Emergence as Innovation in Systems of Systems – a Three Systems Model

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System of Systems Engineering Collaborators Information Exchange (SoSECIE)
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Background

Tom McDermott

Currently serves as Deputy Director of the Systems Engineering Research Center at Stevens Institute of Technology in Hoboken, NJ, as well as a consultant specializing in strategic planning for uncertain environments. He studies systems engineering, systems thinking, organizational dynamics, and the nature of complex human socio-technical systems.

Molly Nadolski

Research Associate at GTRI and research affiliate at the Sam Nunn School of International Affairs at Georgia Tech. Her research interests include issues related to national and international security, geopolitics, cyberspace, urban resilience, decision-making, human behavior, and regional development. Her role at GTRI involves framing and leading policy research in these areas, while expanding and exploring the applications of systems thinking methods to complex socio-technical domains.

OUTLINE

- Introduction
- The 3-Systems Model
- Introduction to the Toolset
- Case study #1: Transportation & IoT
- Case study #2: Gray Zone Conflict
- Current Research
- Wrap up and Next Steps
- Conclusion

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Introduction: SoS Characteristics most relevant to emergence & innovation

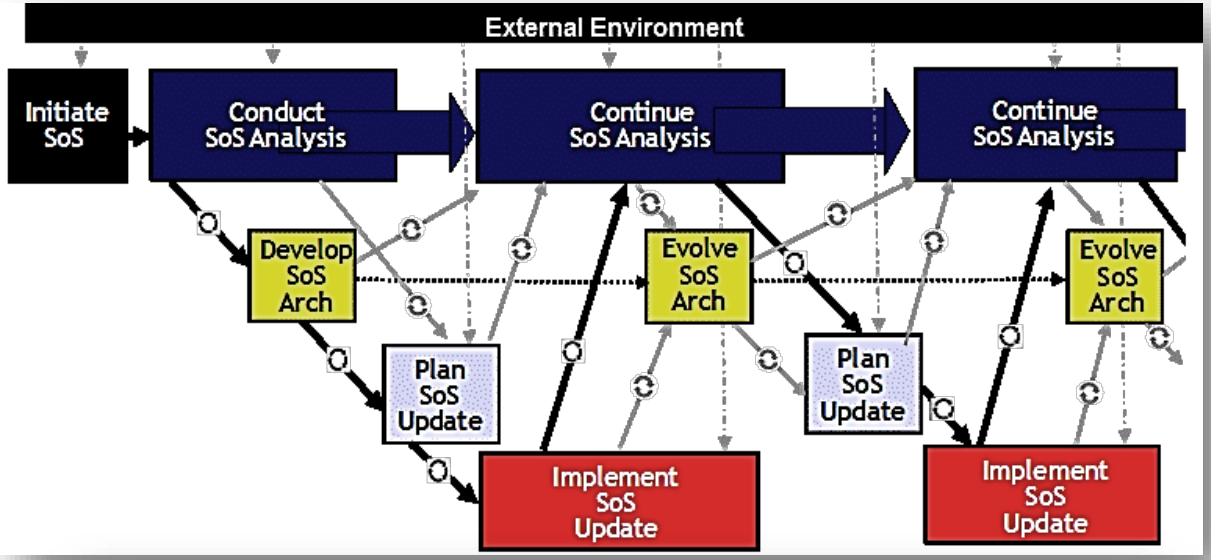
- Self-organization and multi-scale or multi-level hierarchy
- Autonomy and multi-agent interaction
- Emergence and/or Evolutionary development
- Connectivity and Complexity

$$\textit{Emergence} = \frac{\textit{actors + activities + associations}}{\textit{arrangements}}$$

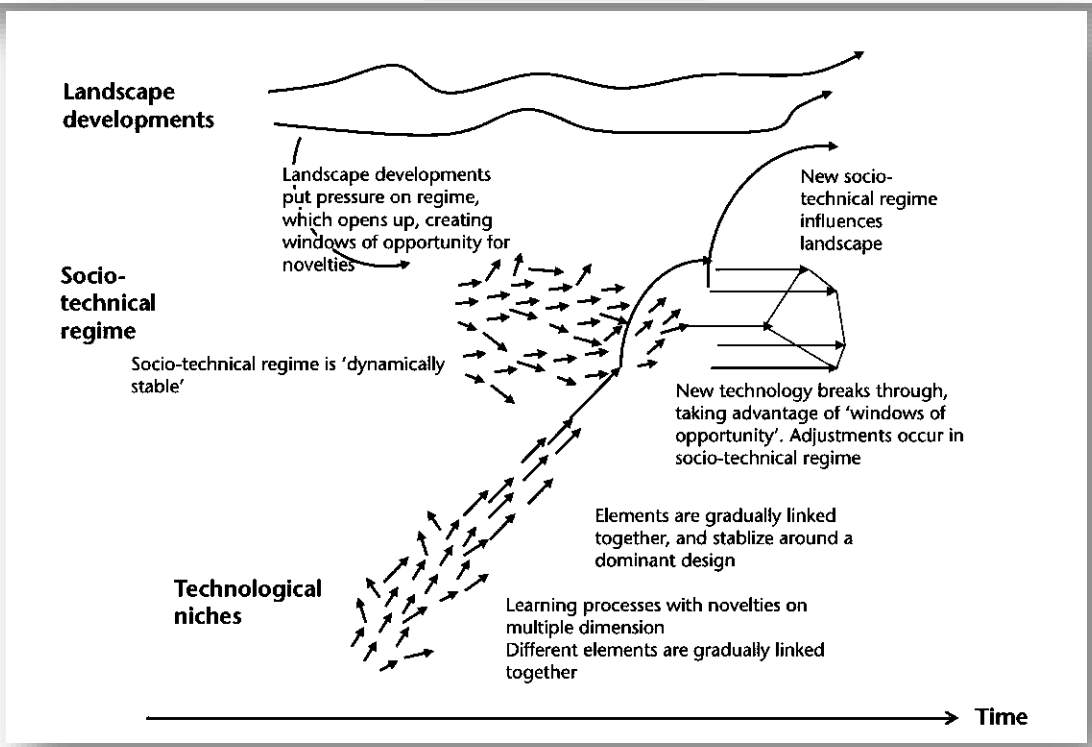
$$\textit{Innovation} = \frac{\textit{insight + invention + implementation}}{\textit{inhibitors/enablers}}$$

