28th Annual INCOSE international symposium

Washington, DC, USA

July 7 - 12, 2018

A Novel "Resilience Viewpoint" to aid in Engineering Resilience in Systems of Systems (SoS)

Demetrios Joannou, Roy Kalawsky, Loughborough University

Loughborough University

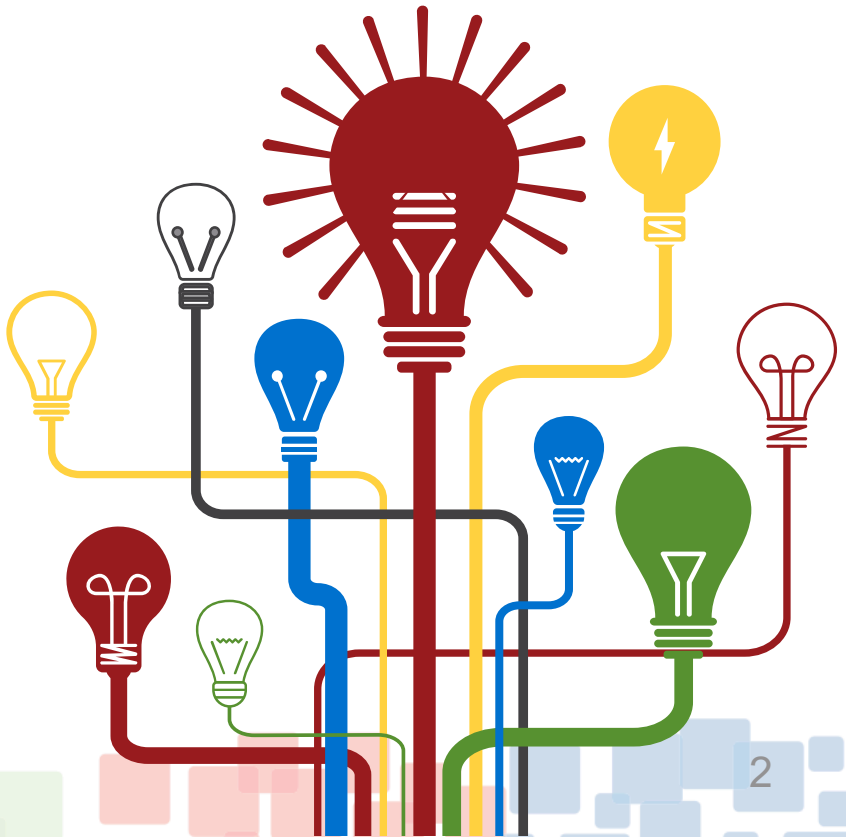
Advanced VR Research Centre

VIRTUAL ENGINEERING CENTRE

www.incose.org/symp2018

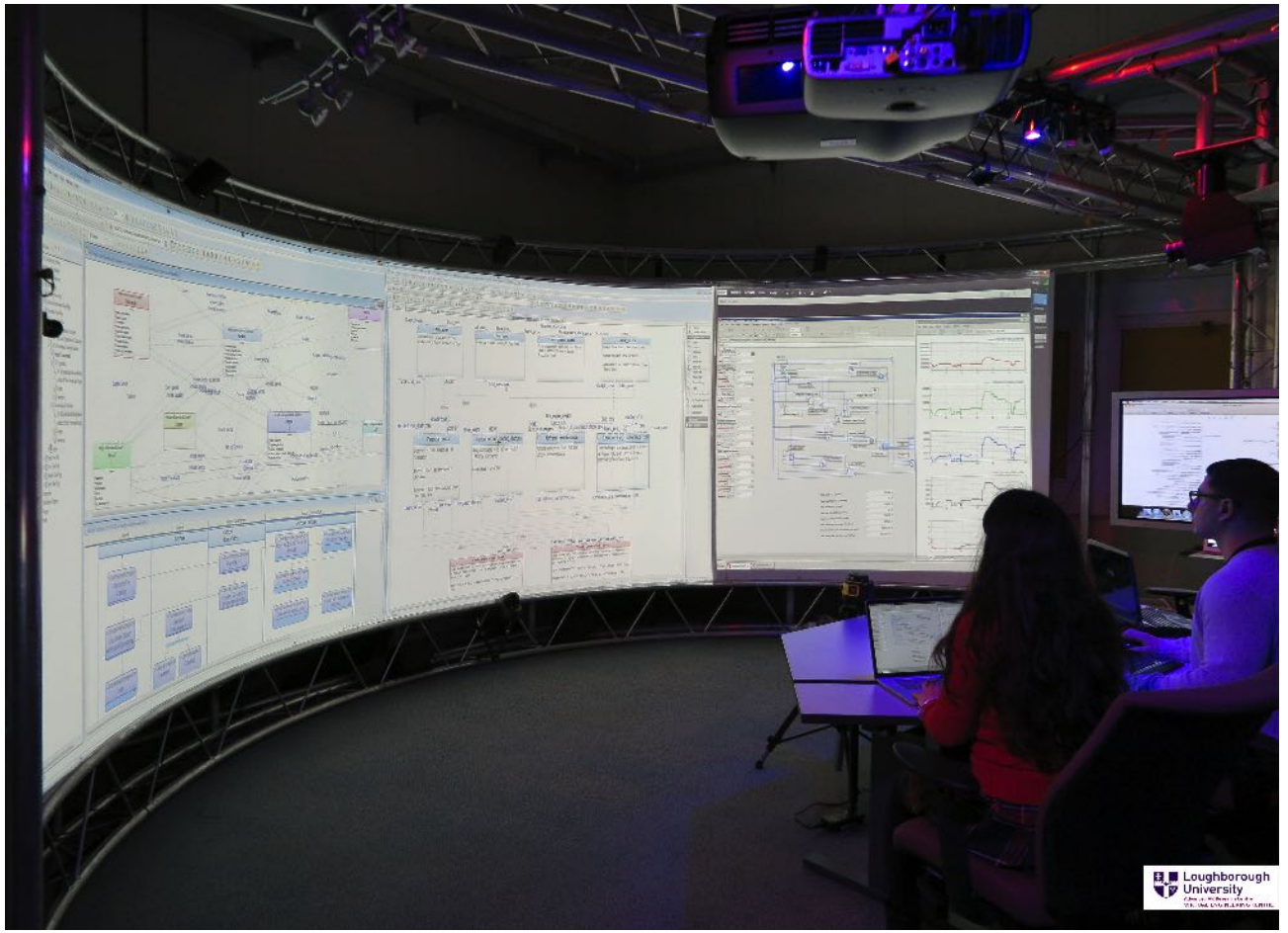
Overview

- The Vision
- Engineering Resilience in Systems of Systems
- The Proposed Resilience Viewpoint (RV)
- Applying the Resilience Viewpoint
- Future Work and Conclusions



Resilience Engineering ('The Vision')

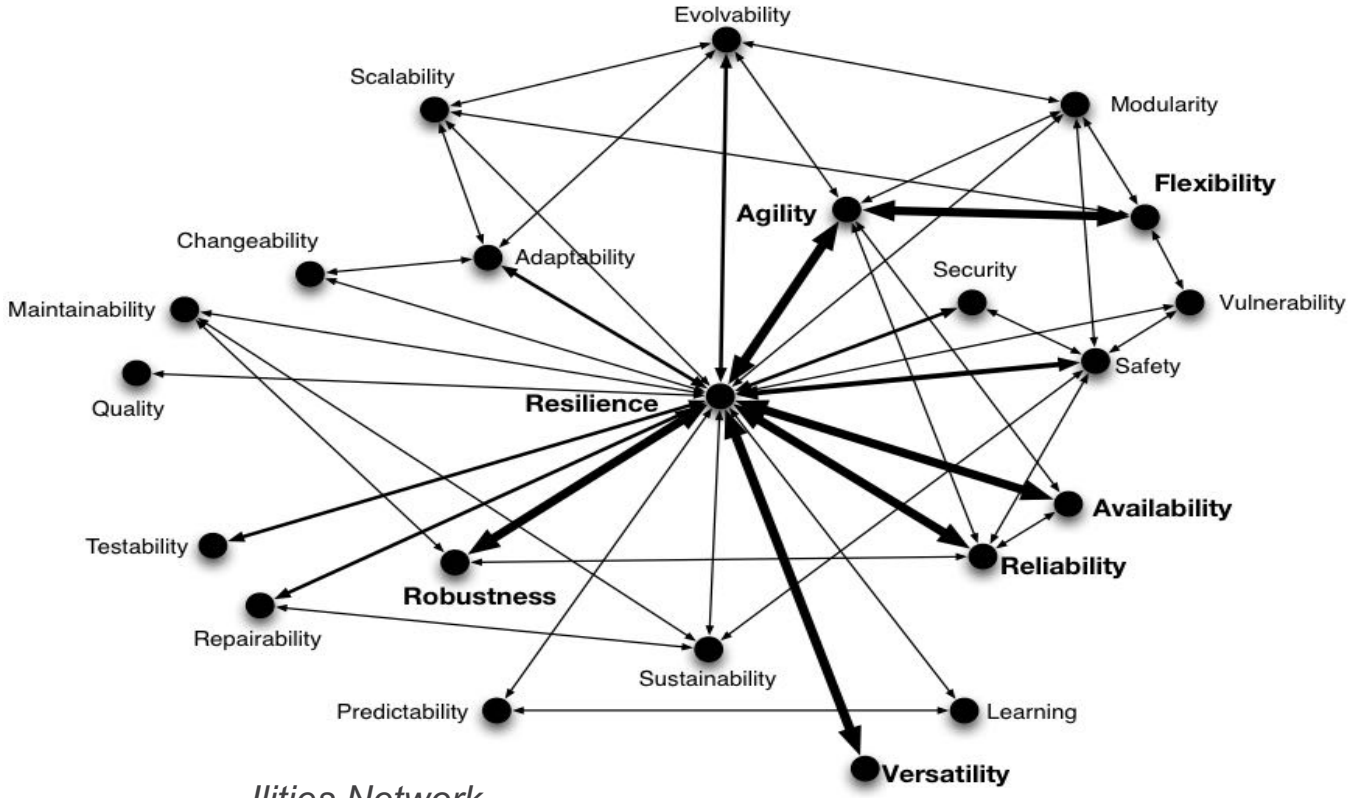
- Develop new **insights** into the engineering of **complex systems**
- Develop new immersive techniques, technologies and tools to support virtual engineering and **MBSE** for **resilience engineering**
- Develop **"Architects Cockpit"** for engineering resilience in systems of systems
- Develop **executable reference architectures** for engineering information systems of systems



Resilience Definition

"The dynamic ability of a SoS to re-adjust when faced with change or disruption, at both the SoS and constituent system level, and to continue to provide operational capacity at a certain level (degraded if necessary) of functionality."

- Resilience is a **combination of ilities**, depending on context
- Challenge is **how can these ilities** (attributes) be modelled and evaluated in a SoS architecture representation?
- **Systematically approach the design phases** of development and to **migrate architectural models** into **executable models** to analyse the behaviours and **performance levels** of CS and SoS alike.

