2015 System of Systems Engineering Collaborators Information Exchange (SoSECIE)

Towards a New Paradigm for Management of Complex Engineering Projects: A System-of-Systems Framework

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1 Problem Statement

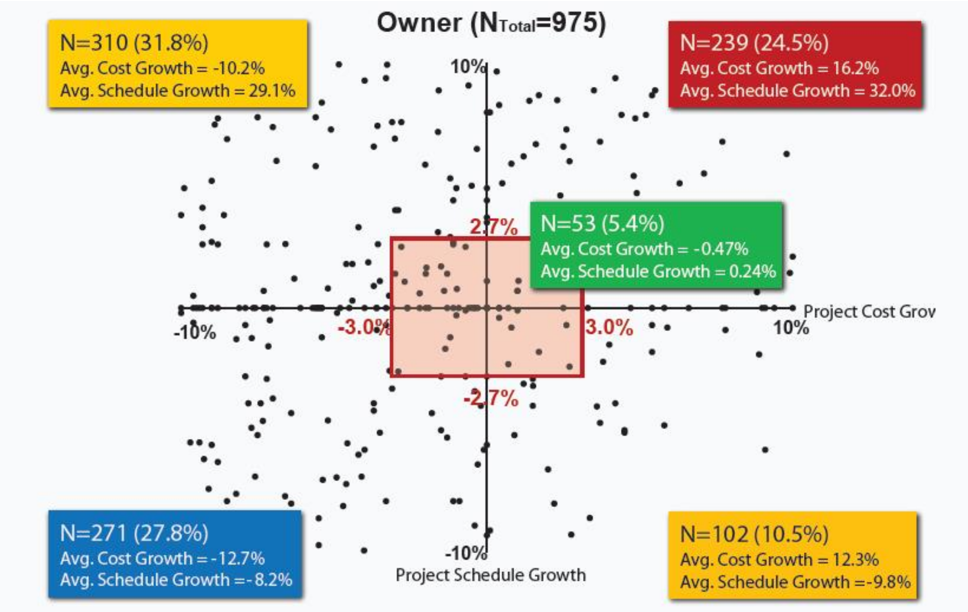
Performance inefficiency: A major challenge in engineering projects

- Performance failures significantly affect the efficiency of investments in engineering projects across different industries:
  - ❑ Cost overruns
  - ❑ Schedule delays
  - ❑ Quality deficiencies

1 Problem Statement

Many engineering projects cannot meet their performance goals.

1 out of 20 construction projects met both authorized cost and schedule goals



Construction Industry Institute (2012)

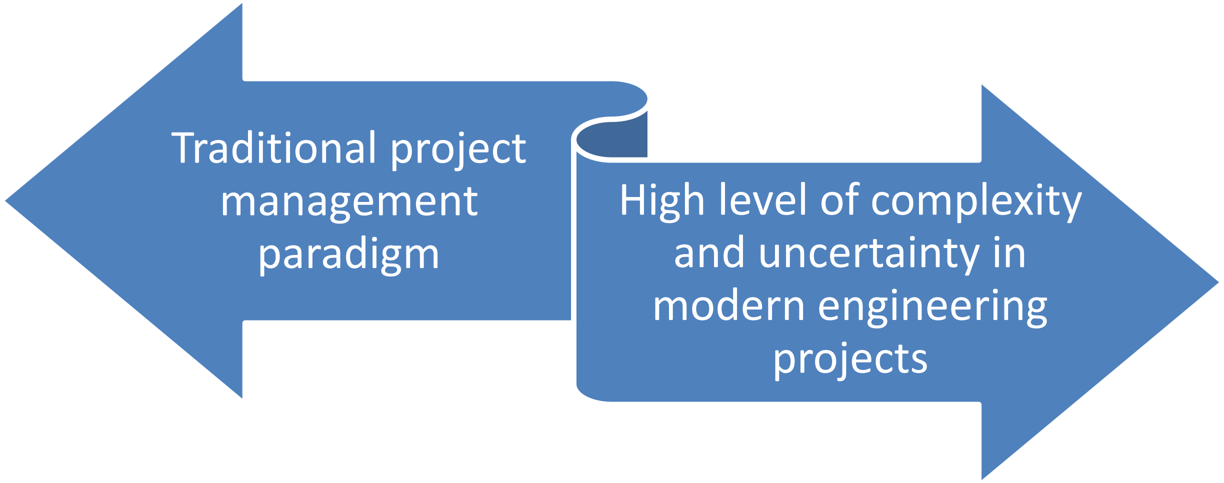
1 out of 10 large software development projects can be identified as successful

The Standish Group (2013)

1 Problem Statement

Traditional project management paradigm is not effective in managing modern engineering projects.

- Traditional project management paradigm
  - Conceptualization of projects: monolithic system
  - Approach: top-down
  - Method: centralized planning and control



A paradigm shift in assessment of engineering projects based on the proper conceptualization of engineering projects is needed.

2 Research Objective

Complex engineering projects are systems-of-systems. The objective of this study is to proposed a system-of-systems framework for the assessment of complex engineering projects.

Traits of SoS
(Maier, 1998)

- Operational Independence
- Managerial Independence
- Emergent Properties
- Evolutionary Development
- Geographic Distribution

Design process

Production/construction process

Finance process

Procurement process

Safety process

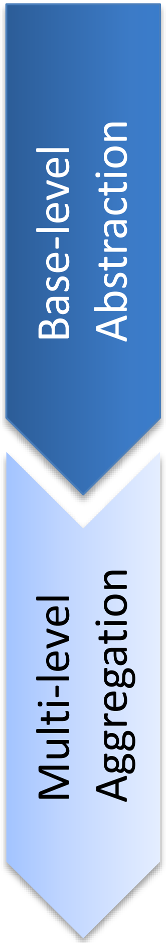
3 Engineering Project System-of-Systems Framework

An engineering project system-of-systems (EPSoS) framework is proposed based on two principles (DeLaurentis and Crossley, 2005):

Base-level Abstraction

Multi-level Aggregation

3 Engineering Project System-of-Systems Framework



Three types of entities are abstracted at the base level.