Courtesy: Steve Cross

Differing Views of SoS Multi-Level Evolution



The wave model (Dahmann, etal.)



Multilevel View of technology transitions (Geels)

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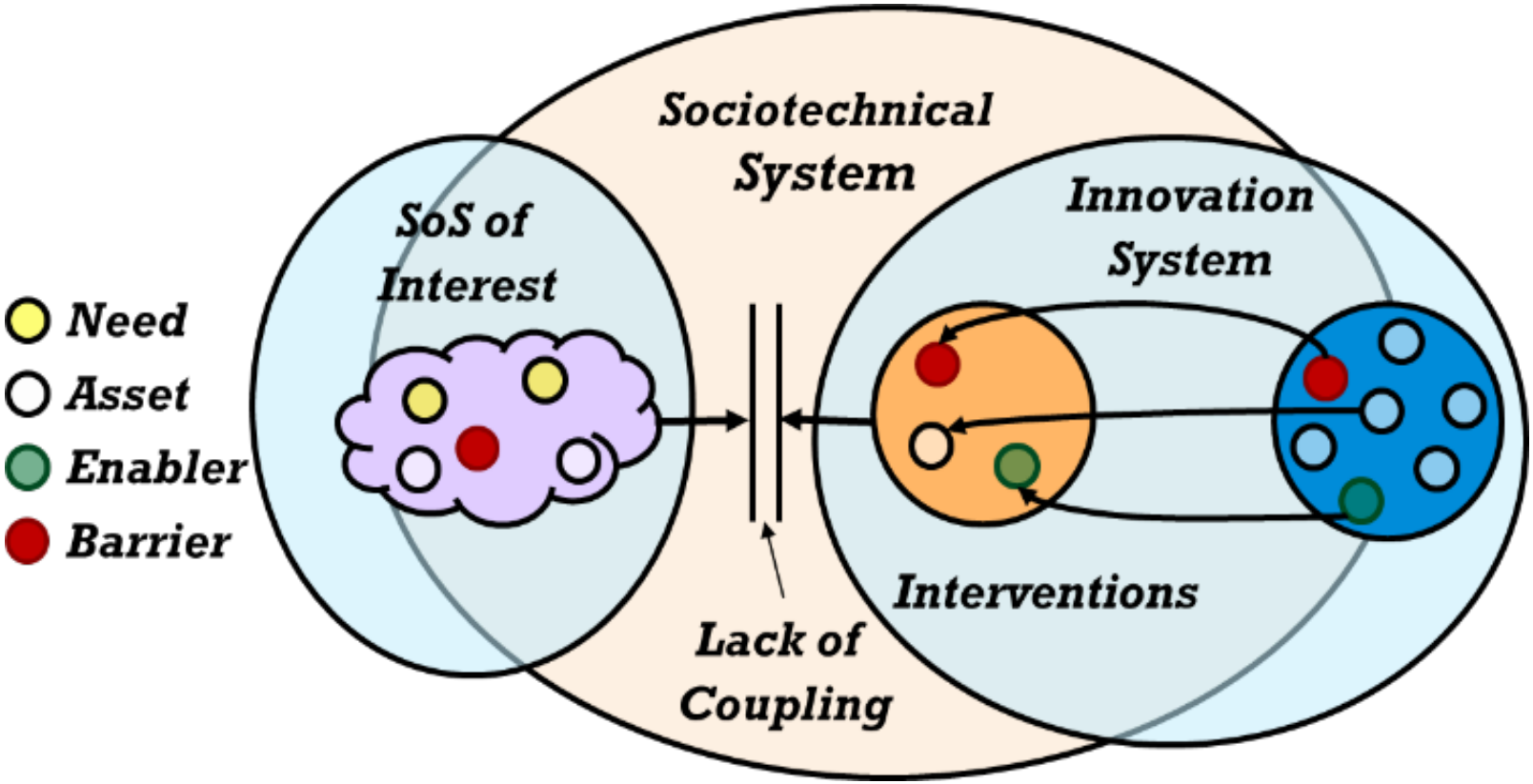
The 3-Systems Model