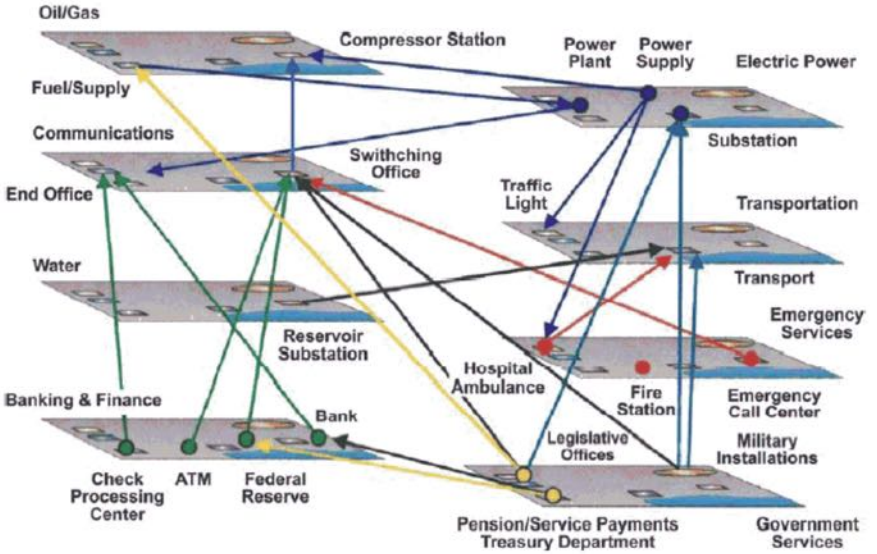


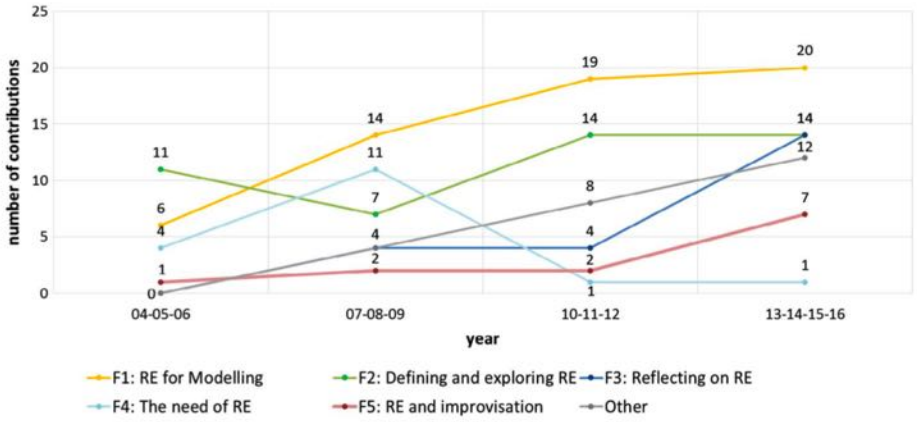
Ilities Network

Adaptation from (de Weck, Rhodes, & Ross, 2012)

Why is Resilience Engineering Research Important?

- Manage **Uncertainty** and **Dynamicity**
- **Proactive vs Reactive** Approach to Risk
- **Economic > Intellectual** Motives
- **Stakeholder Conflicts** in Goals & Requirements
- Increased Connectivity and **Complexity**
- Stricter Regulations on **Safety**
- **New Threats**
- Increased Expectations (Supply and Demand side)
- Finite Resources

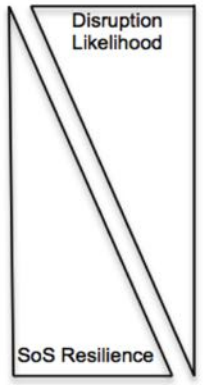




Patriarca, R., Bergström, J., Di Gravio, G., & Costantino, F. (2018). Resilience engineering: Current status of the research and future challenges. Safety Science, 102(August 2017), 79–100. https://doi.org/10.1016/j.ssci.2017.10.005

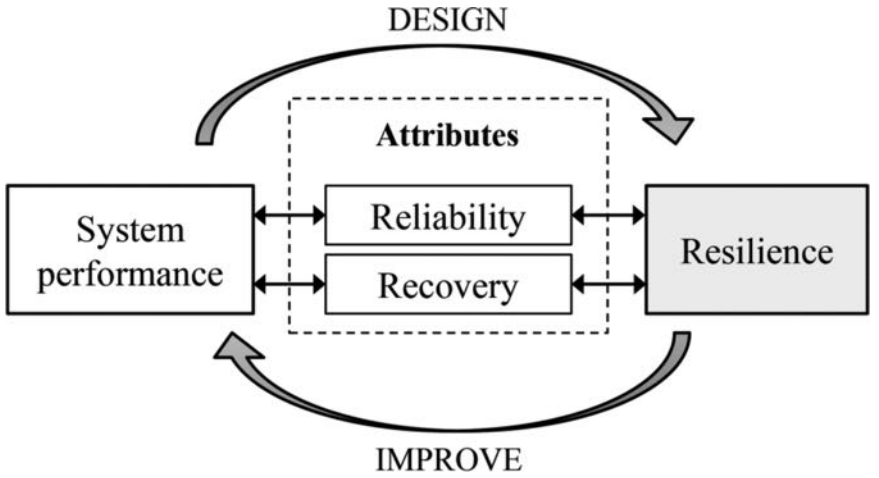
Why is Resilience Engineering Research Important?

Level of Resilience	Level of Vulnerability		Cost
Zero Resilience	0	****	None
Some Resilience	1	***	Extremely Low
Moderate	2	**	Moderate
High Resilience	3	*	High
Full Resilience	4		Extremely High



Levels of Resilience vs Cost

- Systems of Systems are **Evolutionary**
- **Dynamic Environments**
- Define **Acceptable Performance Levels** and Functionality Levels
- Develop Levels of Resilience (**Resilience Scale**)

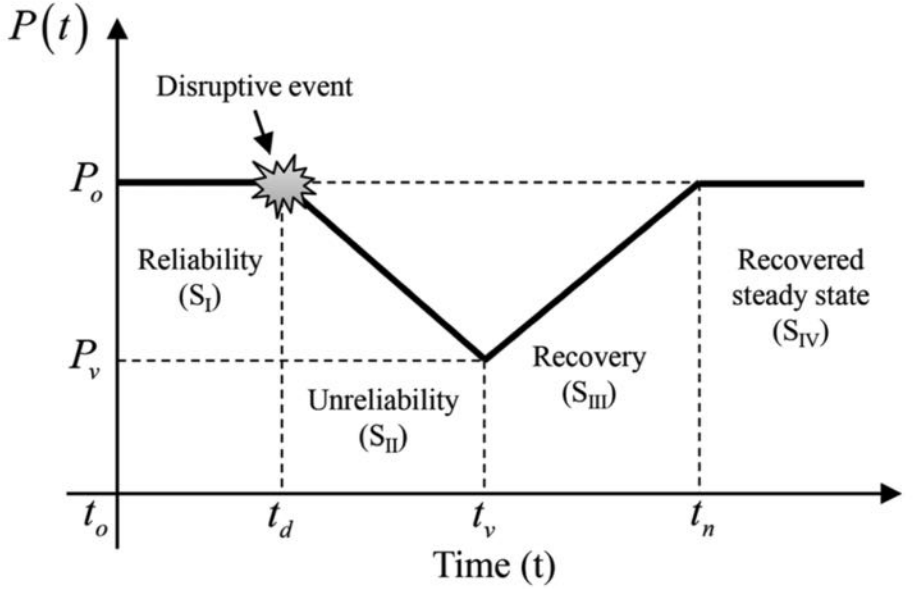


Translating system performance to resilience and vice versa

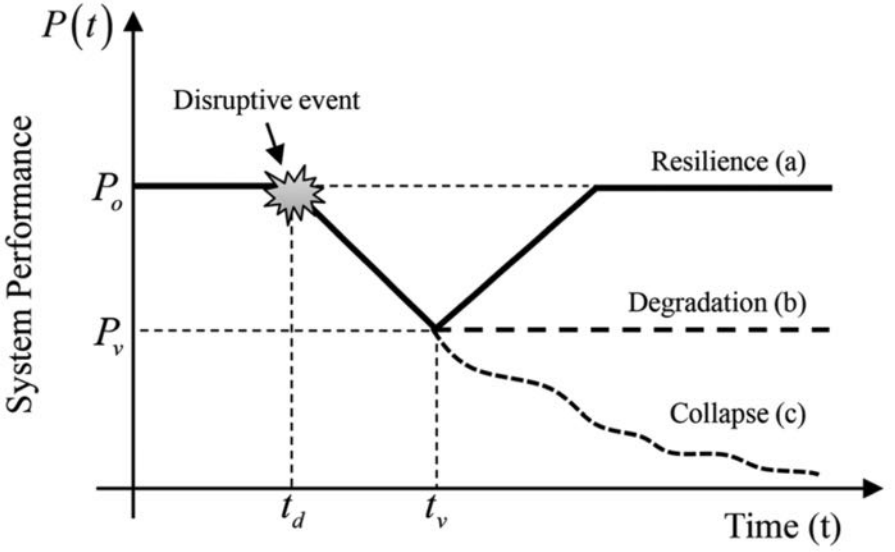
N. Yodo and P. Wang, "Engineering Resilience Quantification and System Design Implications: A Literature Survey," *J. Mech. Des.*, vol. 138, no. 11, p. 111408, 2016.

- Architectures to understand SoS and CS relationships
- **Criticality & Vulnerability** Analysis
- Develop **Resilience Metrics**
- Need to develop **Resilience Cultures**
- **Adaptability** leads to Survivability
- **Optimize SoS** for high resilience levels

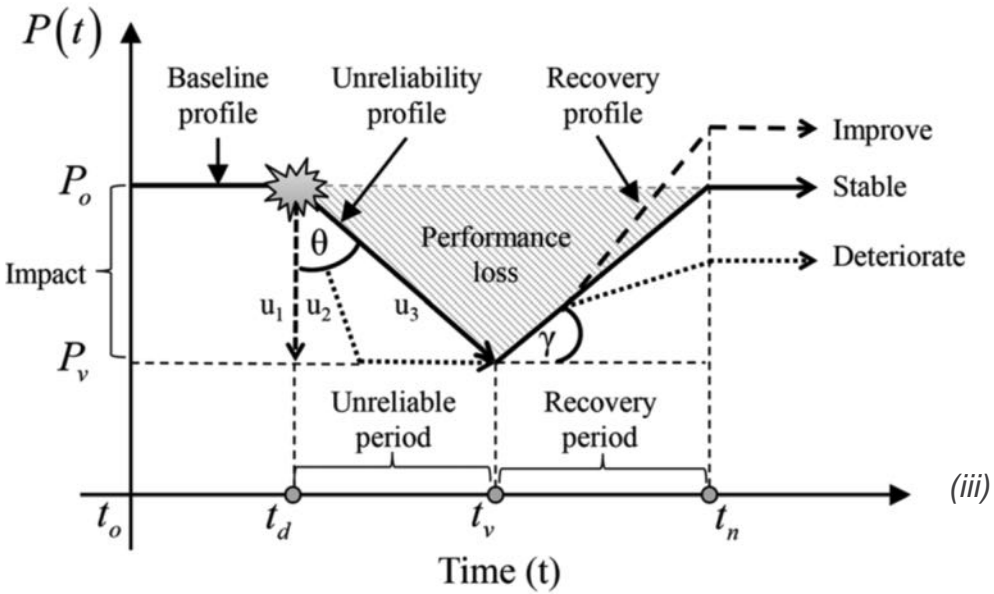
Engineering Resilience: Design Implications



(i) Four stages engineering resilience curve



(ii) Resilient versus non-resilient behaviour



(iii) Variants of a general resilience curve

N. Yodo and P. Wang, "Engineering Resilience Quantification and System Design Implications: A Literature Survey," *J. Mech. Des.*, vol. 138, no. 11, p. 111408, 2016.