Human agent

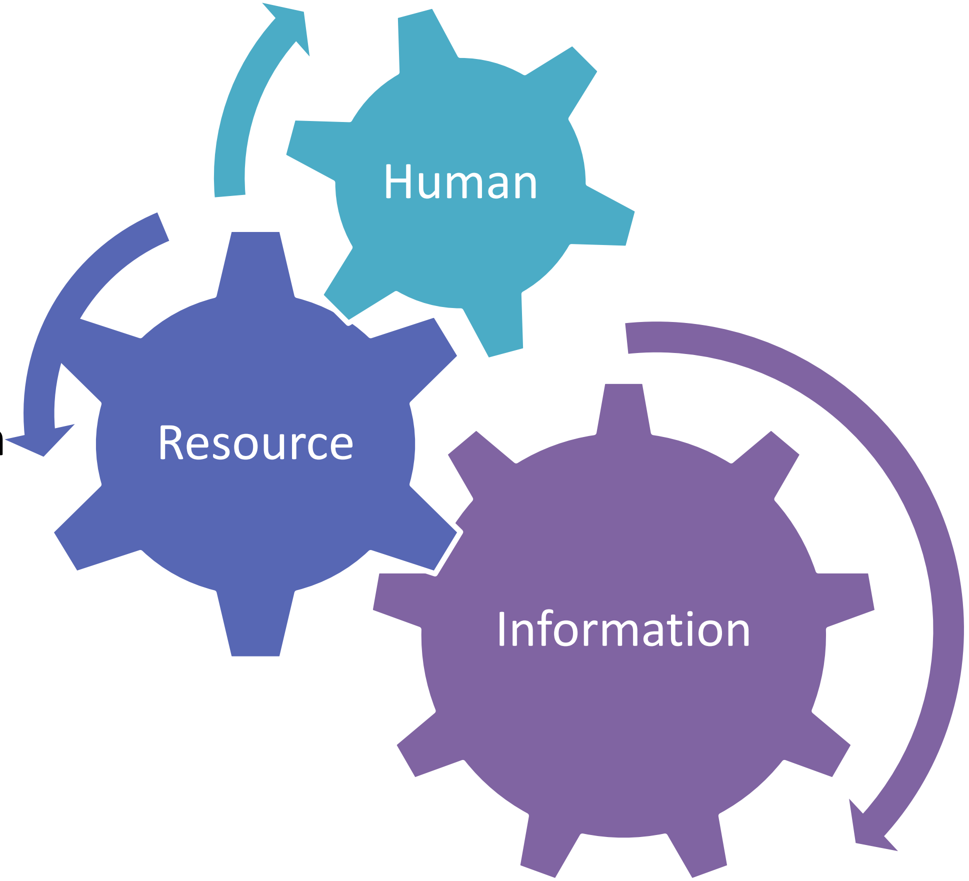
Entities who conduct production work, process information and make decisions

Resource

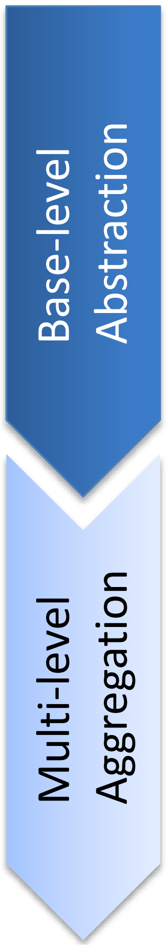
Entities that facilitate production work, information processing and decision making

Information

Knowledge or facts that affect dynamic behaviors of human agents



3 Engineering Project System-of-Systems Framework

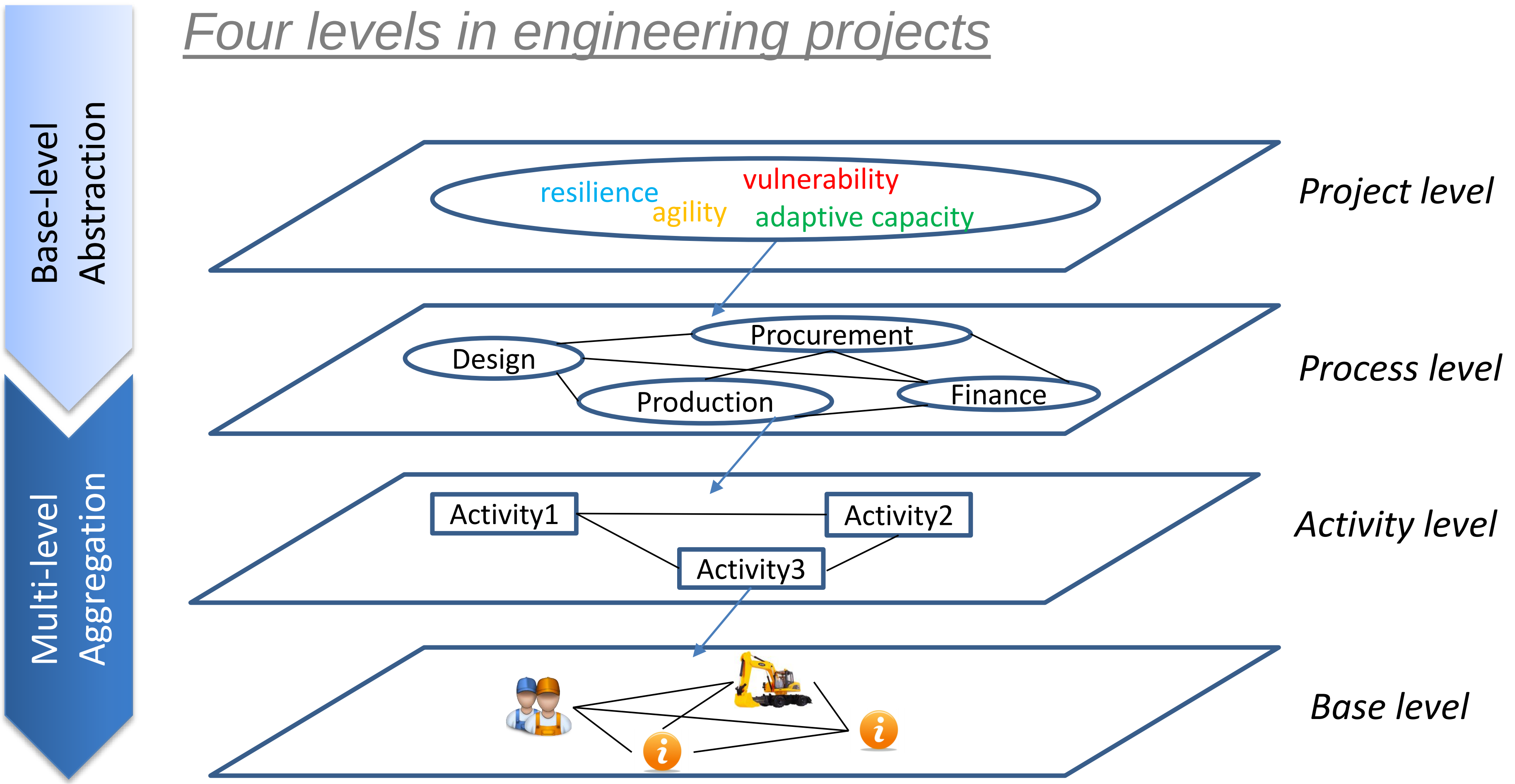


Examples of attributes of base-level entities:

Base-level entity types	Classification	Attributes
Human Agent	Production work agent	Productivity, attention allocation
	Information processing agent	Response time
	Decision making agent	Risk attitude
Resource	Material	Quantity, quality, cost
	Equipment	Productivity, cost
Information	Existing information	Completeness, accuracy
	Emergent information	Completeness, accuracy, recency

3 Engineering Project System-of-Systems Framework

Four levels in engineering projects



4 Application Example

The application and effectiveness of the proposed EPSoS framework is shown in a complex construction project.