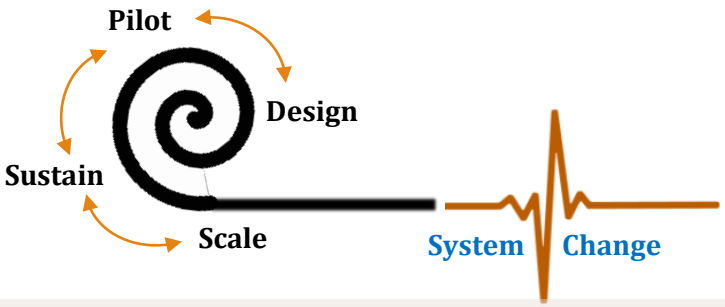
Context: an existing system-of-systems (SoS) that contains technology, policy, economics, social, and environmental drivers

System innovation: occurs in a dynamic system shaped by complex interactions among the stakeholders

The Sociotechnical System: where the SoS of interest and innovation system come together. This view supports analyses of the broader decision context

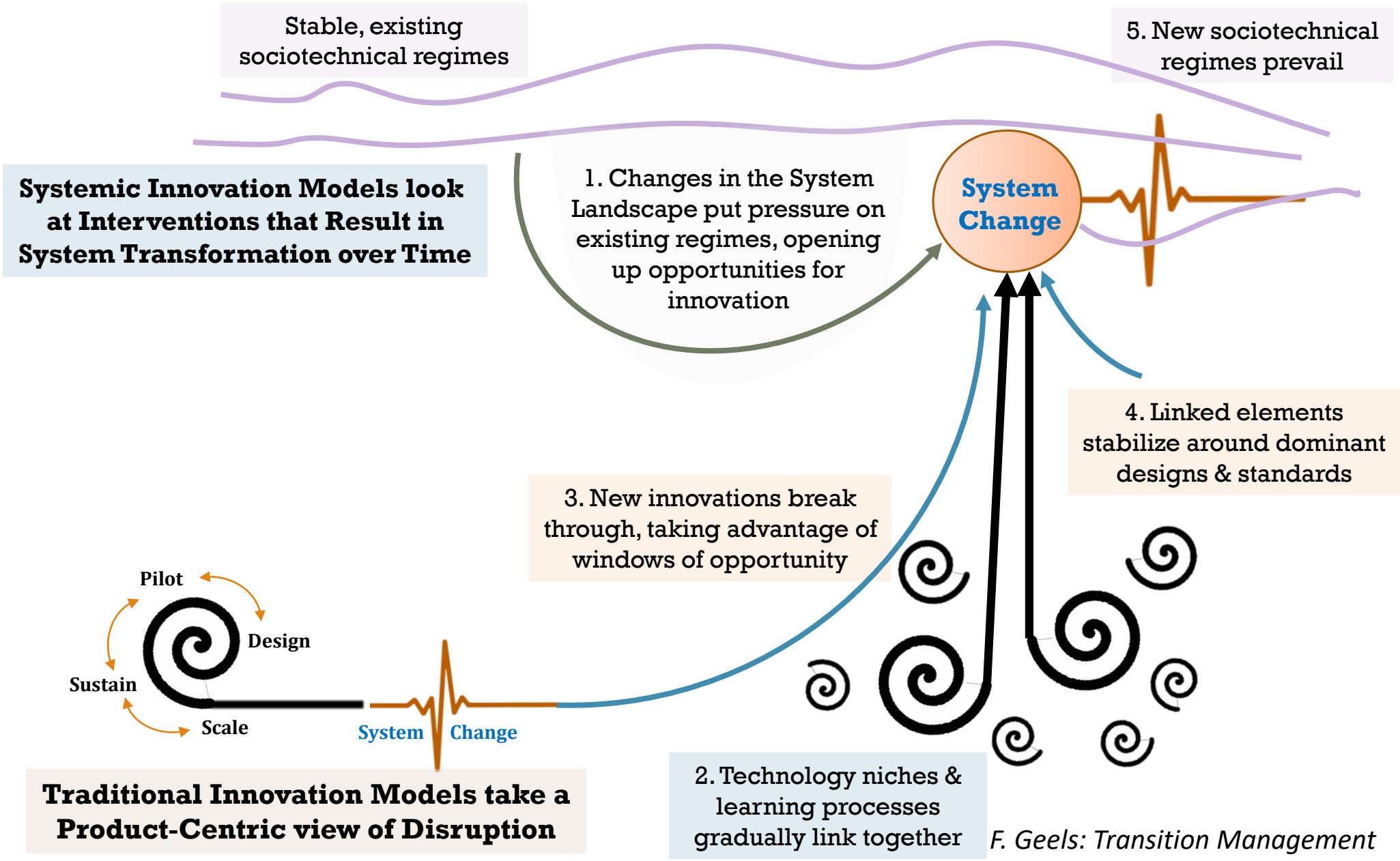
Bud Larsen: Universal Mental Model of a System

Innovation-driven Transitions



Traditional Innovation Models take a Product-Centric view of Disruption

Innovation-driven Transitions



SoS Analysis Framework
(with a nod to Dan Delaurentis and Bill Rouse)

Perspectives: a stakeholder research process best informed by **talking to stakeholders** but that also can be created with selected readings that highlight emergence.