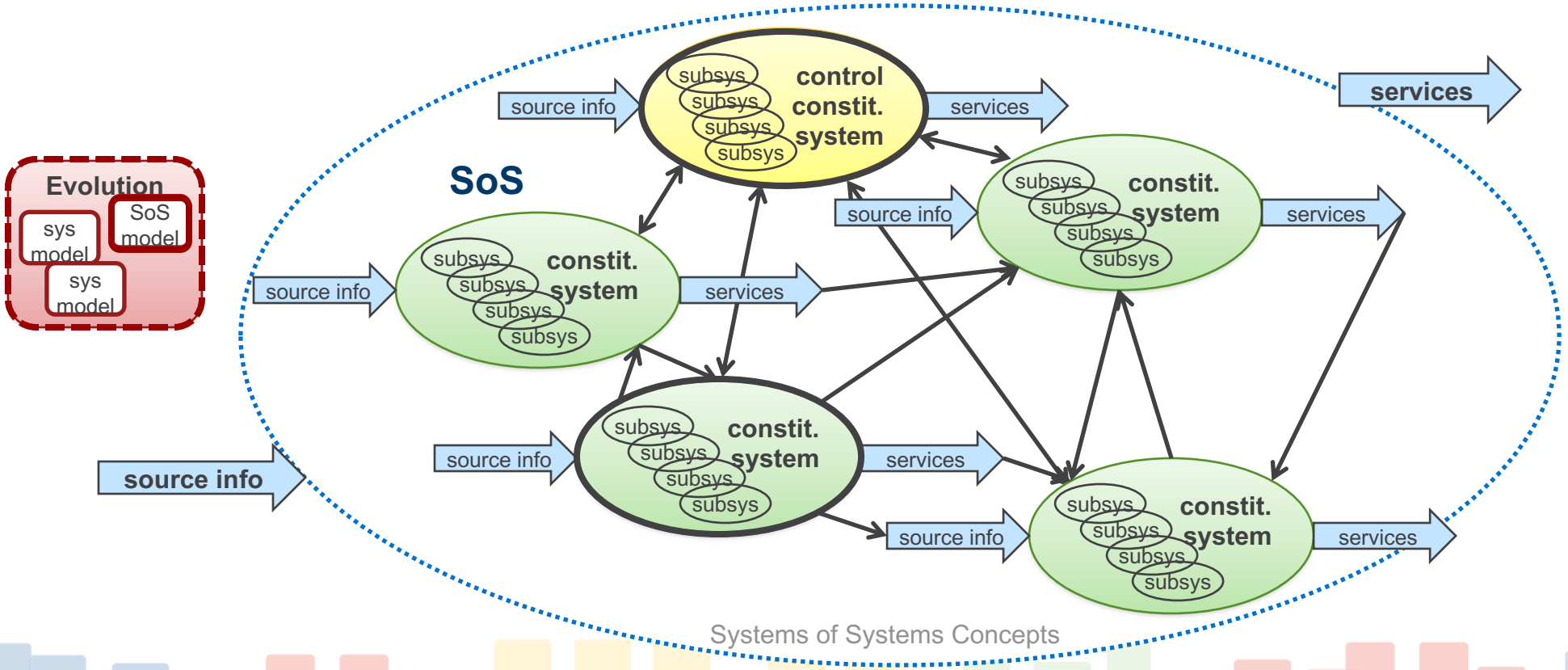
Architecture of an SoS

System of systems

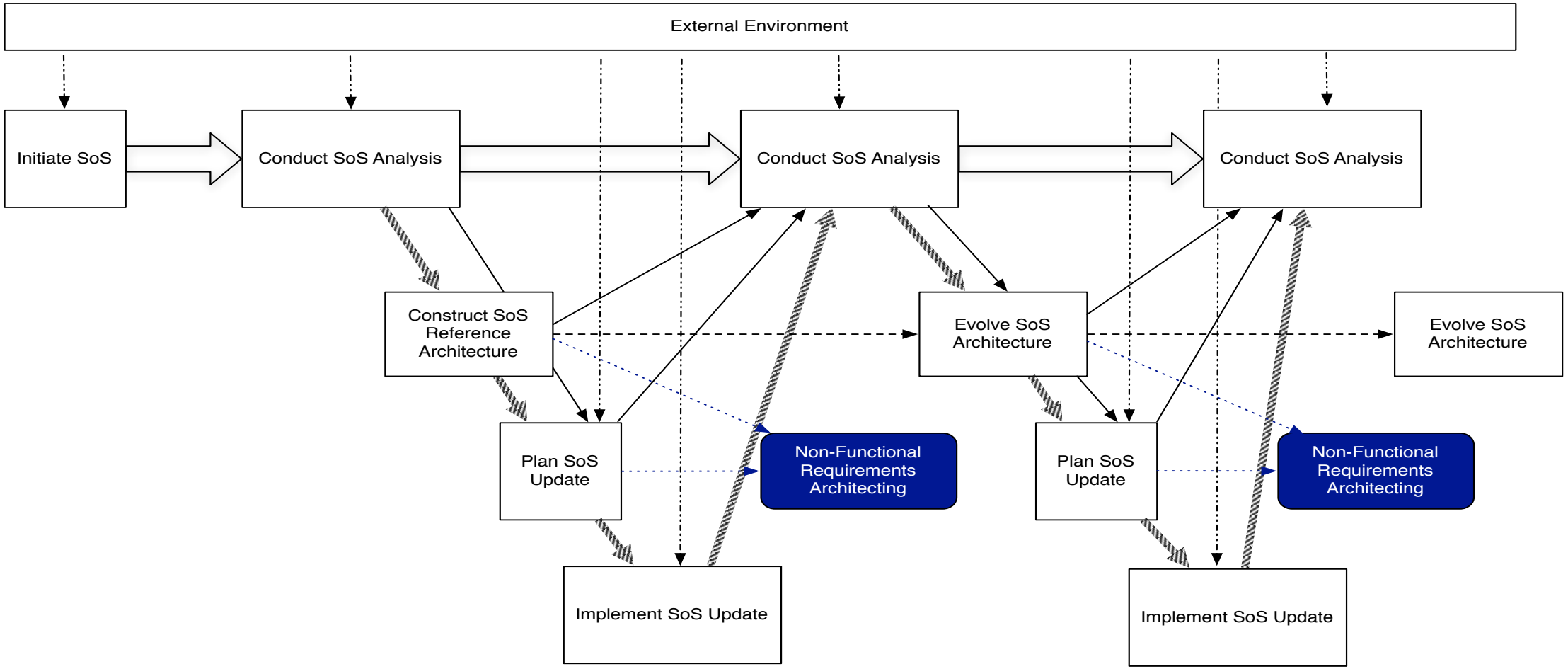
- Provides emergent services through system interactions
- May need control
- Can be modelled

Constituent systems

- Independently operated and managed
- Gather/receive source info
- Perform services
- Interact
- Independently evolve

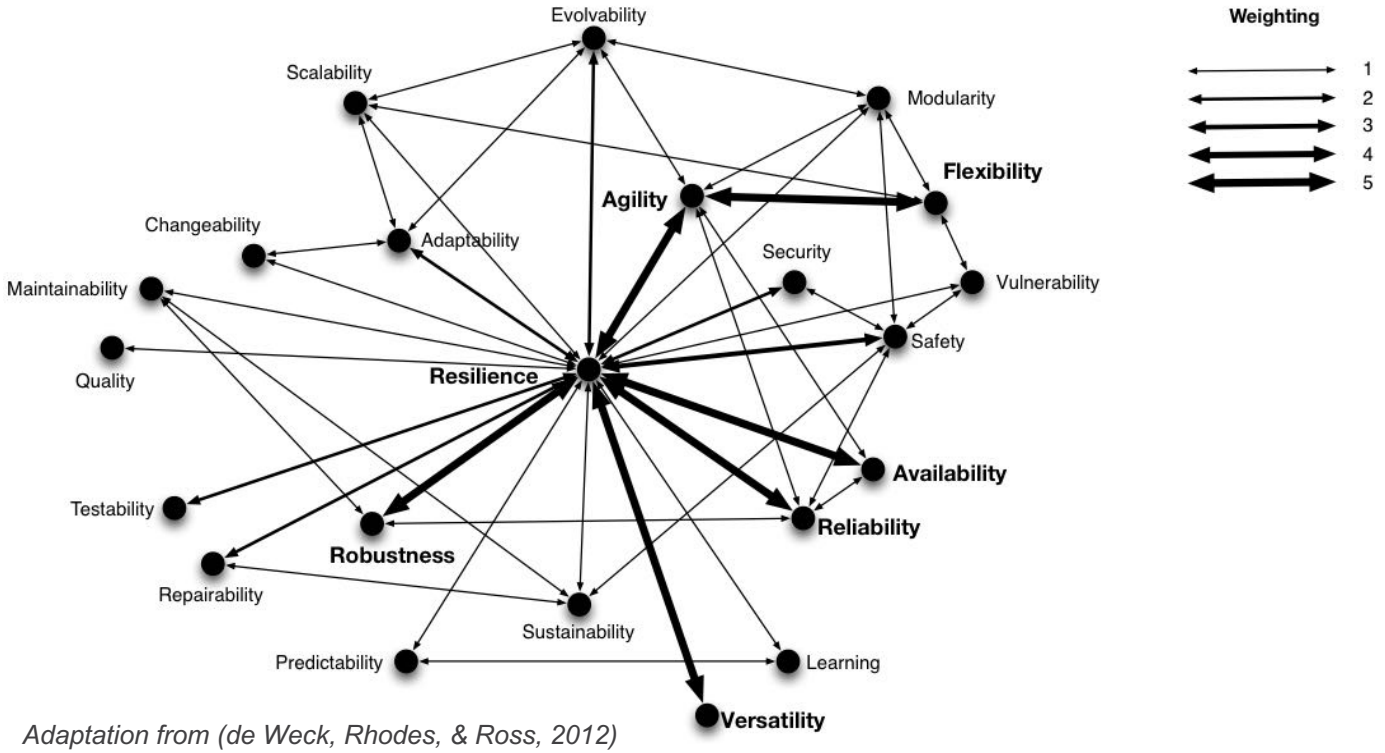


Architecting with Ilities



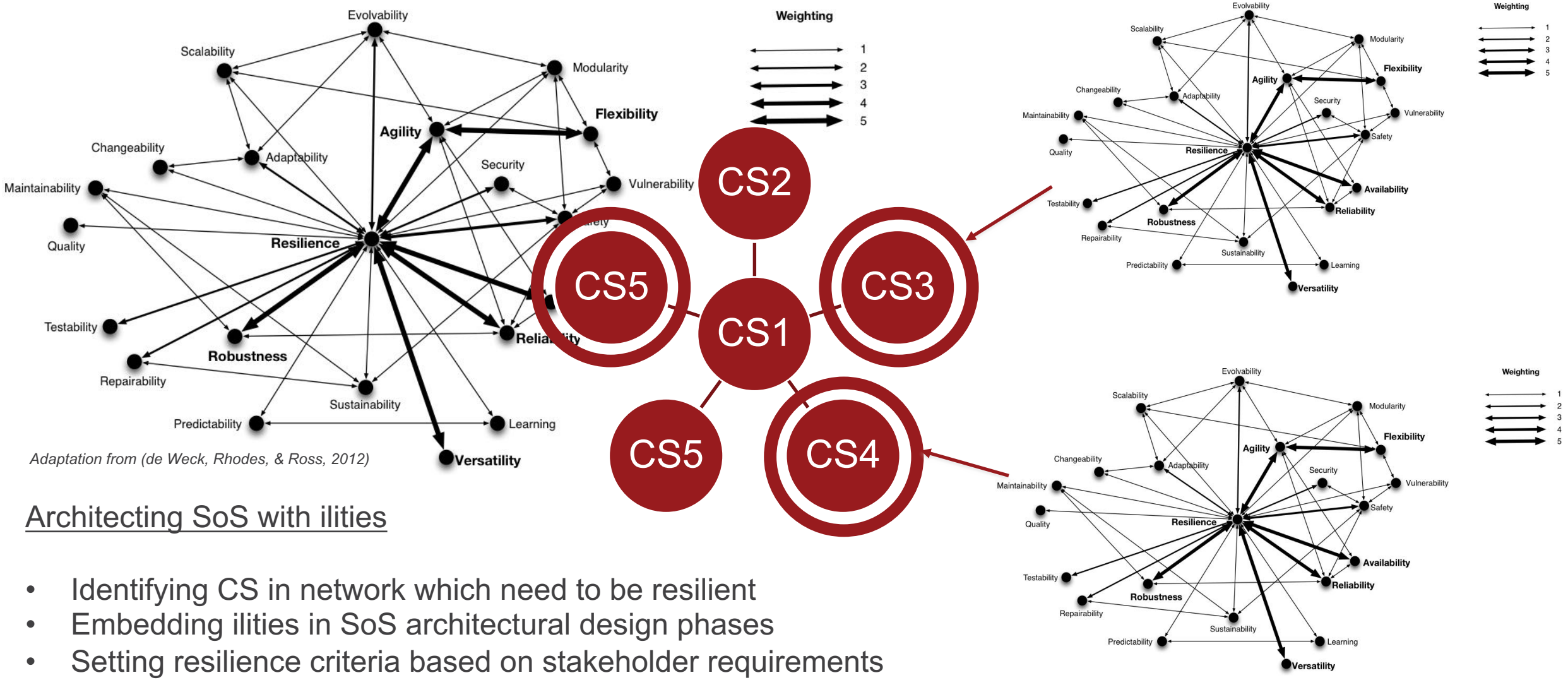
SoS Wave Model Modified to Show Non-functional Architecting

