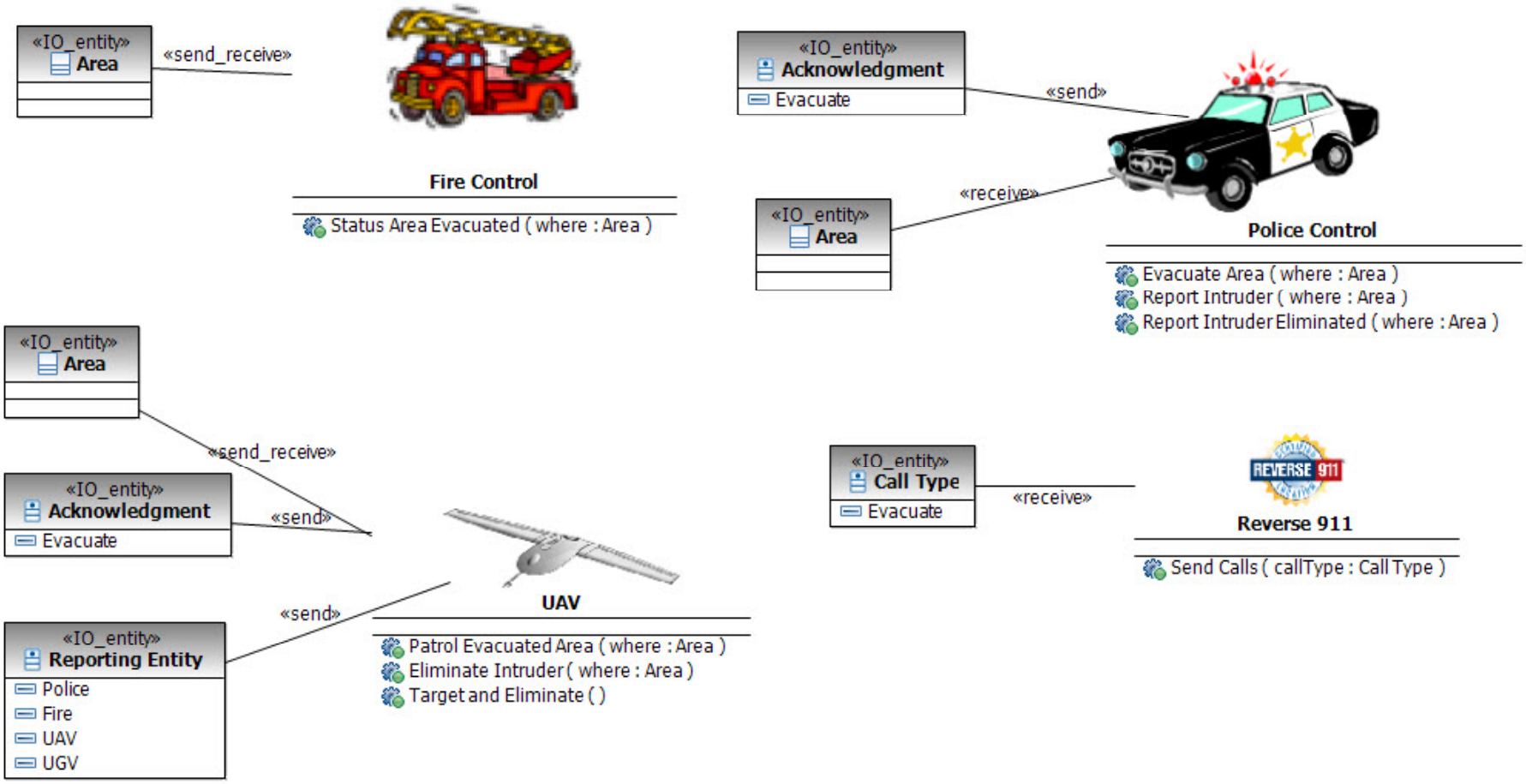
Command Control Center



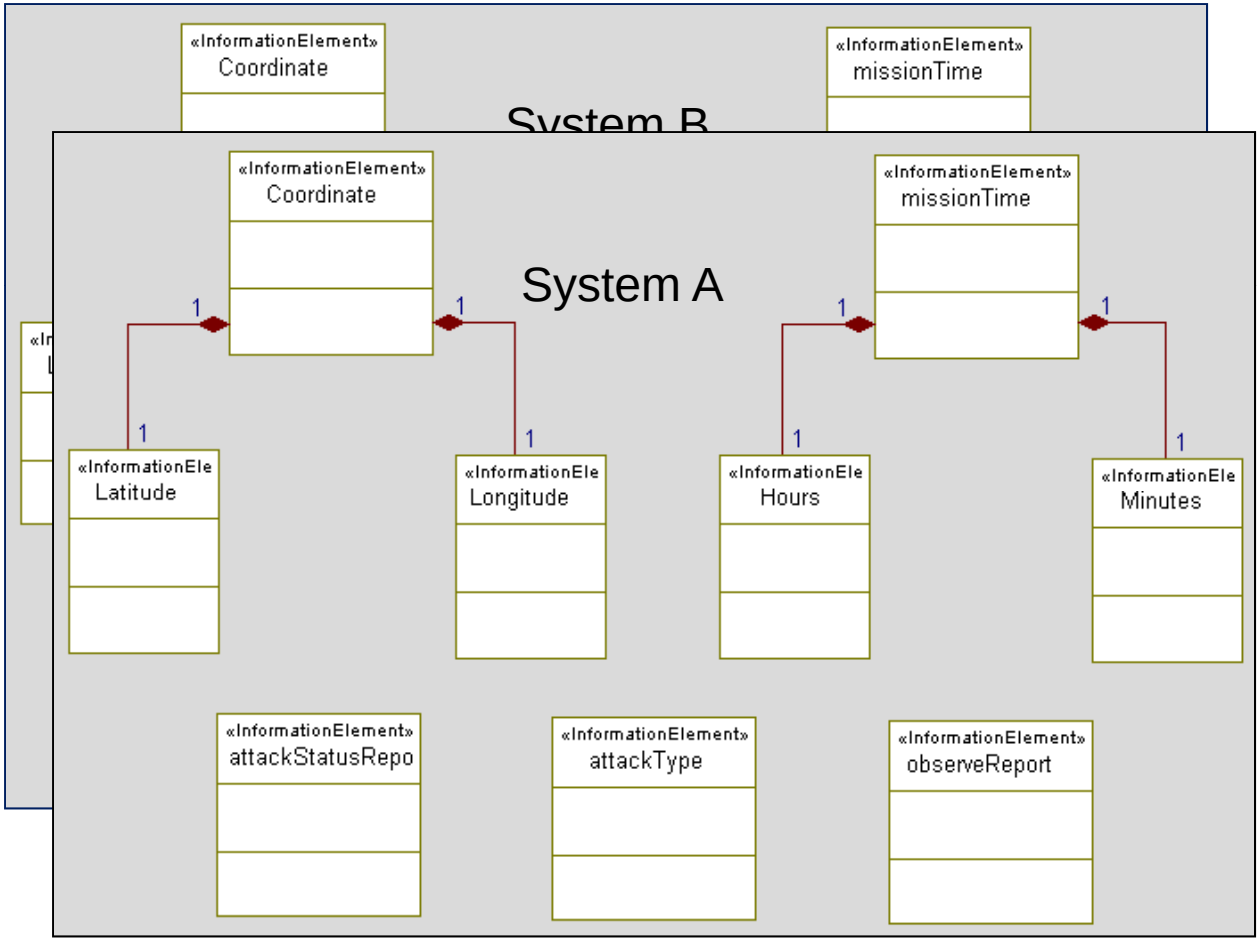
# Evacuate Area I/O Entities



# Evacuate Area I/O Entities by Actor



# UML View for Interoperability: Logical Data Models



# Summary and Conclusions

- Recent SoSE research identified need for useful SoSE models
- Goal of presentation to show how SysML models can be used to support some of these needs
  - Context diagrams
  - Use cases
  - Object blocks
  - Interface classes
  - I/O classes
  - Logical data models (UML)

# Summary and Conclusions
*(continued)*

- Captures information distilled from multiple sources and integrates to provide a "bigger" picture and support
  - End-to-end performance of SoS mission scenarios
  - Evaluate new capability alternatives
  - Evaluate proposed architecture changes
  - Evaluate impacts of proposed CS changes not related to SoS capability changes
- Key to success in modeling SoSs
  - Model only the aspects that are important for the engineering activity
  - Consider using models in new ways, for example I/O classes to capture interface data attribute information

# Acknowledgements


- DoD Director, Defense Research and Engineering (DDR&E)
  - Stevens-USC Systems Engineering Research Center (SERC) support
  - SoS case study work that has provided considerable engineering insights into SoSE