Definition: a systems thinking oriented process to define **context** (or boundaries of analysis), appropriate levels of analysis, and **enablers or barriers** that might exist in the context of interest.

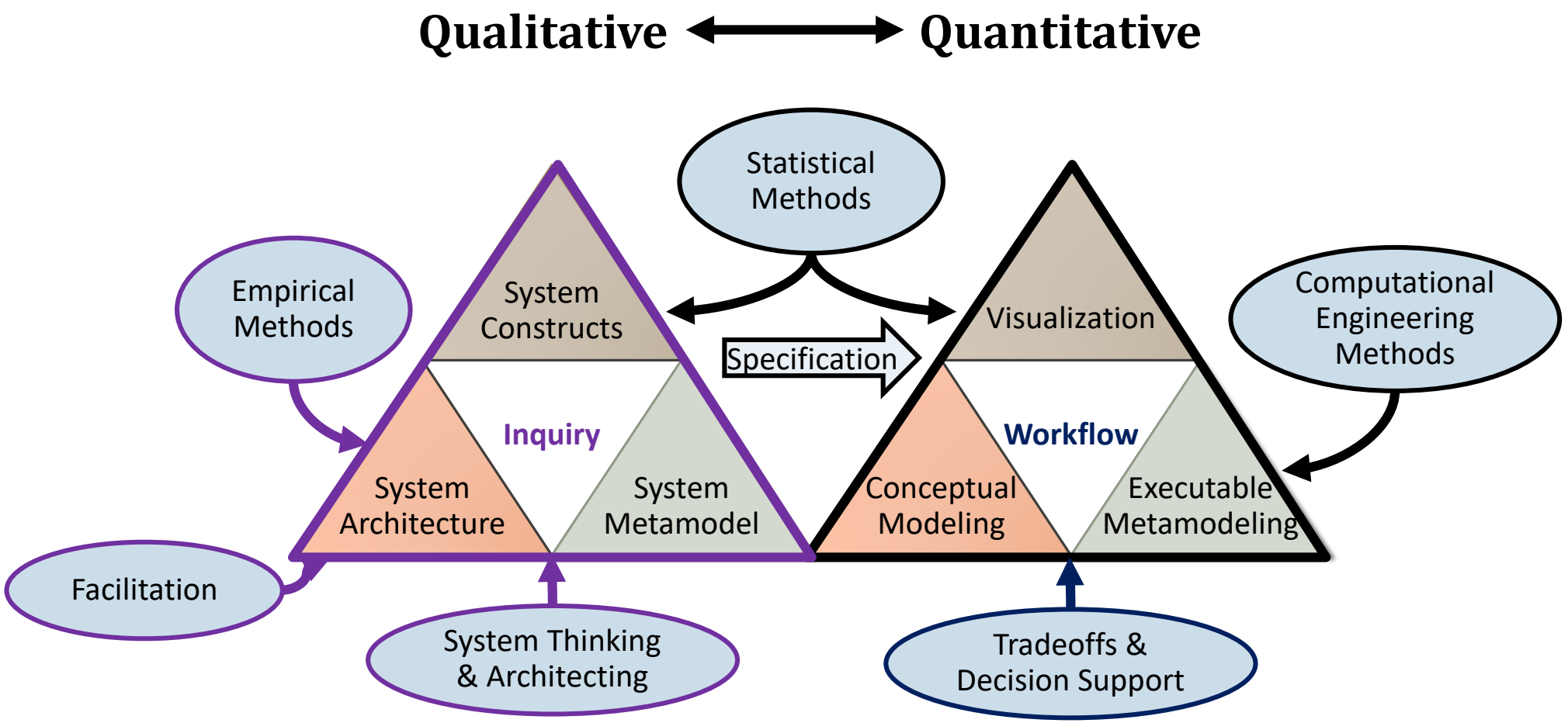
Multi-Layer Abstractions: identifies all of the actors at each societal layer and "what they bring with them" - what **abstractions** would represent primary performance measures of the current SoS and the desired evolution.

Implementation: build a model of all dimensions considering system outputs, outcomes (or goals), and the **interactions** that cause them.