System of Systems (SoS) Resilience



Adaptation from (de Weck, Rhodes, & Ross, 2012)

System of Systems (SoS) Resilience

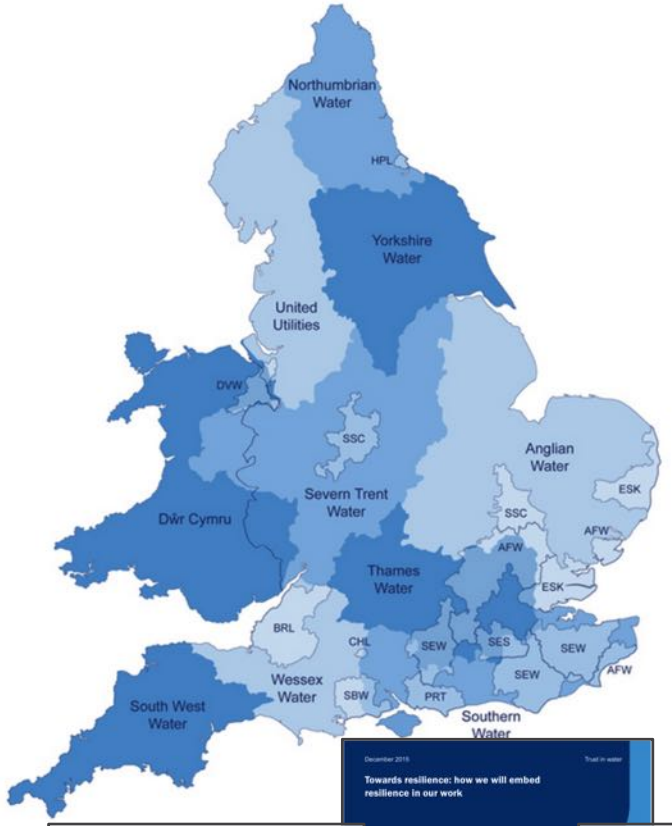


Adaptation from (de Weck, Rhodes, & Ross, 2012)

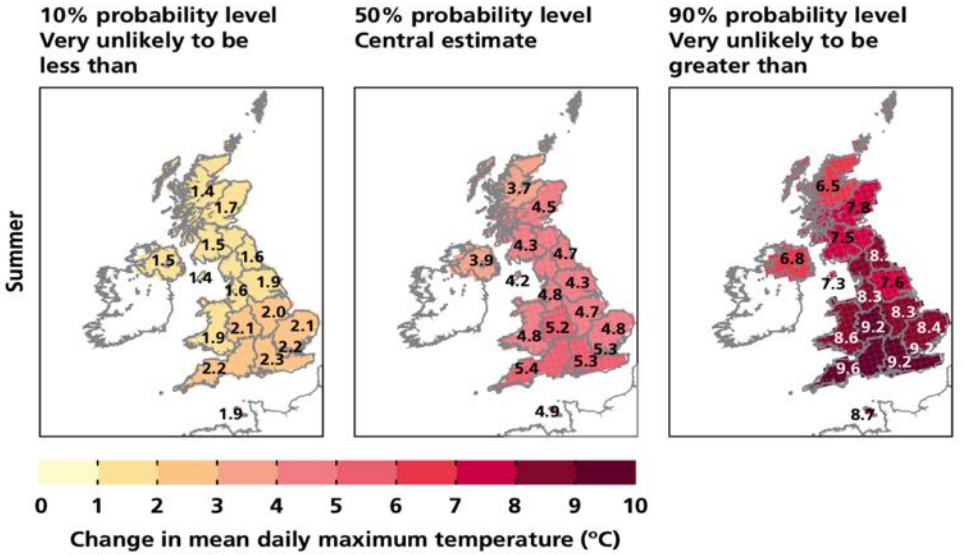
Architecting SoS with ilities

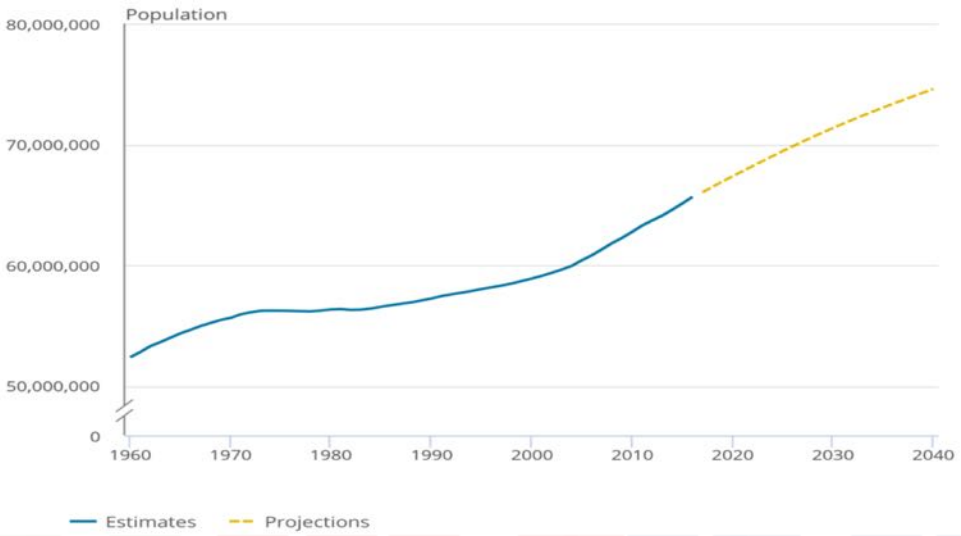
- Identifying CS in network which need to be resilient
- Embedding ilities in SoS architectural design phases
- Setting resilience criteria based on stakeholder requirements

Water Resilience in UK



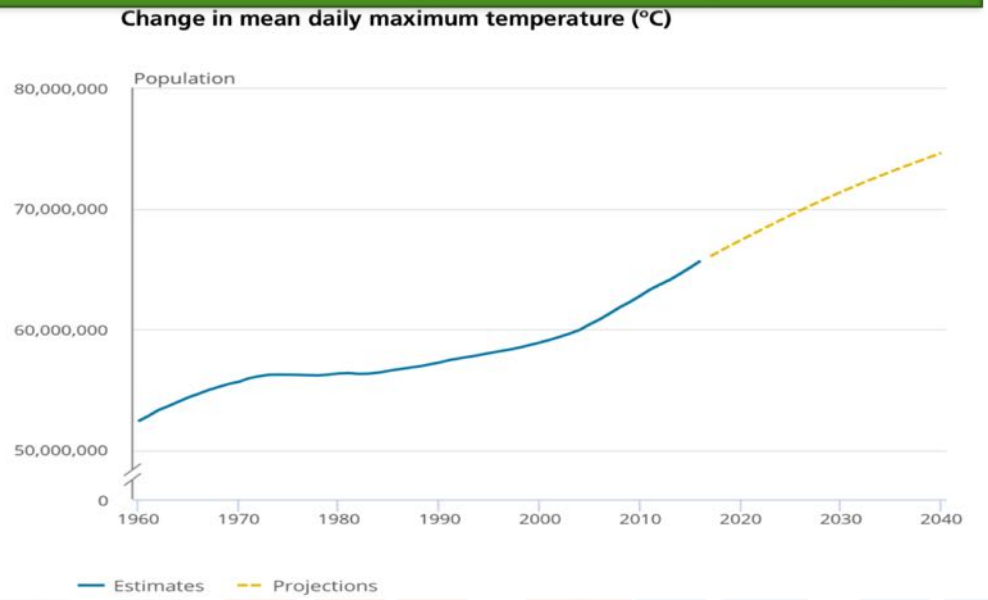
- A growing population
- A growing economy
- Climate changes
- Uncertainty
- Regulation on abstraction
- Environmental protection regulations



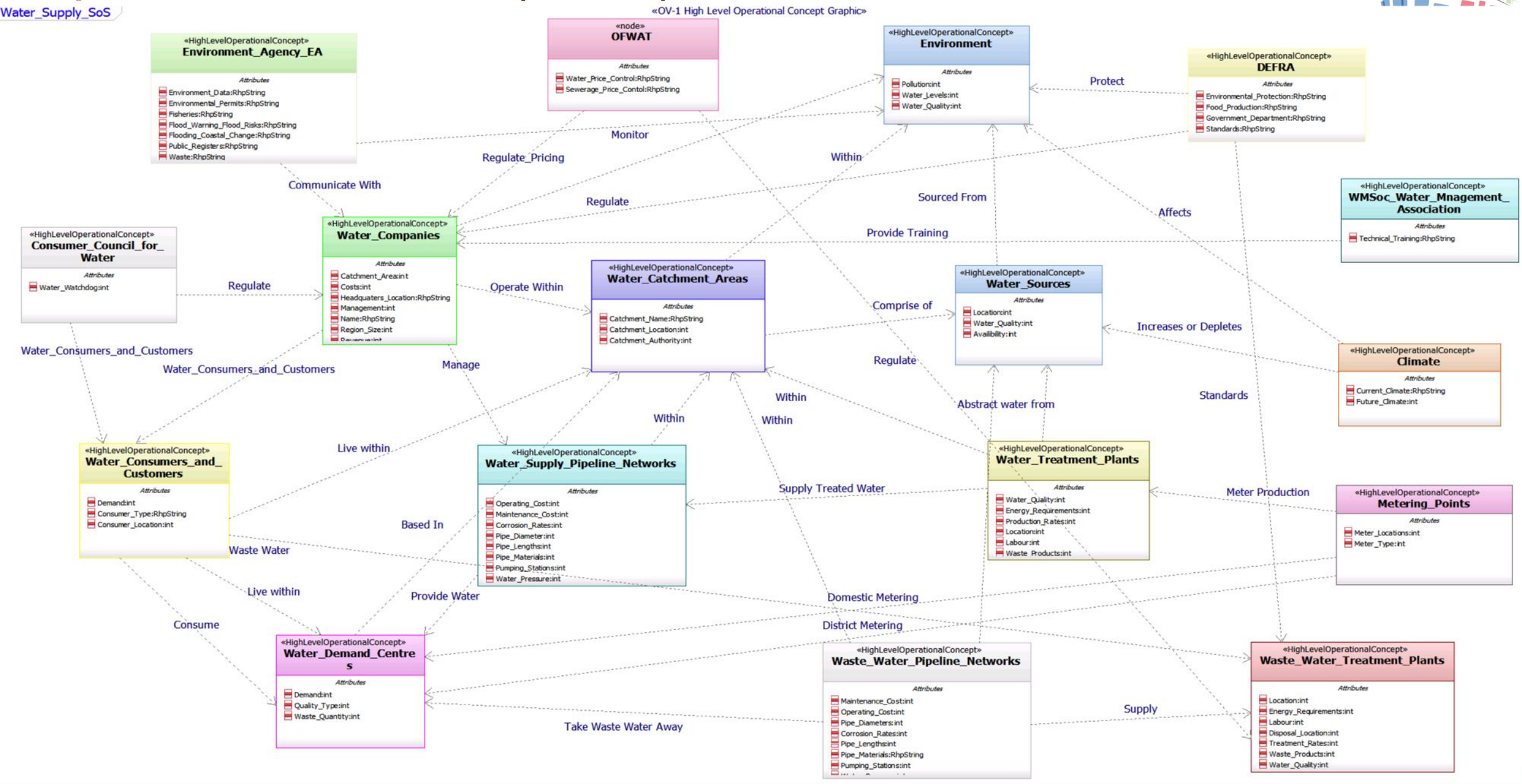


Water Resilience in UK

> ***"Resilience is the ability to cope with, and recover from, disruption, and anticipate trends and variability in order to maintain services for people and protect the natural environment, now and in the future."***
>
> *Ofwat - Definition from the Task and Finish Group*