Study 1

How do the attributes and micro behaviors of base-level entities affect project performance?

Study 2

How to get a better understanding of project behaviors under uncertainty via emergent properties?

4 Application Example

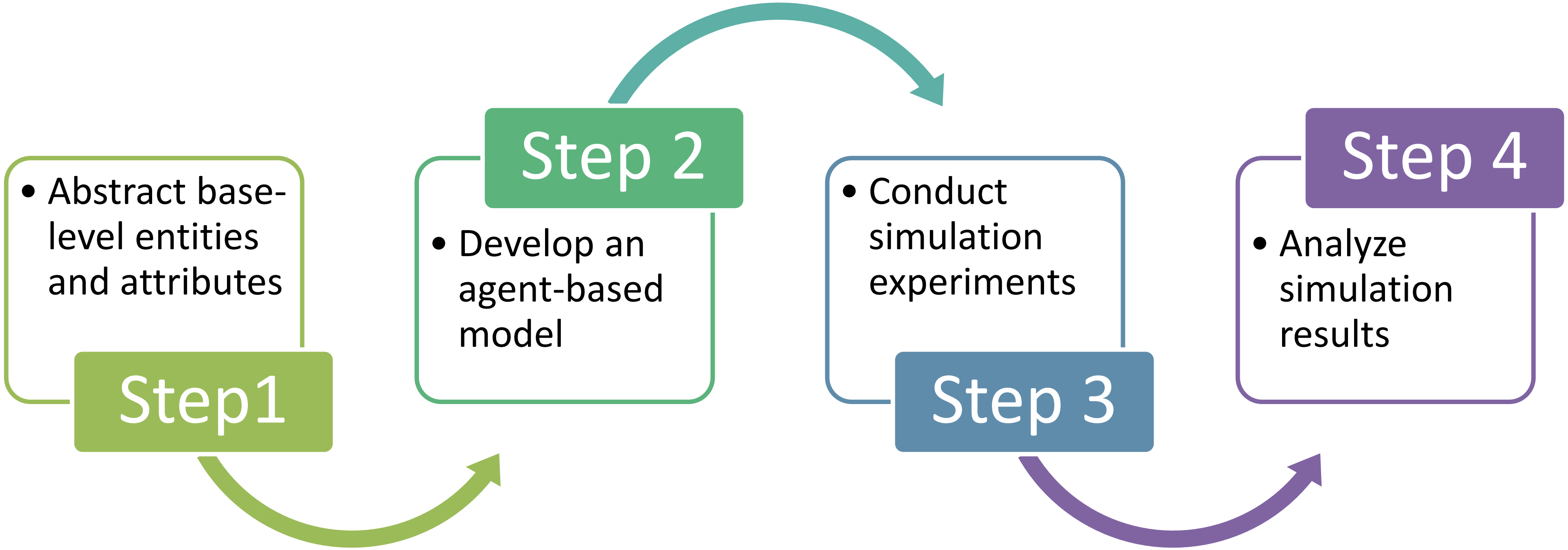
Case Description

- A complex construction project (Ioannou and Martinez, 1996)
- 1600-meter tunnel
- Varied ground conditions (Good, Medium, or Poor)
- New Austrian Tunneling Method (NATM)
- Adjusting design during the construction phase based on the changes of the ground condition

4 Application Example

Study 1: Base-level entities

Study 1: Investigate the impacts of attributes and micro behaviors of base-level entities on project performance