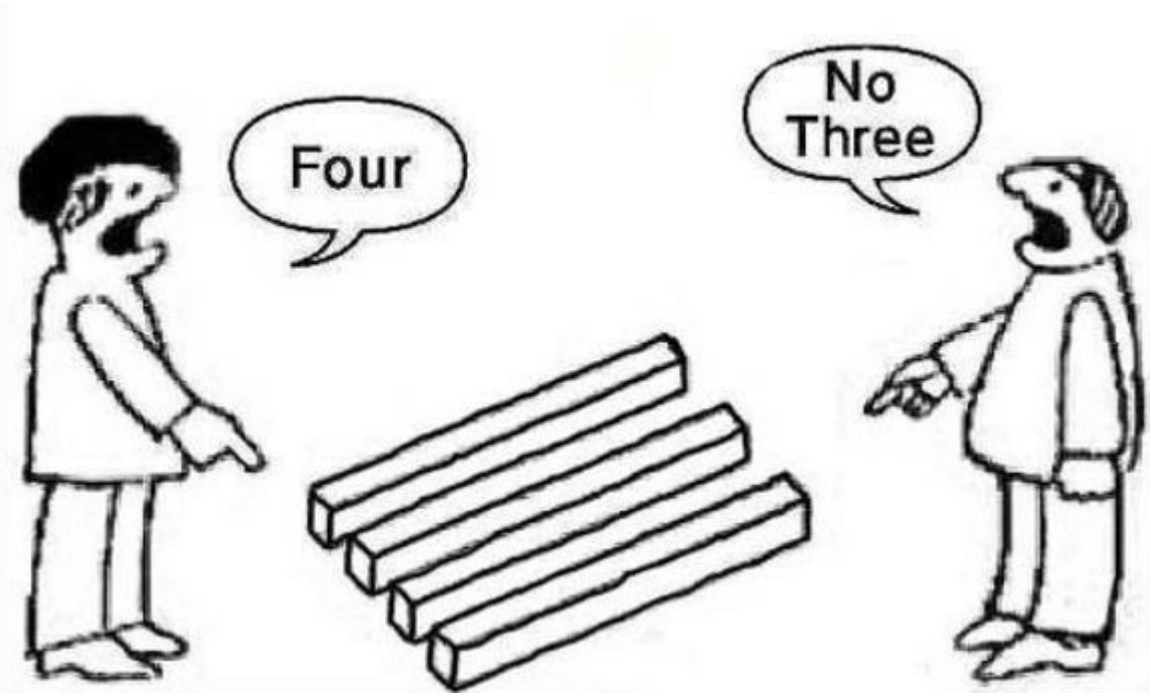
Communication: information flows that are relevant to decision making in the SoS. This should include **transparency** (availability to all parts of the system), **timeliness** (to make decisions), **accuracy**, and **trust**.

Outcomes: goals, interactions, and leading indicators of change which are necessary to evaluate evolutionary choices in the SoS.

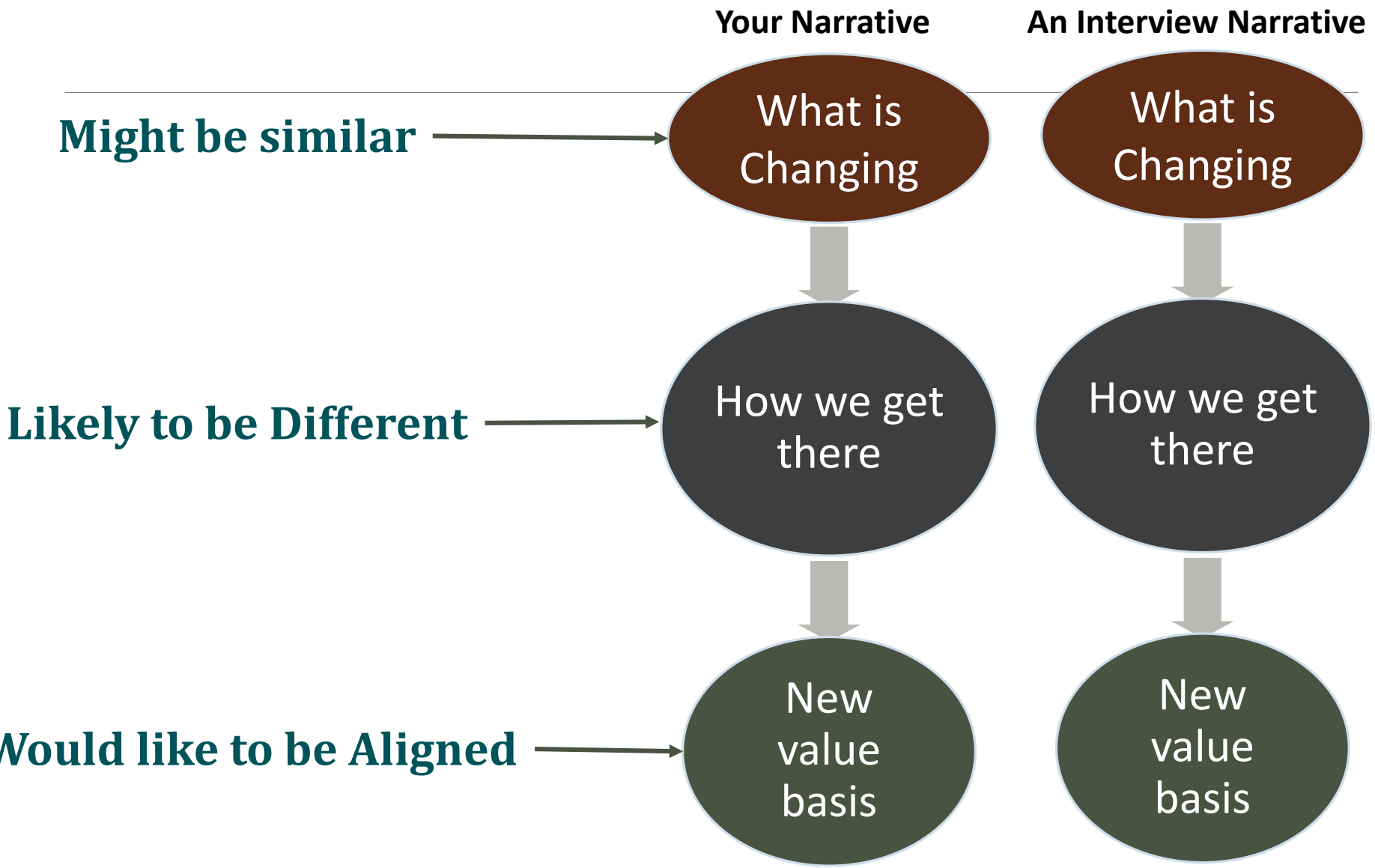
SoS Metamodel: Bridging Systems Thinking and Systems Engineering