Operational View 1(OV-1)



BRIM Feasibility Study CONOPs

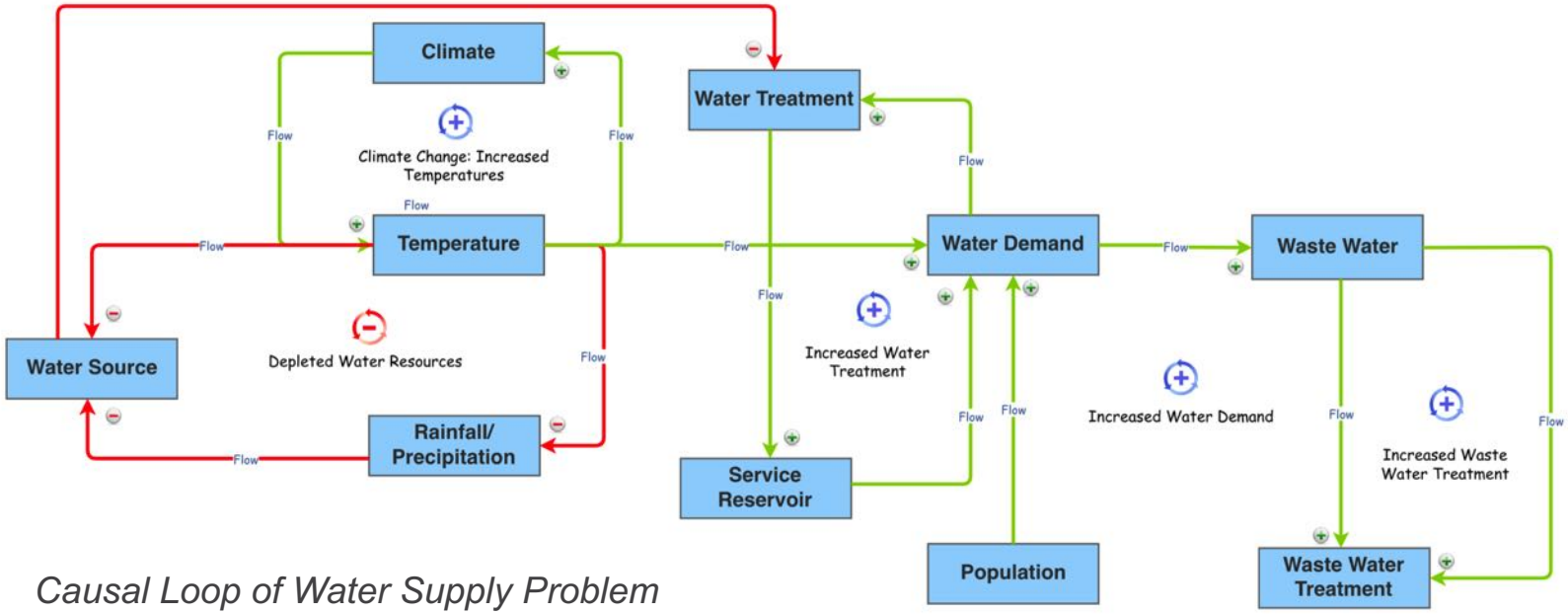
BRIM Project Details:

- To create a reference architecture of the existing water supply network (SoS) in the UK, using systems modelling languages (SysML) and Architectural Frameworks.

- Define what is meant by resilience in the context of water supply.

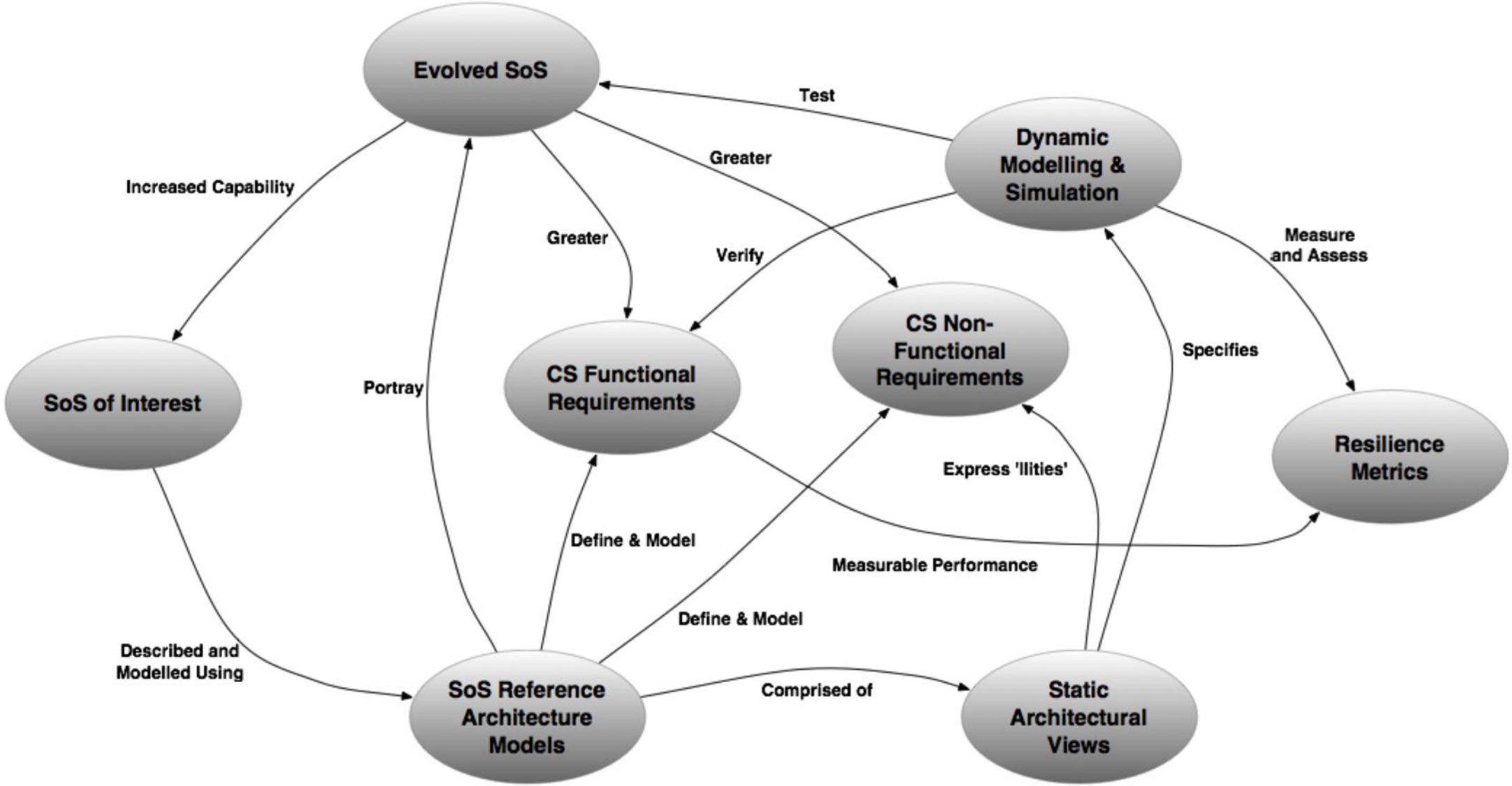
- To identify non-functional attributes which could potentially (if designed into early phases of development lifecycle) increase level of overall resilience (e.g. availability, robustness, flexibility).

- Apply novel resilience viewpoint in SysML/UPDM to demonstrate its analytical capability