- NDIA Modeling and Simulation (M&S) Committee for their "M&S in SoS" survey responses

- LAI for their research into lean enterprise concepts

# References


- Bohn, T., Nolan, B., Brown, B., Balmelli, L, Wahli, U. (2008); Model Driven Systems Development with Rational Products, IBM Redbooks, DOI= http://www.redbooks.ibm.com/abstracts/SG247368.html?Open
- Dahmann, J., Asrat, W., Rebovich, G., Lane, J., and Lowry, R. (2009); Results of M&S Committee Survey on M&S and SoS SE. In Proceedings of the August 13, 20009 Meeting of the National Defense Industrial Association (NDIA) Modeling and Simulation (M&S) Committee. DOI= http://www.ndia.org/Divisions/Divisions/SystemsEngineering/Pages/Modeling_and_Simulation_Committee.aspx
- Dahmann, J. and K. Baldwin. 2008. Understanding the current state of US defense systems of systems and the implications for systems engineering. *Proceedings of the IEEE Systems Conference*, April 7-10, in Montreal, Canada.
- Department of Defense (DoD) (2008); *Systems Engineering Guide for System of Systems,* version 1.0. DOI= http://www.acq.osd.mil/sse/docs/SE-Guide-for-SoS.pdf
- Maier, M. (1998); "Architecting Principles for Systems-of-Systems"; *Systems Engineering*, Vol. 1, No. 4 (pp 267-284)
- Object Management Group (2008); OMG System Modeling Language (SysML), version 1.1. DOI= http://www.omg.org/spec/SysML/index.htm