SoS Perspectives



SoS Perspectives: Using Interviews and Narrative to Conceptually Map the System



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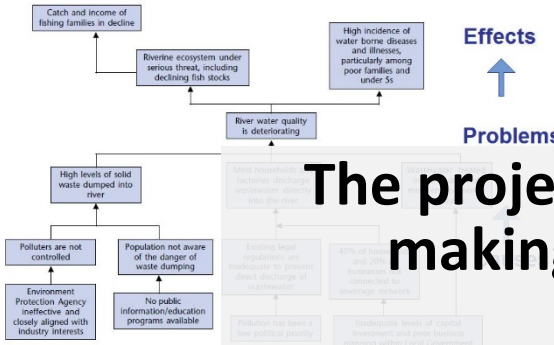
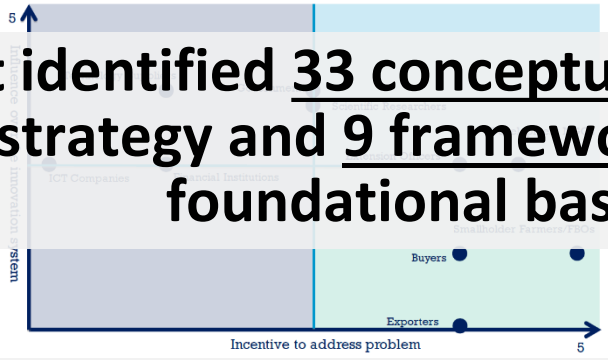
Examples of Tools

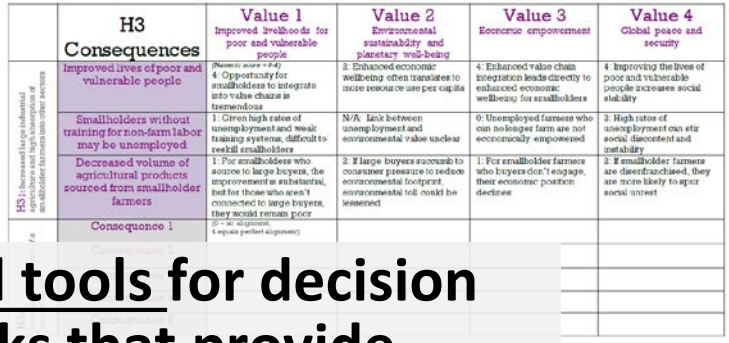
Objectives Tree Analysis



Influence and Incentives Scoring Table



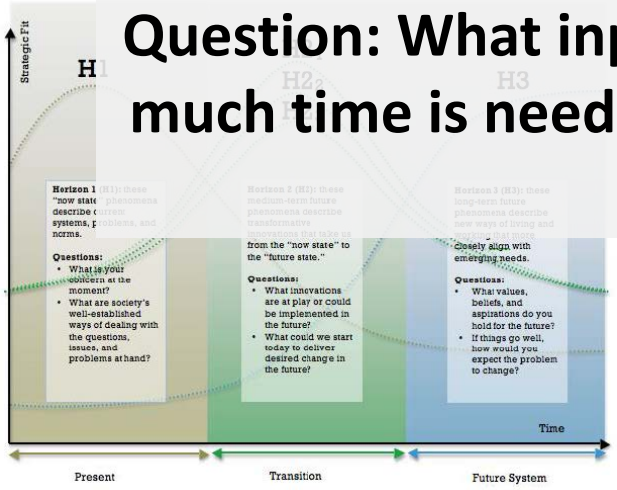
Values Map



	H3 Consequences	Value 1 Improved livelihoods for poor and vulnerable people	Value 2 Environmental sustainability and planetary well-being	Value 3 Economic empowerment	Value 4 Global peace and security
H3: Increased large industrial and smallholder farmers into other sectors	Improved lives of poor and vulnerable people	(Numeric score = 0-4) 4: Opportunity for smallholders to integrate into value chains is tremendous	3: Enhanced economic wellbeing often translates to more resource use per capita	4: Enhanced value chain integration leads directly to enhanced economic well-being for smallholders	4: Improving the lives of poor and vulnerable people increases social stability
	Smallholders without training for non-farm labor may be unemployed	1: Given high rates of unemployment and weak training systems, difficult to reskill smallholders	N/A: Link between unemployment and environmental value unclear	0: Unemployed farmers who can no longer farm are not economically empowered	2: High rates of unemployment can stir social discontent and instability
	Decreased volume of agricultural products sourced from smallholder farmers	1: For smallholders who source to large buyers, the improvement is substantial, but for those who aren't connected to large buyers, they would remain poor	2: If large buyers succumb to consumer pressure to reduce environmental footprint, environmental toll could be lessened	1: For smallholder farmers who buyers don't engage, their economic position declines	2: If smallholder farmers are disenfranchised, they are more likely to spur social unrest
	Consequence 1	(0 = no alignment, 4 equals perfect alignment)			

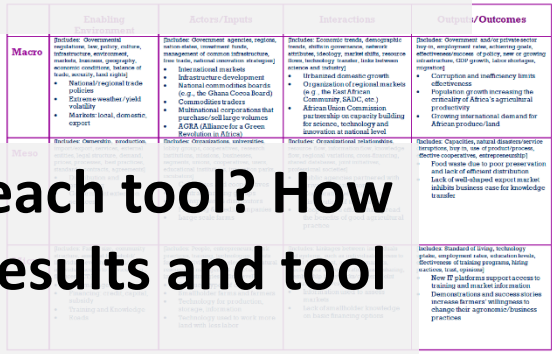
The project identified 33 conceptual tools for decision making strategy and 9 frameworks that provide foundational basis.