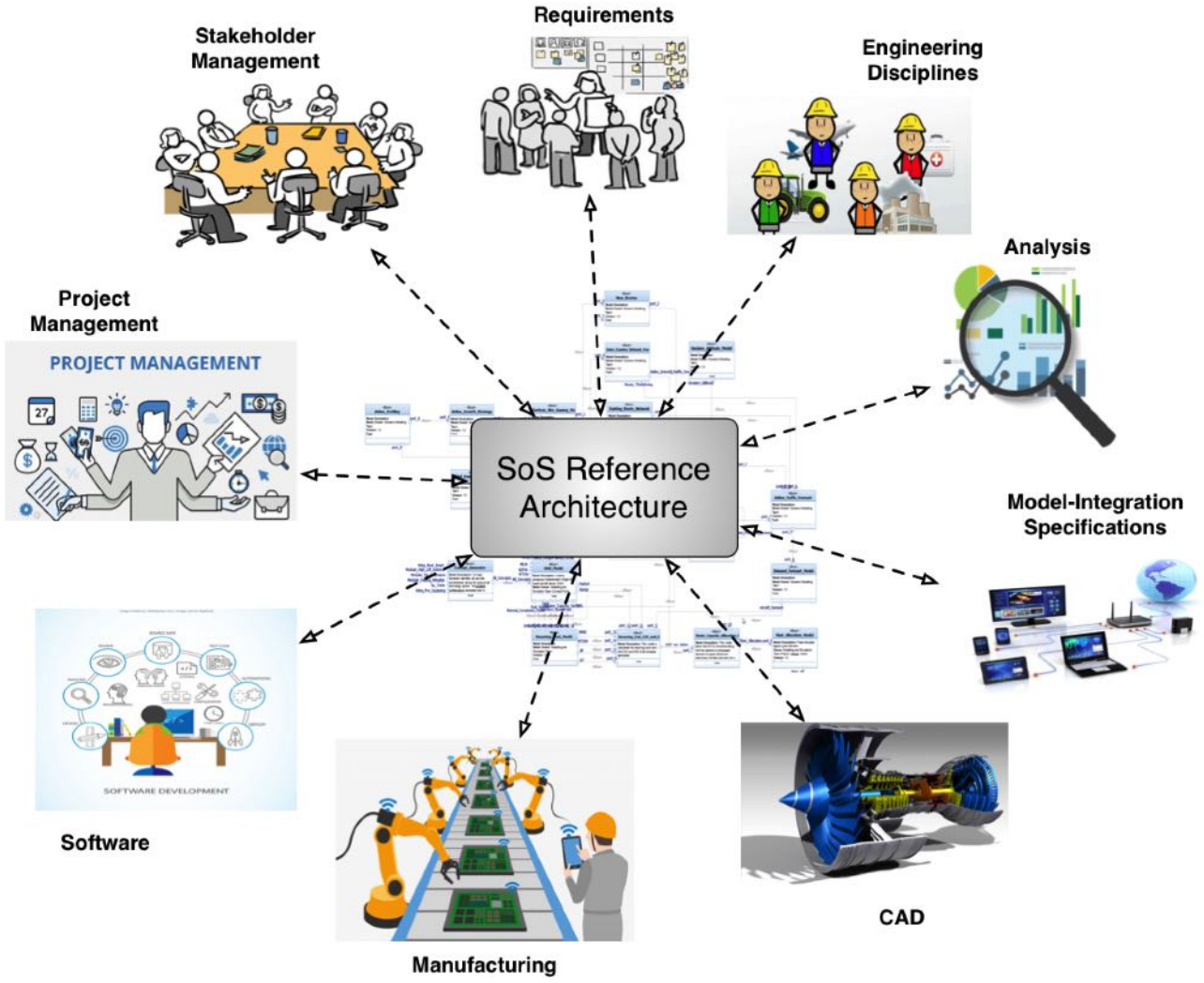
Causal Loop of Water Supply Problem

System of Systems (SoS) Resilience

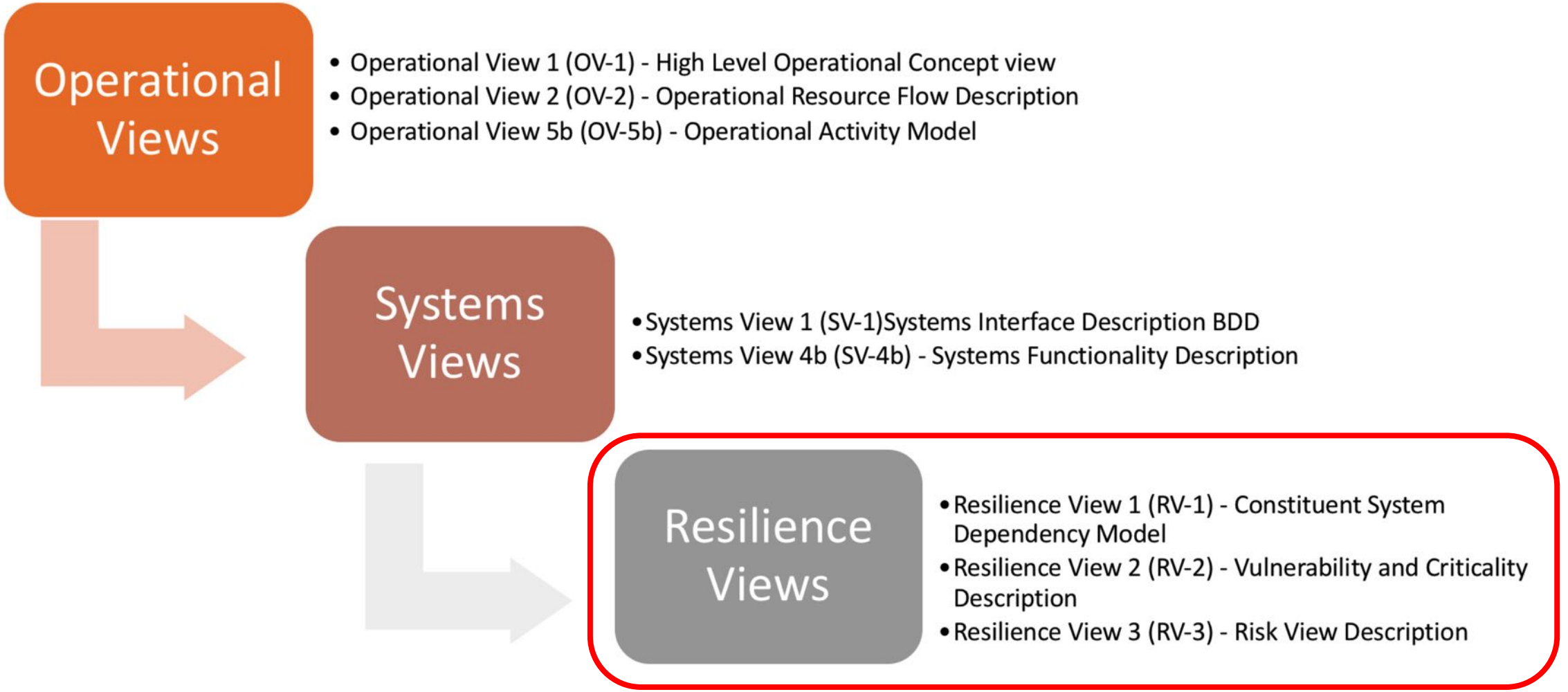


SoS Reference Architecture

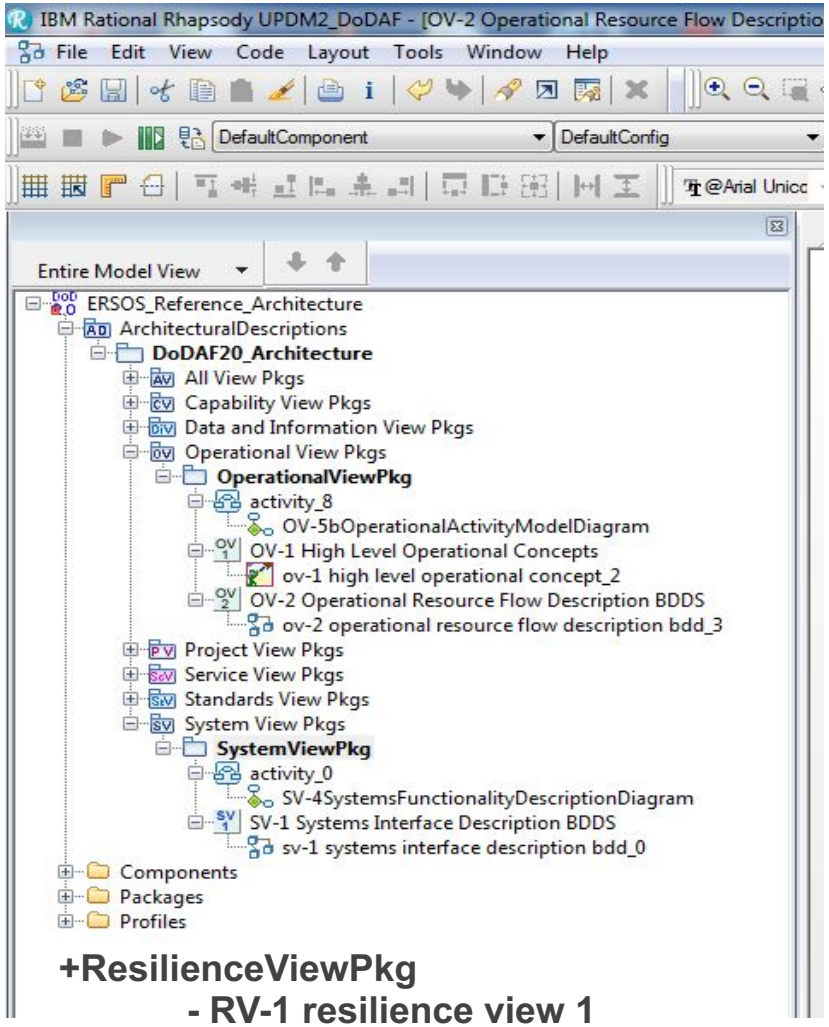
- MBSE process and reference architectures used to;
  - Systems models are used to **communicate requirements** to customers and help **elicit further requirements**
  - Help to represent a system from various **perspectives** (both developer perspectives and user perspectives)
  - Systems modelling helps engineering and design teams to understand the **functionality** of the system
  - Systems Models (plus model simulation) help to evaluate **system performance**
  - Systems models help to **optimize designs** (costs, time, performance)



Reference Architecture & Resilience Viewpoint



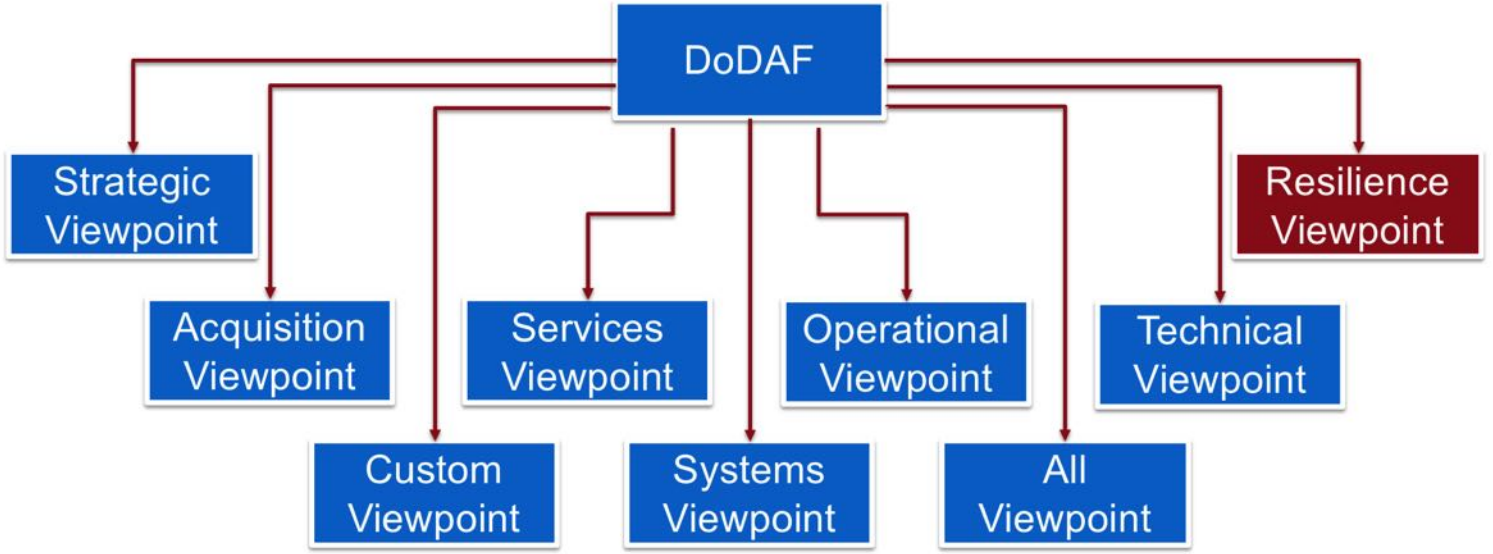
Proposed Resilience Viewpoint



+ResilienceViewPkg

- **RV-1 resilience view 1**
- **RV-2 resilience view 2**
- **RV-3 resilience view 3**

Resilience Viewpoint: The Resilience Viewpoint is a **technical viewpoint** that describes interactions amongst constituent systems. Provides details of interaction types and particulars about vulnerability and criticality aspects of constituent elements. Additionally, the viewpoint is to be developed to include constraints and requirements from a resilience standpoint, showing the redundancy and common-mode failure aspects in designs.