4 Application Example

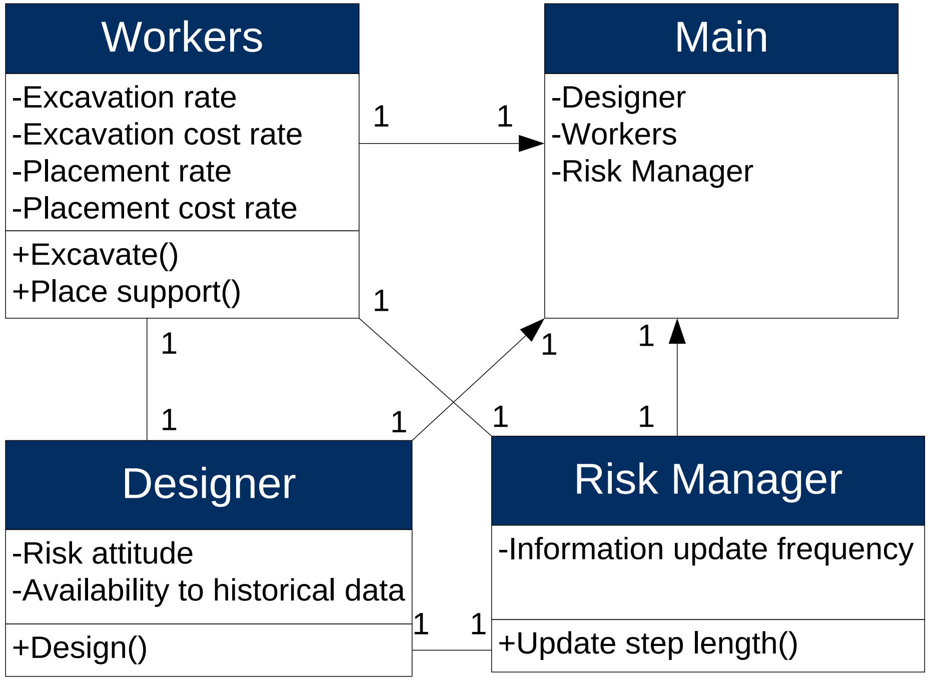
Study 1: Base-level entities

Step1: Abstract base-level entities and attributes

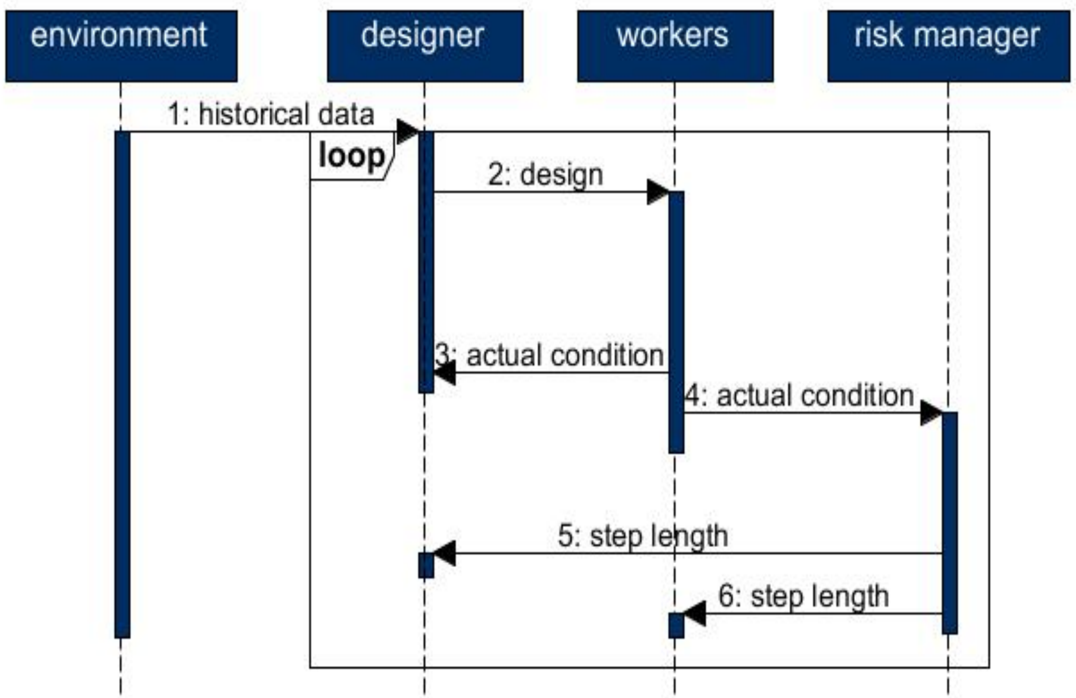
Examples of base-level entities and their attributes in the case project			
Category	**Base-level entities**	**Classification**	**Attributes**
Human Agent	Designer	Production/information processing/decision-making	response time, risk attitude
	Workers	Production/information processing	Productivity, cost, response time
Resource	Excavator	Equipment	Productivity, cost
	Support	Material	Quantity, quality, cost
Information	Historical data	Existing information	completeness, accuracy
	Current ground condition	Emergent information	completeness, accuracy, recency
	Step length	Emergent information	completeness, accuracy, recency

4 Application Example
Study 1: Base-level entities

Step 2: Develop an agent-based model



Class diagram



Sequence diagram

4 Application Example

Study 1: Base-level entities

Step 3: Conduct simulation experiments

	Risk attitude	Impact
 **Designer**	Risk seeking	Design decisions are made for better outcomes with higher levels of uncertainty
	Risk neutral	Design decisions are not affected by the degree of uncertainty
	Risk averse	Design decisions are made for outcomes with lower levels of uncertainty

Simulation experiment example:

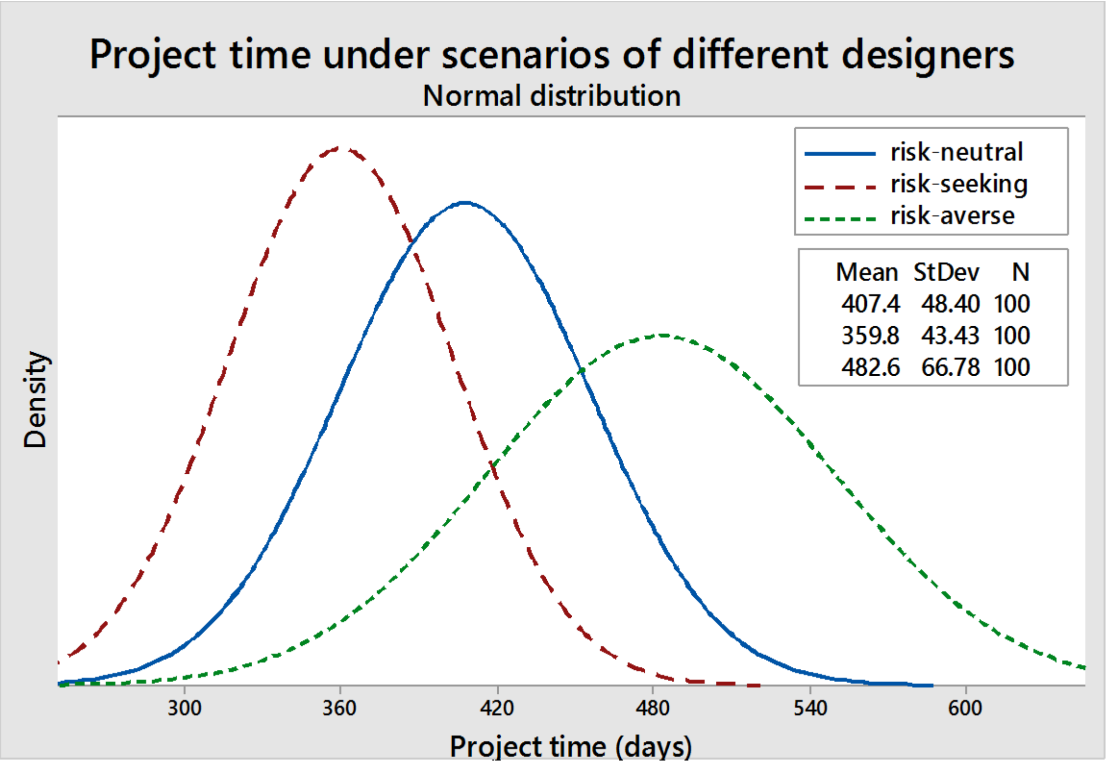
changing the risk-attitude of designer

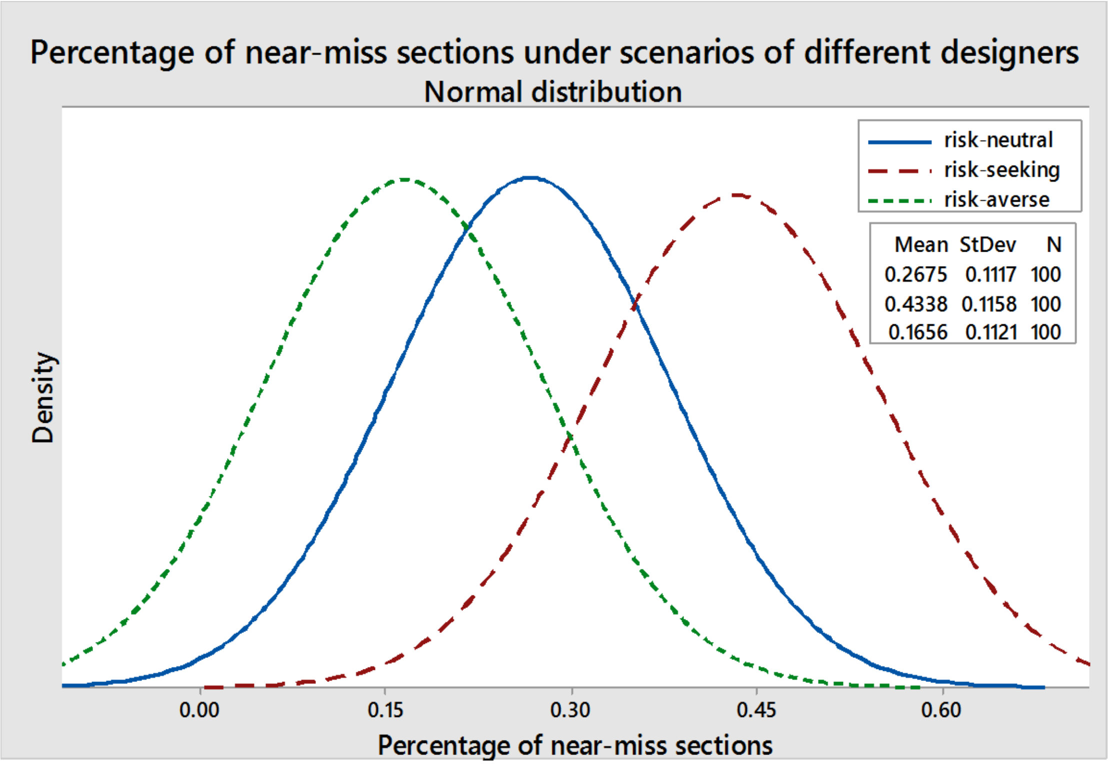
4 Application Example

Study 1: Base-level entities

Step 4: Analyze simulation results

- A risk-seeking designer improves project time, but increases the near-miss sections