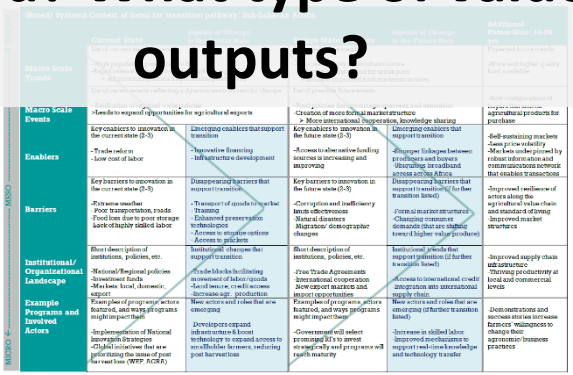
Three Horizons Map



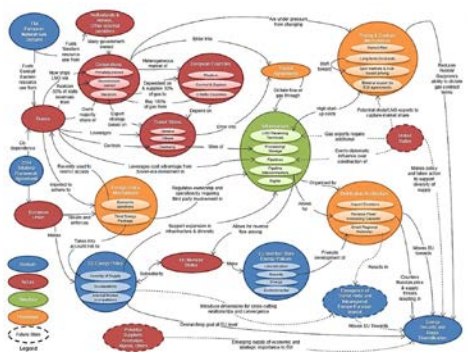
Question: What inputs are required to run each tool? How much time is needed? What type of value results and tool outputs?

Context Analysis





Systemigram



Key Toolset Elements

Inputs

Facilitator

A facilitator enables users to effectively deploy certain tools.

Workshop

Participant interaction and stakeholder engagement on a tool.

Literature Review

Reviewing various literature sources (reports, databases) to support sensemaking.

Stakeholder Interviews

Interviewing subject matter experts for pertinent stakeholder perspective.

Data from Other Tools

Insights and data produced from previous tool inform the use of subsequent tools.

Time

Minimal Time Requirement

- Less than 1 week

The tool requires minimal time commitment to planning, implementation and follow-up.

Moderate Time Requirement

~ Between 1 and 4 weeks

Depending on the system complexity, more commitment might be needed for interviews, data gathering, and analysis.

Significant Time Requirement

+ More than 4 weeks

More substantial commitment and time investment is needed for stakeholder engagement and tool iteration process.

Value

Convergence between Stakeholders

Align participants and decision making activity.

Input into Subsequent Tool

Data and insights feed into other tools.

Prioritization of Key Ideas

Supports prioritization of ideas and strategy.

Foresight Assessment

More foresightful perspectives harnessed.

Threat Assessment

Richer understanding of threats.

Insight into Complex System

Provides clarity on systems layers and behaviors.

Capability and Gap Assessment

More clarity on capabilities and gaps.

Pathways for Decision Making

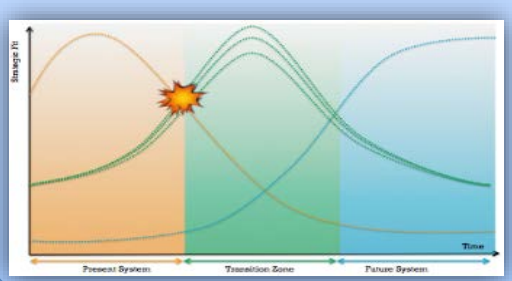
Supports strategic decision making.

Stakeholder Facilitation Toolset

GLOBAL KNOWLEDGE INITIATIVE

Futures Map

- Captures evidence about current problem space, desired future, and possible transitions in between
- Helps users identify innovation paths poised to drive transitions