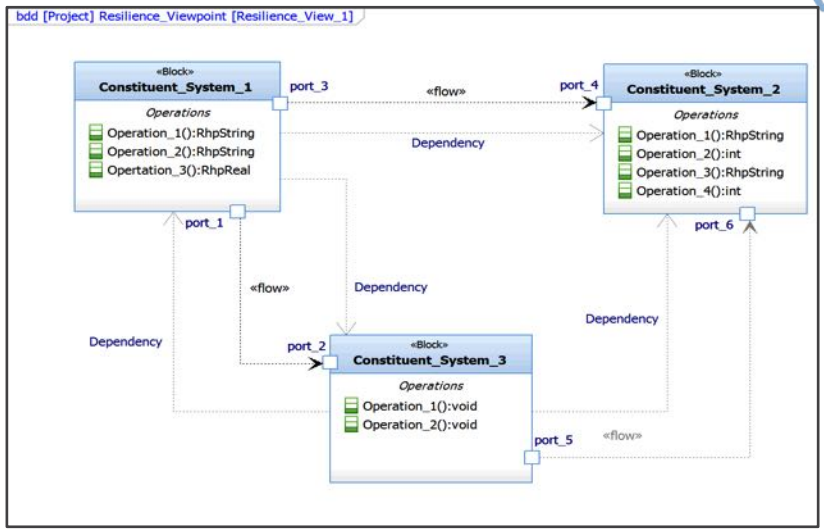


Proposed Resilience Viewpoint with DoDAF Architecture Framework

The Resilience Viewpoint

Resilience Views

- Resilience View 1 (RV-1) - Constituent System Dependency Model
- Resilience View 2 (RV-2) - Vulnerability and Criticality Description
- Resilience View 3 (RV-3) - Risk View Description

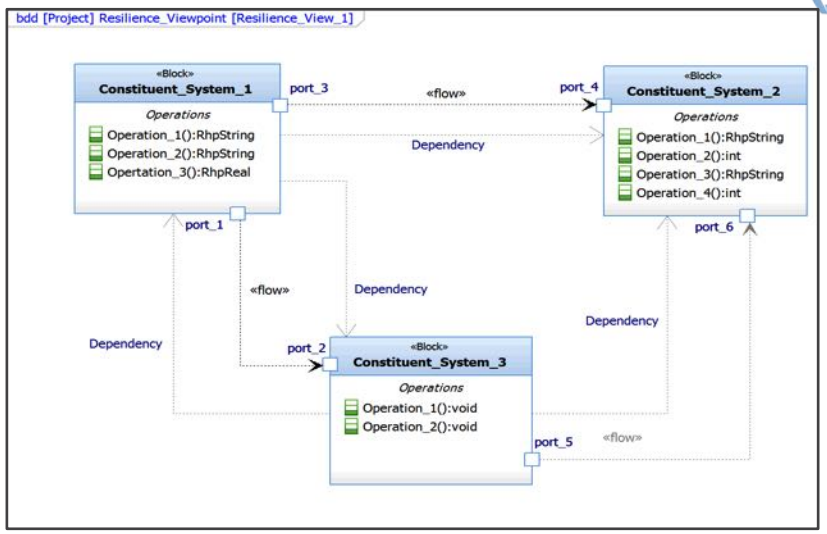


Resilience View 1 (RV-1) - Constituent System Dependency Model - Shows the high-level integration of constituent systems and their dependencies, communication and information channels and general operational relationships

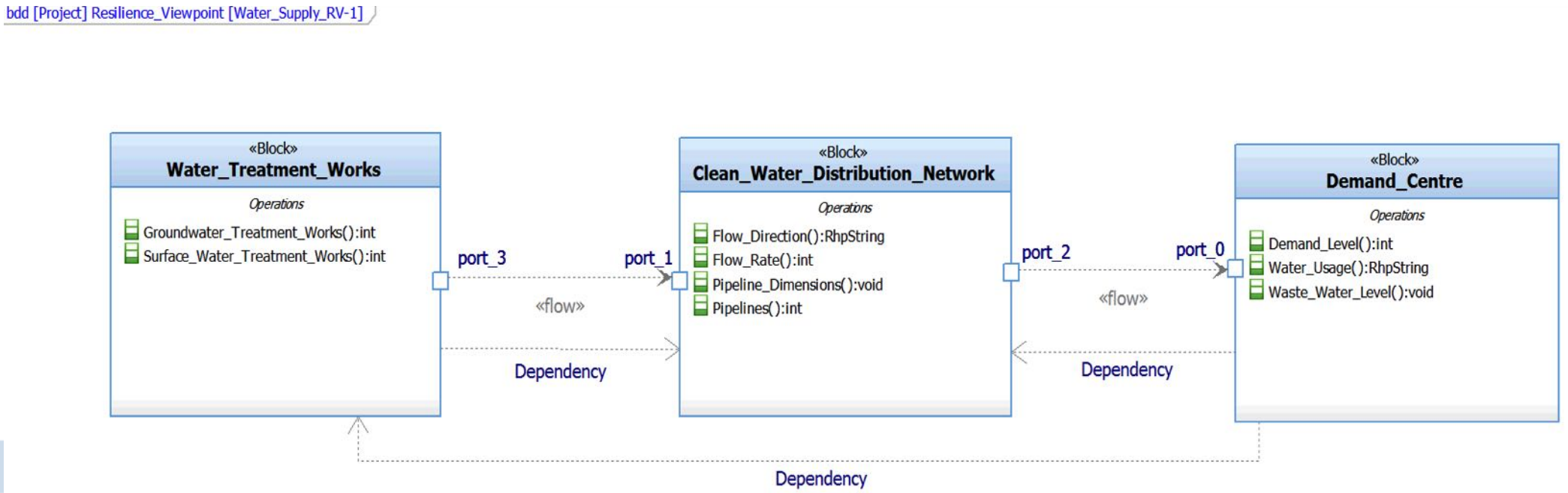
The Resilience Viewpoint

Resilience Views

- Resilience View 1 (RV-1) - Constituent System Dependency Model
- Resilience View 2 (RV-2) - Vulnerability and Criticality Description
- Resilience View 3 (RV-3) - Risk View Description



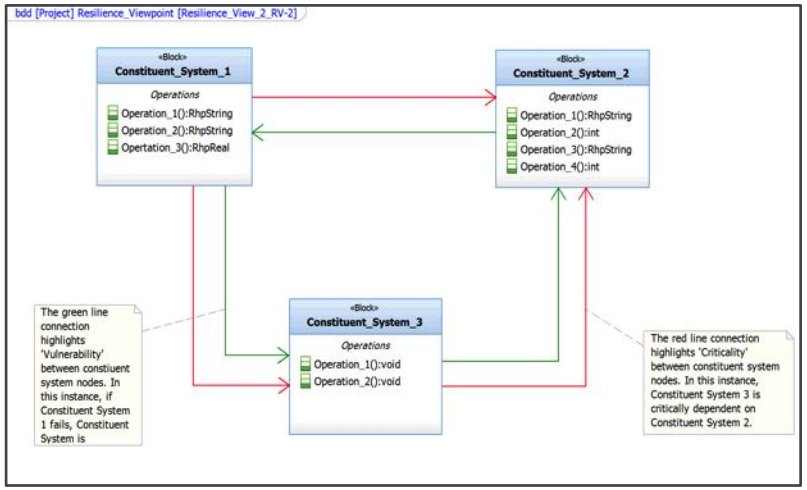
Resilience View 1 (RV-1) - Constituent System Dependency Model - Shows the high-level integration of constituent systems and their dependencies, communication and information channels and general operational relationships



Resilience View 2

Resilience Views

- Resilience View 1 (RV-1) - Constituent System Dependency Model
- Resilience View 2 (RV-2) - Vulnerability and Criticality Description
- Resilience View 3 (RV-3) - Risk View Description

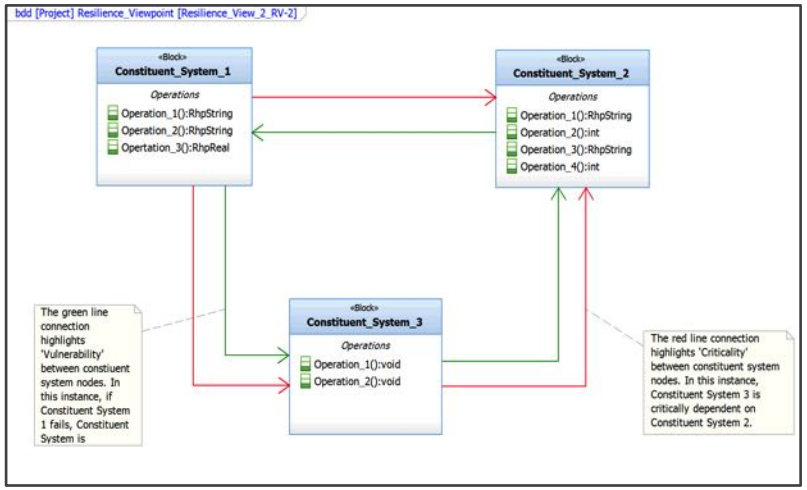


Resilience View 2 (RV-2) - Vulnerability and Criticality Description - Created to examine the vulnerability and criticality of system elements within a defined scope of interest.

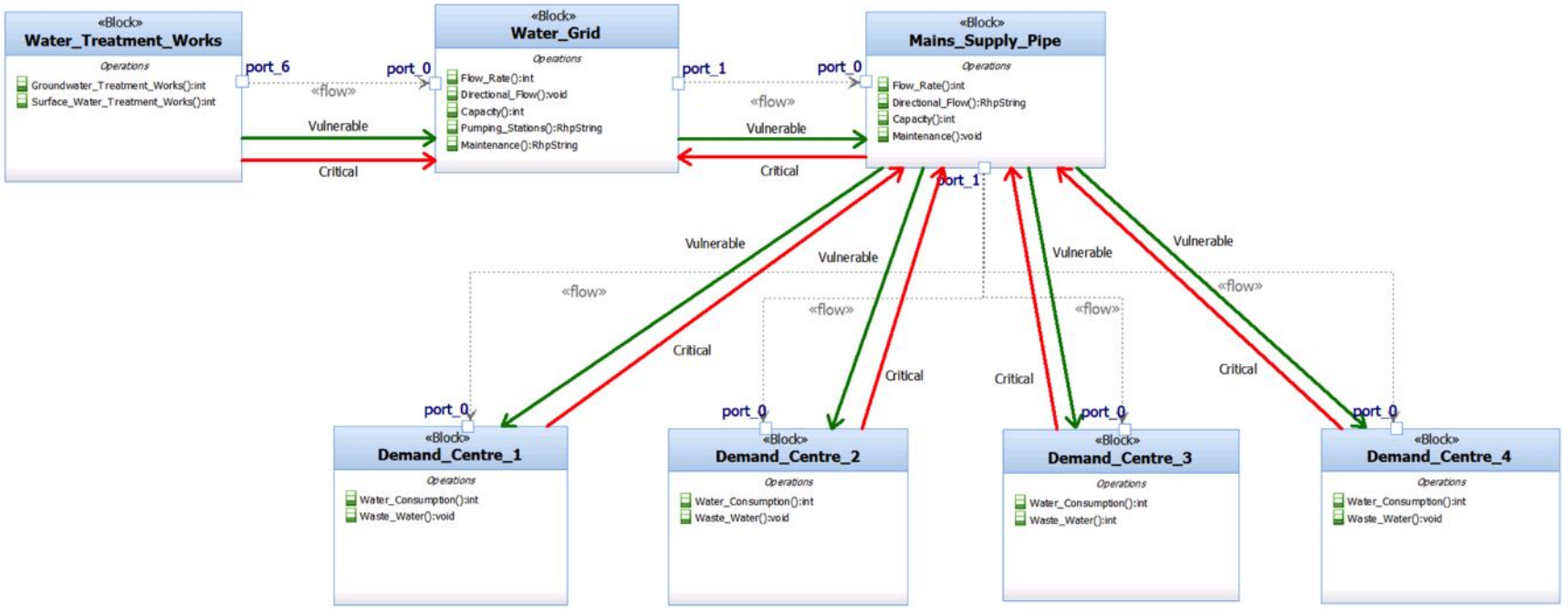
Resilience View 2

Resilience Views

- Resilience View 1 (RV-1) - Constituent System Dependency Model
- Resilience View 2 (RV-2) - Vulnerability and Criticality Description
- Resilience View 3 (RV-3) - Risk View Description



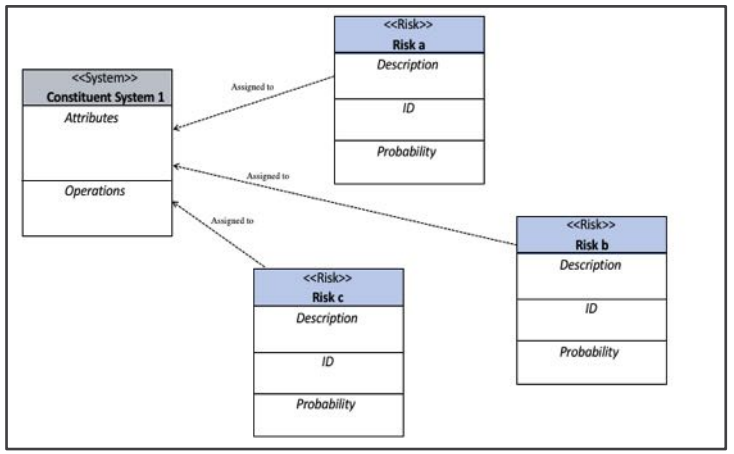
Resilience View 2 (RV-2) - Vulnerability and Criticality Description - Created to examine the vulnerability and criticality of system elements within a defined scope of interest.