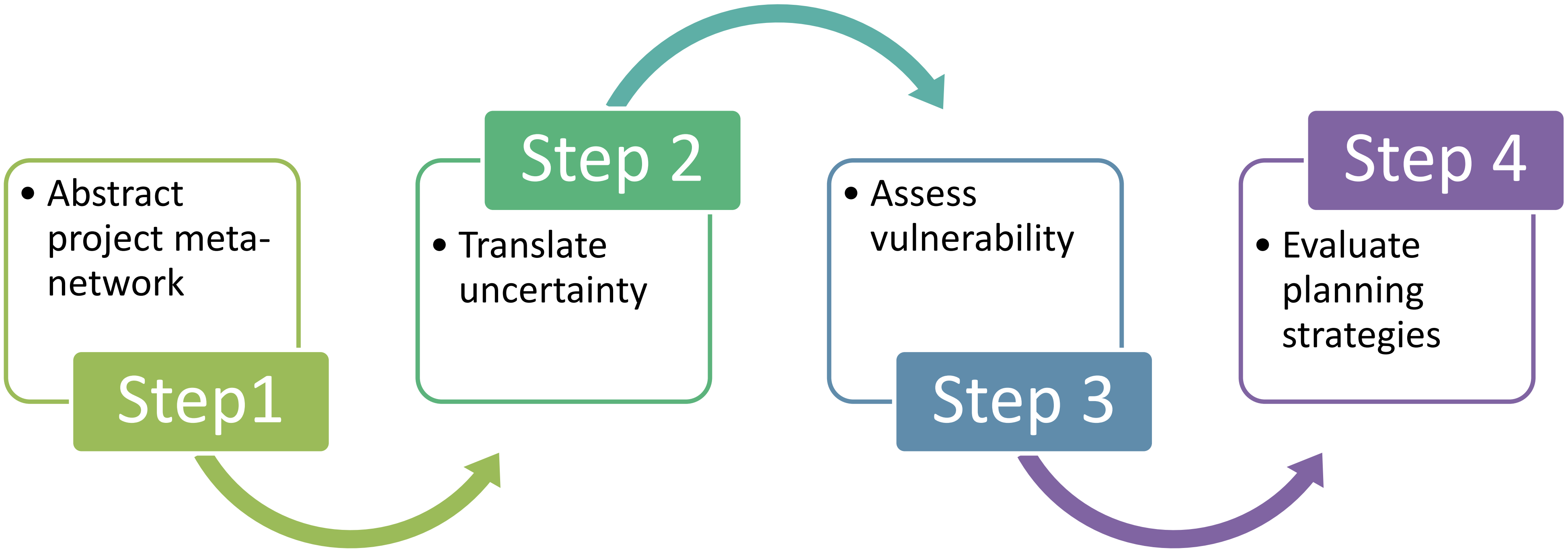




4 Application Example

Study 2: Emergent properties

Study 2: Investigate emergent properties arising from interactions and interdependencies in projects

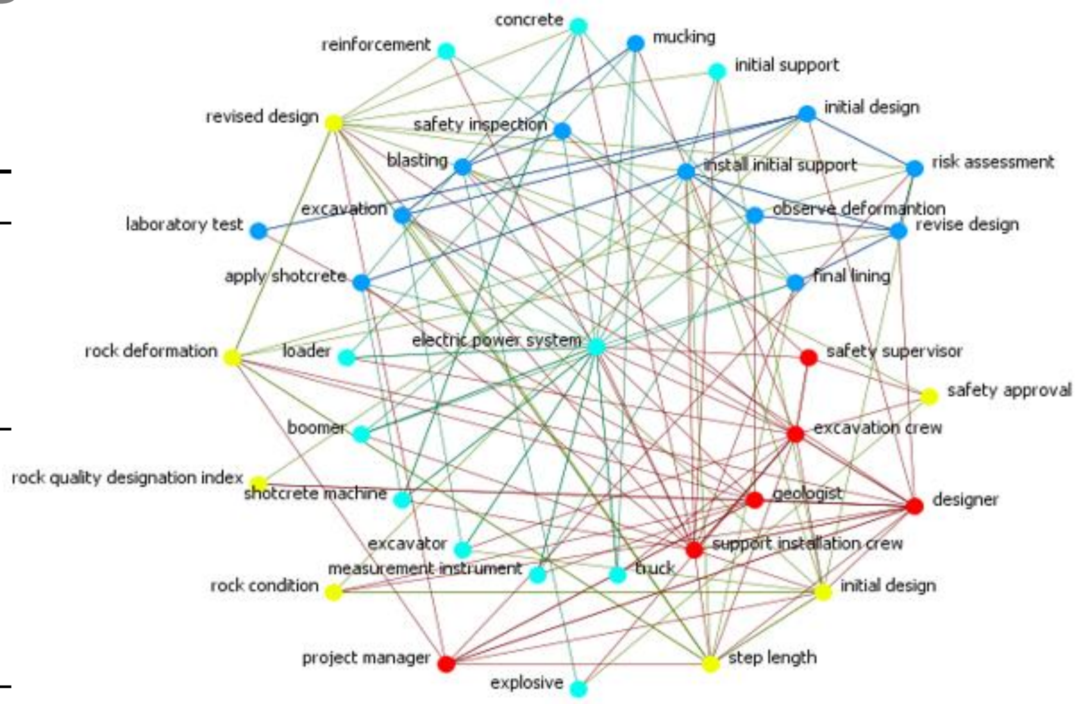


4 Application Example

Study 2: Emergent properties

Step 1: Abstract project meta-network

	Agent	**Information**	**Resource**	**Activity**
Agent	who works with and reports to whom	who knows what	who can use what resource	who is assigned to what activity
Information		what information is related to other information	what information is needed to use what resource	what information is needed for what activity
Resource			what resource is used for other resources	what resource is needed for what activity
Activity				what activity is related to other activities