Resilience View 3

Resilience Views

- Resilience View 1 (RV-1) - Constituent System Dependency Model
- Resilience View 2 (RV-2) - Vulnerability and Criticality Description
- Resilience View 3 (RV-3) - Risk View Description

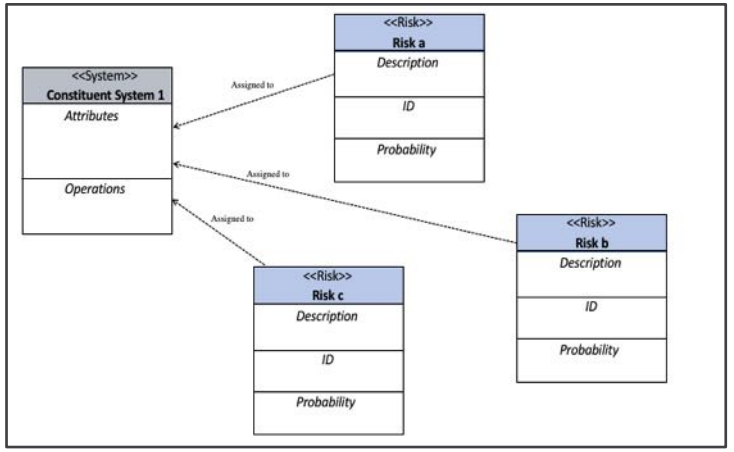


Resilience View 3 (RV-3) - Risk View Description - Provides a clear description of a set of risks and the assignment of risks to system elements.

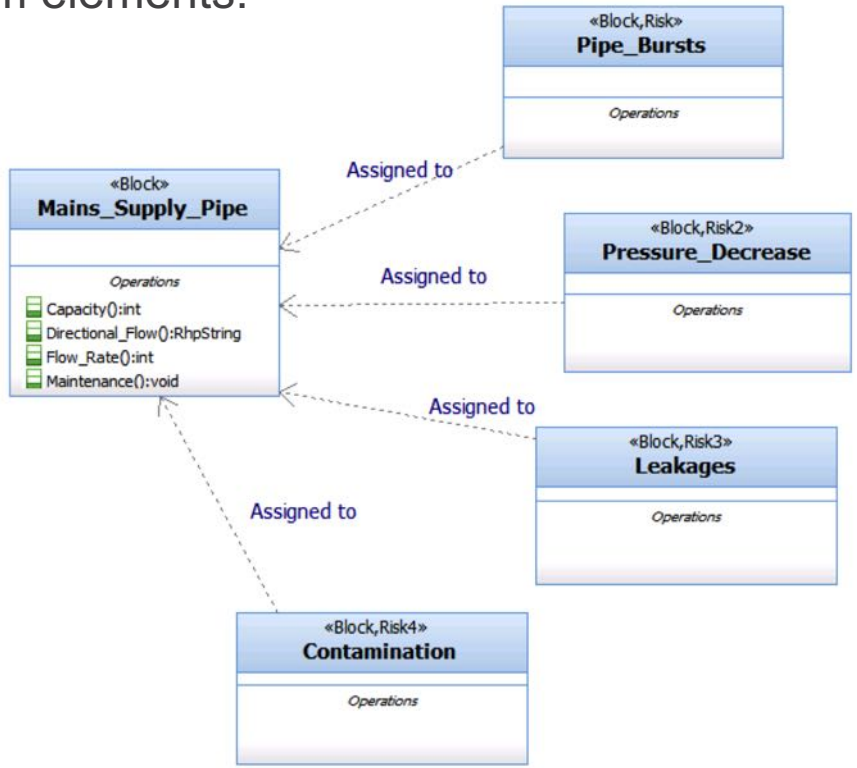
Resilience View 3

Resilience Views

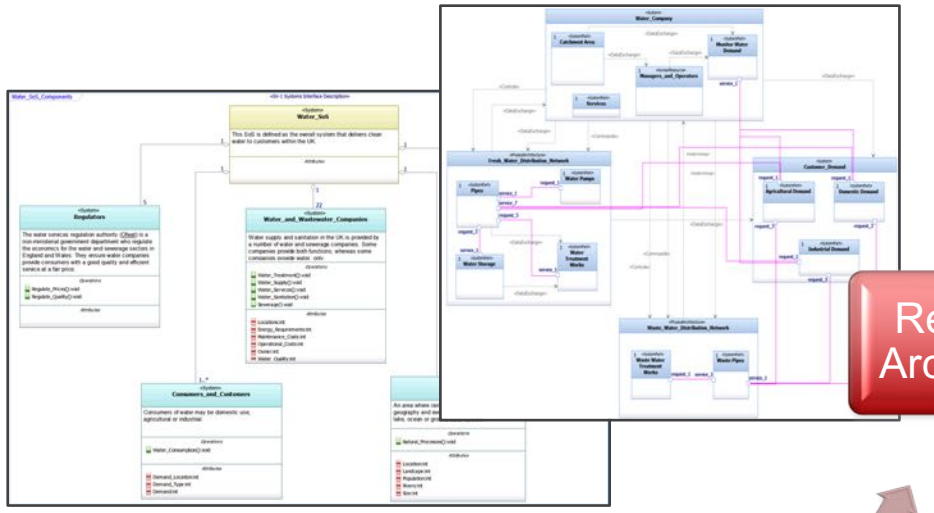
- Resilience View 1 (RV-1) - Constituent System Dependency Model
- Resilience View 2 (RV-2) - Vulnerability and Criticality Description
- Resilience View 3 (RV-3) - Risk View Description



Resilience View 3 (RV-3) - Risk View Description - Provides a clear description of a set of risks and the assignment of risks to system elements.



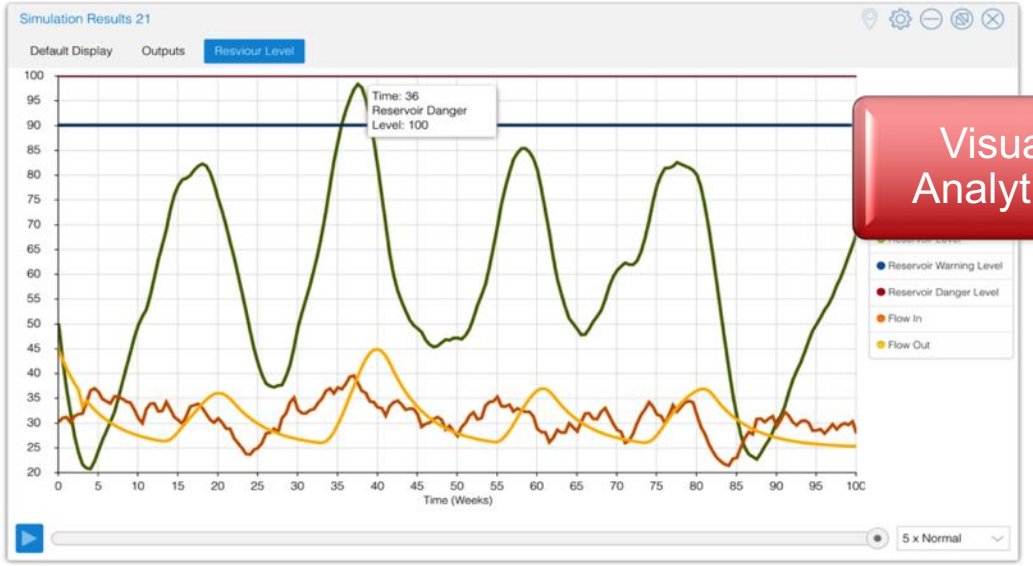
Design Space Exploration Process



Reference Architecture

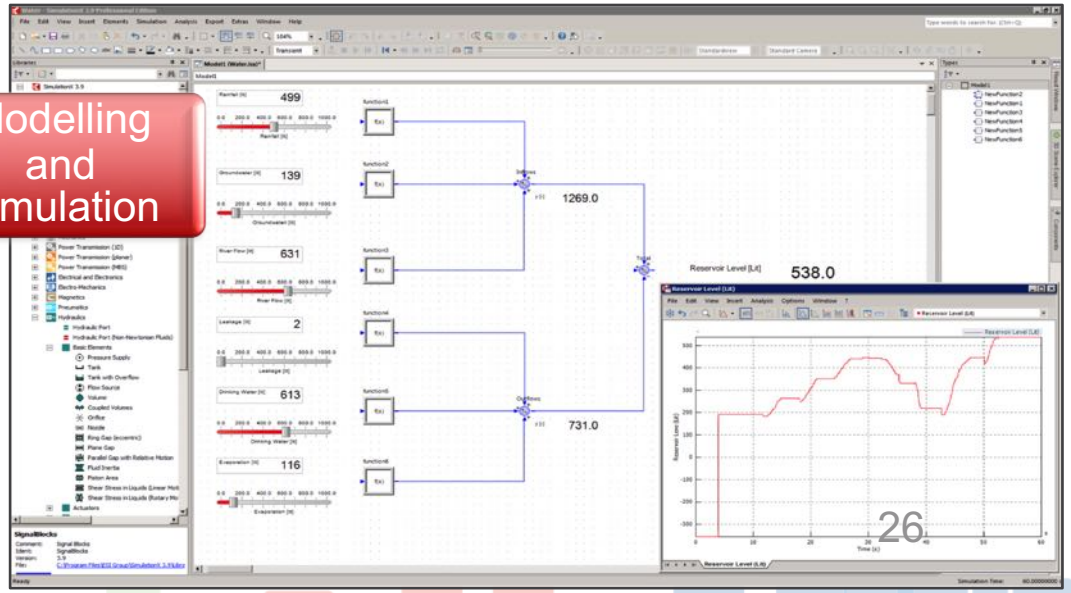
Benefits:

- Stakeholder engagement
- Requirements capture
- Iterative design process
- Model checking
- Insights into system performance
- Data formats
- Validating requirements



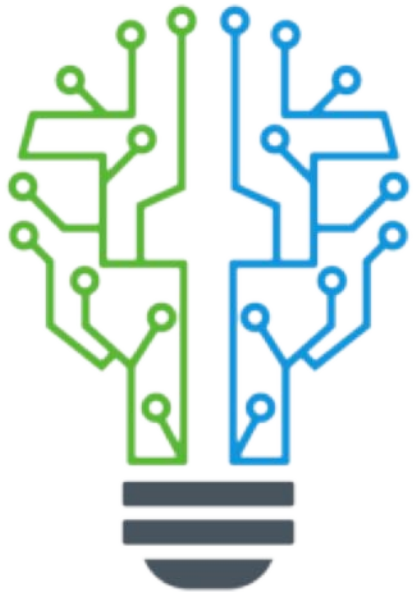
Visual Analytics

Modelling and Simulation



Future Work and Conclusions

- Develop use cases to demonstrate the value of Resilience Viewpoint
- Test the SoS resilience framework developed
- Create an ilities-based view in Resilience Viewpoint
- Talk to experts to assess the requirement for a Resilience Viewpoint
- Understand the process to include in OMG Standards



28th Annual INCOSE international symposium

Washington, DC, USA

July 7 - 12, 2018

www.incose.org/symp2018

Loughborough University

Advanced VR Research Centre

VIRTUAL ENGINEERING CENTRE