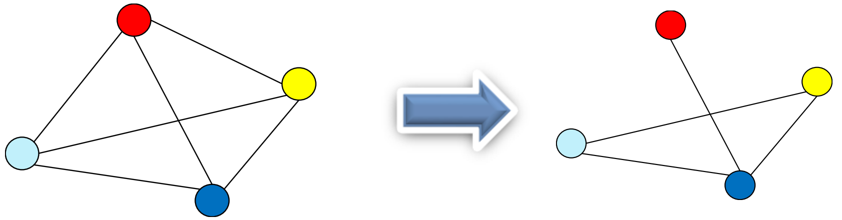
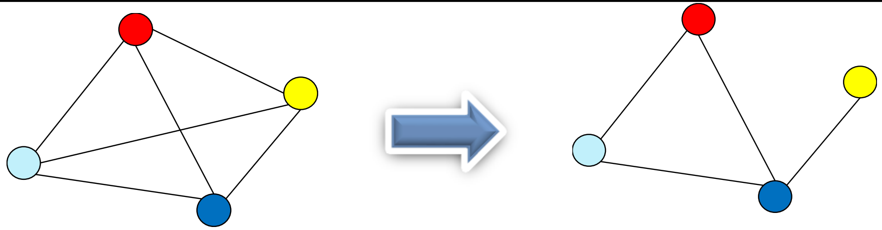
Meta-network of the tunneling project case

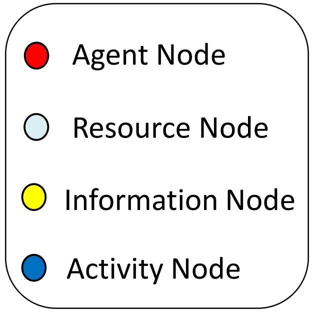
Nodes	36
Links	118
Density	0.187

4 Application Example

Study 2: Emergent properties

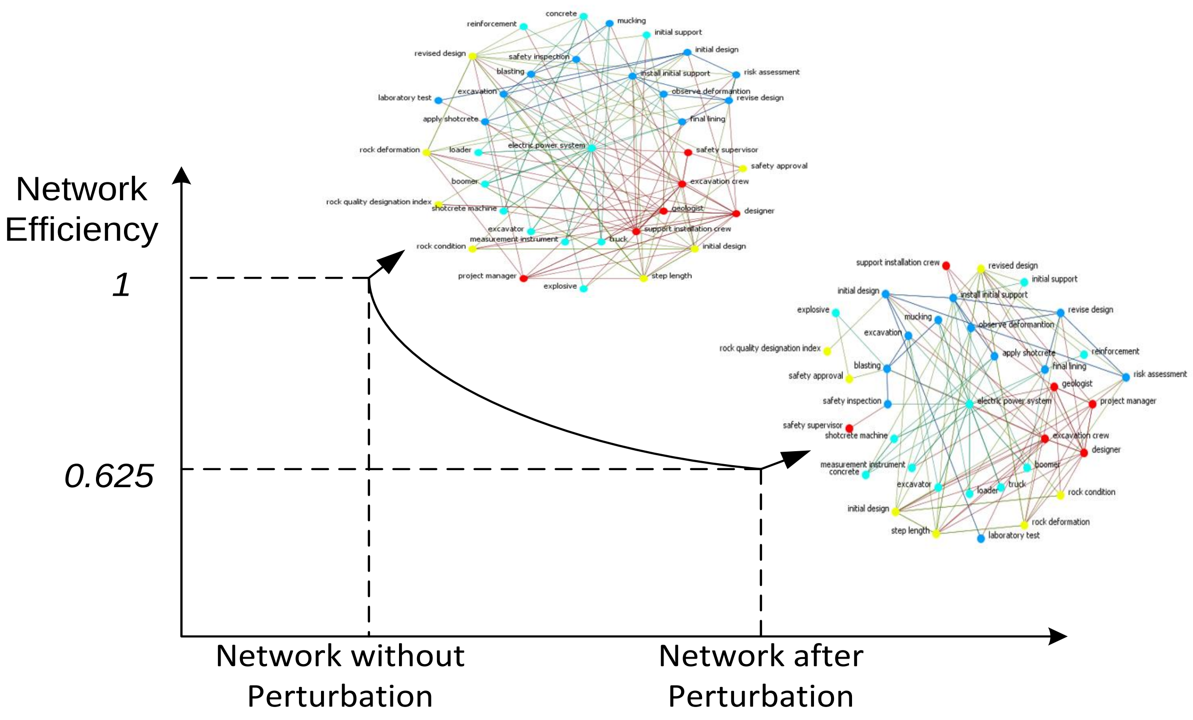
Step 2: Translate uncertainty

Uncertainty	Examples	Network Perturbation
Agent-related	➢ Staff turnover ➢ Dereliction of duty ➢ Safety accident or injury	
Resource-related	➢ Defective materials ➢ Equipment breakdown ➢ Late delivery of material	
Information-related	➢ Unclear scope/design ➢ Limited access to required knowledge ➢ Miscommunication	



4 Application Example
Study 2: Emergent properties

Step 3: Assess Vulnerability *(Carley and Reminga, 2004)*



Vulnerability assessment of project meta-networks

Network Efficiency

- the percentage of activities that can be completed by the agent assigned to them based on whether the agents have the requisite information and resources

Project Vulnerability

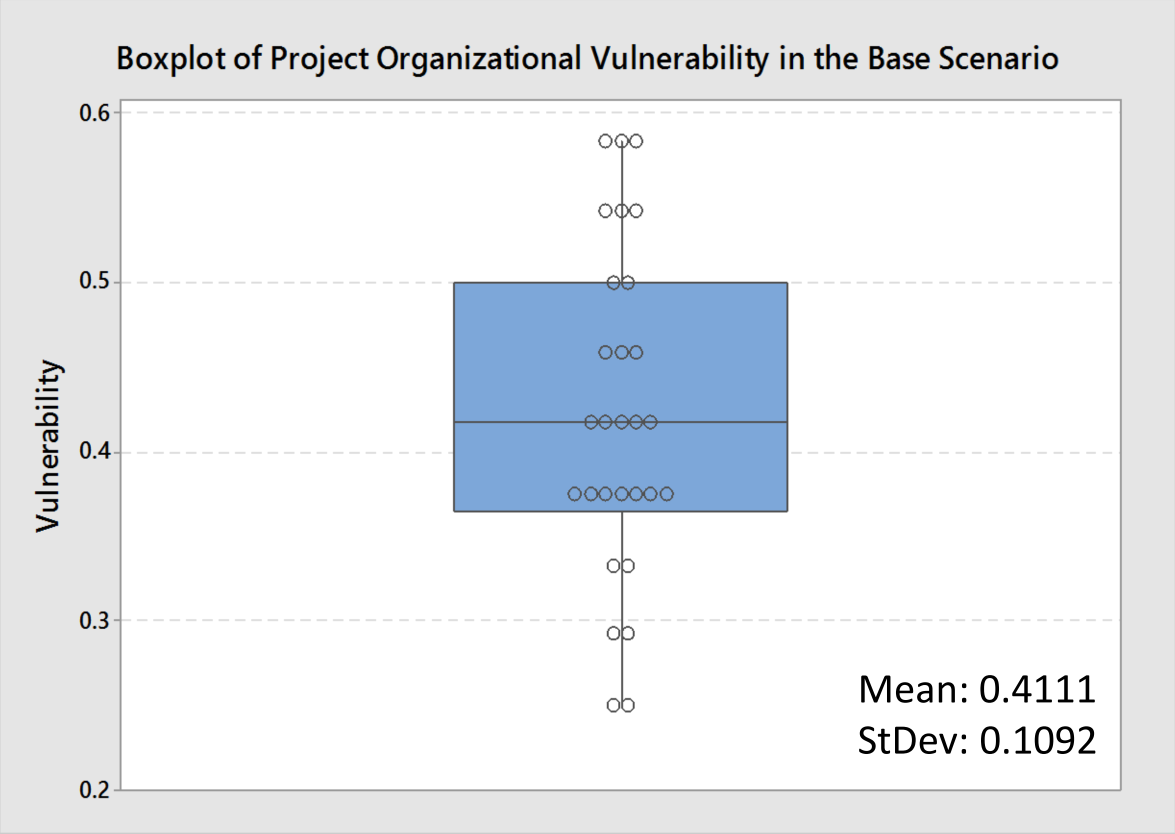
- the extent of the changes in network efficiency due to uncertainty-induced perturbations

4 Application Example
Study 2: Emergent properties

Step 3: Assess Vulnerability

Uncertain environment of the tunneling project

Uncertain Events	Perturbation	Probability
Dereliction of duty	Agent-related	Medium
Staff turnover	Agent-related	Low
Inadequate information	Information-related	Medium
Equipment breakdown	Resource-relation	Medium
Late delivery of material	Resource-related	High
Power system failure	Multiple resource-related	Medium
Severe weather	Agent and resource-related	Low
Economic fluctuation	Agent and resource-related	Low

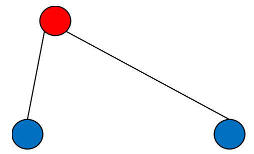
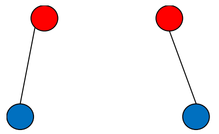
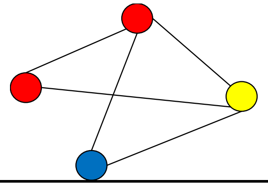
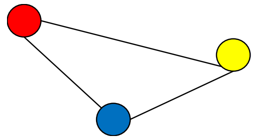
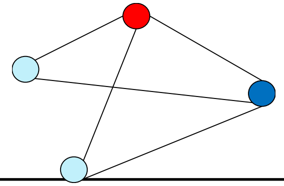
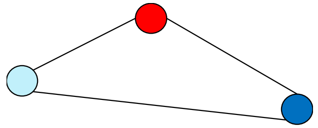


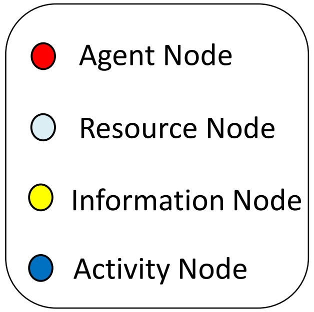
4 Application Example

Study 2: Emergent properties

Step 4: Evaluate planning strategies

Examples of planning strategy reflections in project meta-networks

Task Assignment	Generalization of labor	Division of labor
		
Decision-making authority	Centralized decision-making	Decentralized decision-making
		
Resource management	Redundancy	Non-redundancy
		



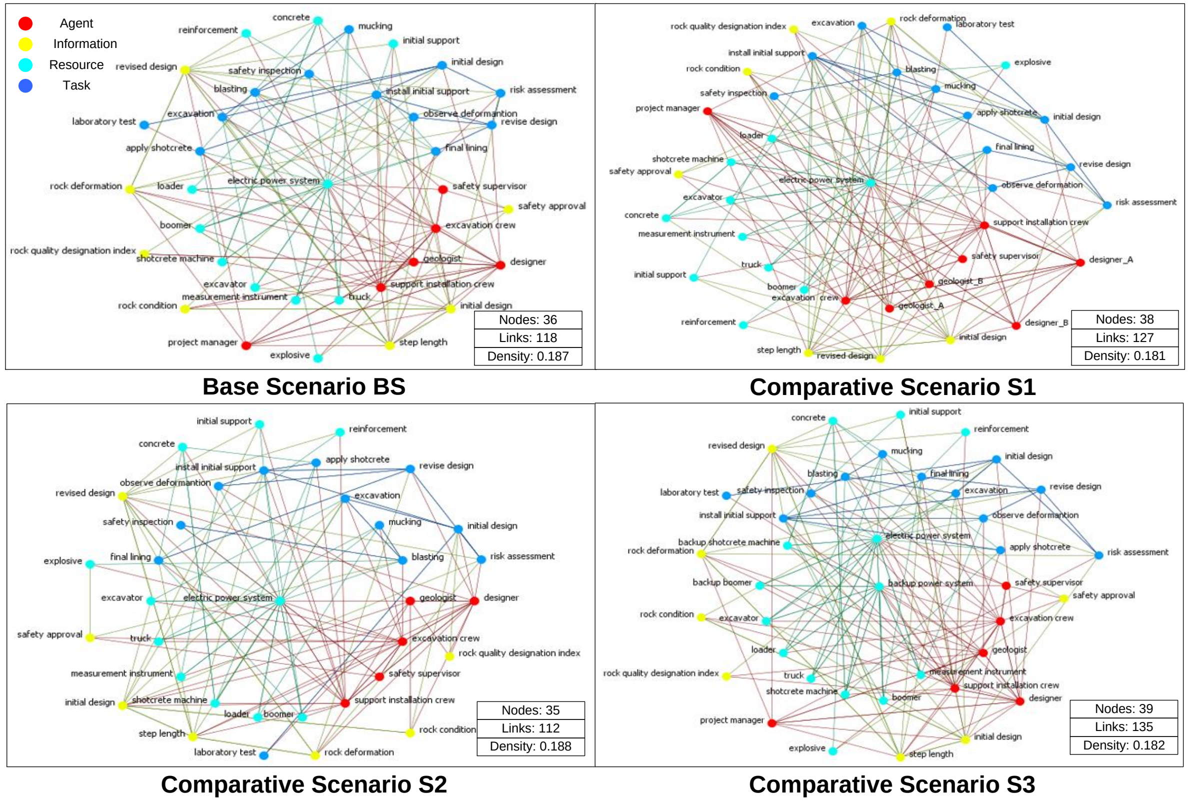
4 Application Example

Study 2: Emergent properties

Step 4: Evaluate planning strategies

Scenarios by combinations of planning strategies

Planning Strategies		BS	S1	S2	S3
Task assignment	Generalization of labor	√		√	√
	Division of labor		√		
Decision-making authority	Centralized	√	√		√
	Decentralized			√	
Resource management	Non-redundancy	√	√	√	
	Redundancy				√

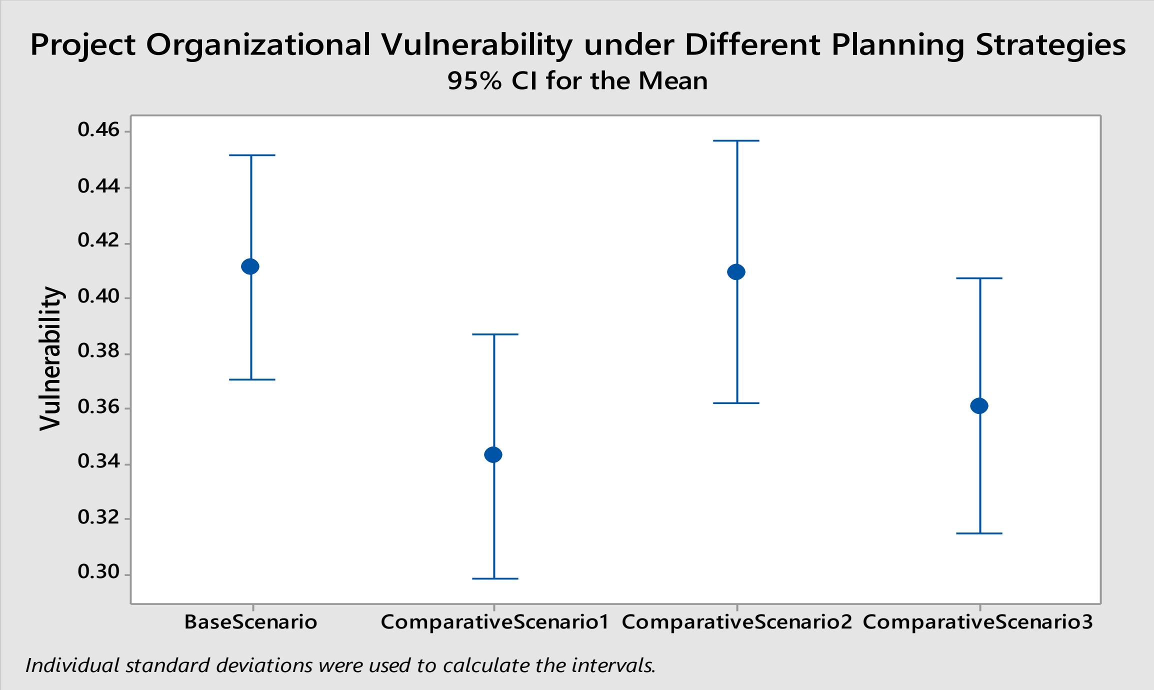


Project meta-networks of the tunneling project under different planning scenarios without perturbations

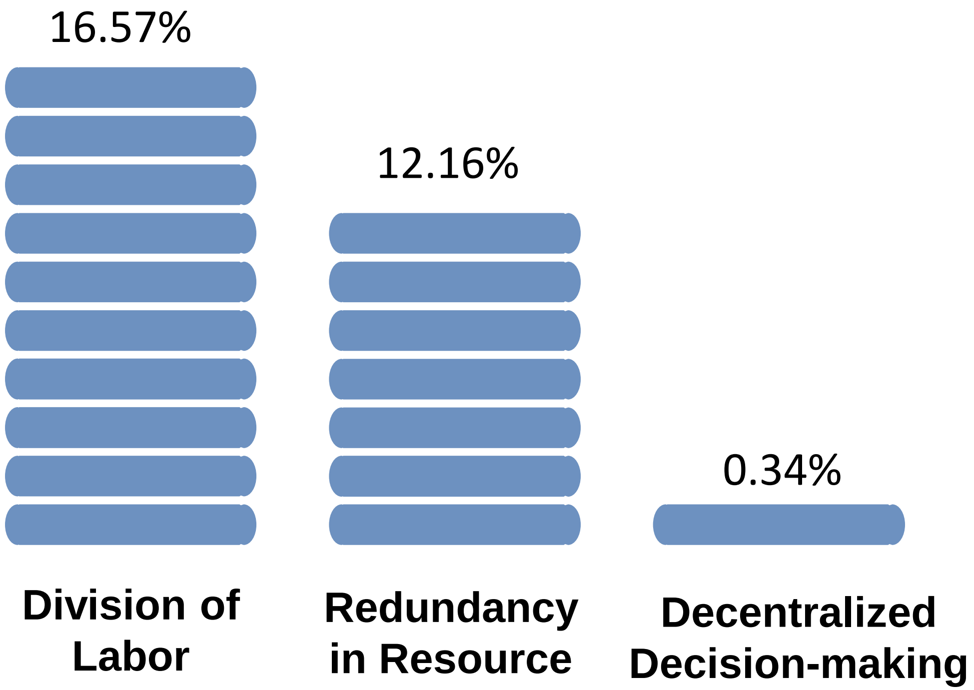
4 Application Example

Study 2: Emergent properties

Step 4: Evaluate planning strategies



	N	Mean	StDev	95% CI	effectiveness
Base Scenario	30	0.4111	0.1092	(0.3703, 0.4519)	-
Comparative Scenario 1	30	0.343	0.1186	(0.2987, 0.3873)	16.57%
Comparative Scenario 2	30	0.4097	0.1267	(0.3624,0.4570)	0.34%
Comparative Scenario 3	30	0.3611	0.1235	(0.3150, 0.4072)	12.16%



Effectiveness of planning strategies in mitigating project vulnerability compared to the base scenario

5 Concluding Remarks

The results from the application example show that the EPSoS framework is capable of facilitating investigation of: (1) micro behaviors of base-level entities and (2) project emergent properties using:

A proper level of abstraction
- *Capture micro behaviors and interdependencies at the base-level*

A bottom-up aggregation approach
- *Capture emergent properties as macro behaviors at the project level*

A dynamic perspective
- *Consider the impacts of uncertainty and dynamic changes*

5 Concluding Remarks

Body of knowledge

- A new theoretical lens for assessment of engineering projects
- First of its kind to assess the performance measures at the project level based on the micro-behaviors and interdependencies of project entities at the base level
- Exploration of emergent properties

Body of practice

- Design more resilient and less vulnerable engineering projects in pre-planning phase
- Develop contingency plan based on the expected performance loss and recovery

Reference

[1] Construction Industry Institute, “Performance Assessment 2012,” Austin, TX, 2012.

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[4] M. W. Maier, “Architecting principles for systems-of-systems,” *Syst. Eng.*, vol. 1, no. 4, pp. 267–284, 1998.

[5] P. G. Ioannou and J. C. Martinez, “Comparison of construction alternatives using matched simulation experiments,” *J. Constr. Eng. Manag.*, vol. 122, no. 3, pp. 231–241, 1996.

[6] K. M. Carley and J. Reminga, “*Ora: Organization risk analyzer*,” 2004.

The research team at I-SoS Research Group focuses on solving the challenges pertaining to the sustainability and resilience of civil systems at the interface of the infrastructure, economy, environment and society based on System-of-Systems (SoS) analysis, computational simulation, and quantitative data analysis models.

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