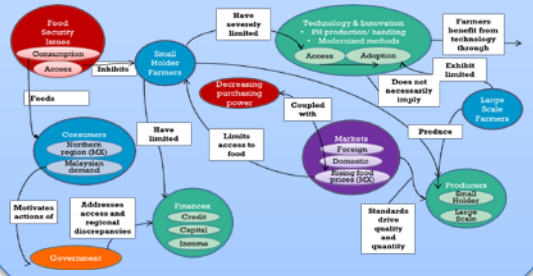


Context Analysis

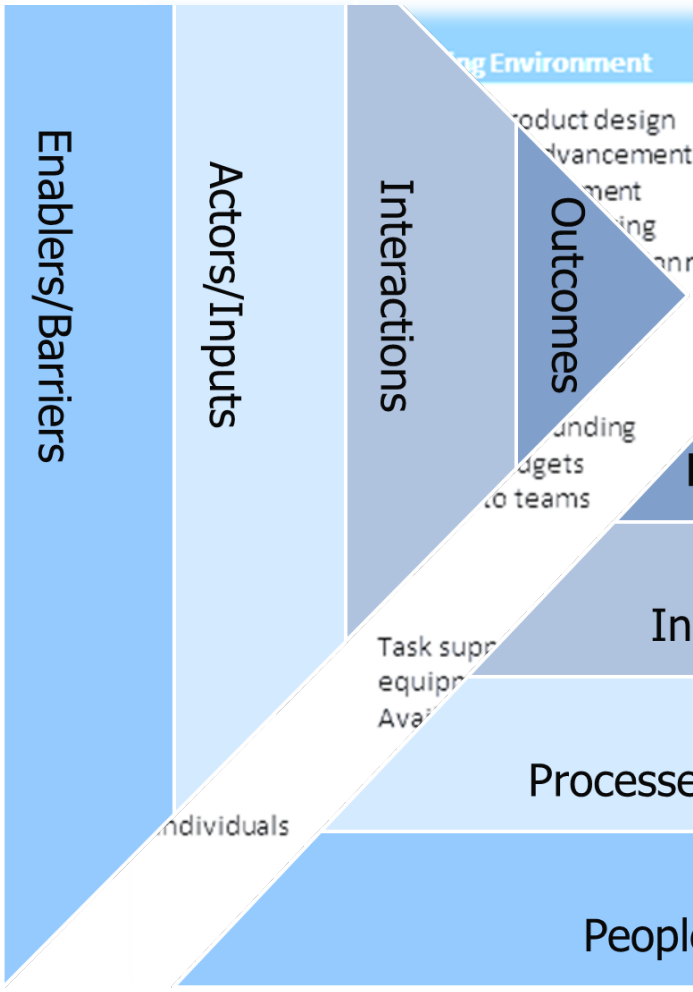
- A Sociotechnical Systems Taxonomy
- Captures Entities & Relationships & Outcomes at multiple levels
- Helps users identify general & contextual relationships

Systems Map

- Visualizes entities, environment, interactions, and phenomena / patterns in the system at any level
- Integrates semantic and visual models of complex systems

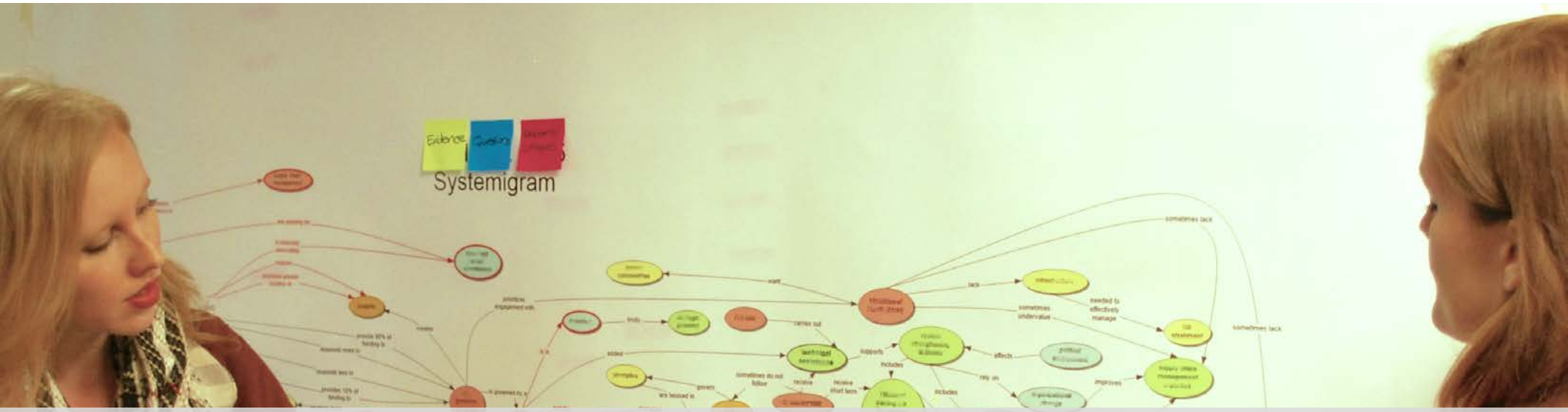


Context Analysis Tool



Environment	Actors (and what they bring with them)	Interactions/ Activities	Outcomes
oduct design dvancement ment ing nrates	Engineering/Design needs Market complexity Supply chain complexity Political Influence Skill specialization	Changing threat Defense budgeting/ political process Defense policy changes Related markets	Market growth or decline Technology outsourcing (domestic or foreign) R&D funding growth or decline Number of suppliers/sources of supply Ability to address threat
unding dgets o teams	Product portfolios Market access ket position chain position sources facilities	R&D spending Capital spending on R&D Sales Partnerships/ teaming Subcontracting	Innovation R&D Intensity (R&D spending as a % of sales) Market position Profitability Program performance
Task supp equipm Avai	cs physical nce	Training Mentoring Feedback on performance Design activities	Team skill acquisition Team Skill Decay Skill reconstitution time Team task performance
ndividuals		Initial skills Availability of tasks Task speed Longevity of teams	Skill acquisition Skill obsolescence Skill Decay Task Performance

The Systemigram and Emergence Narratives



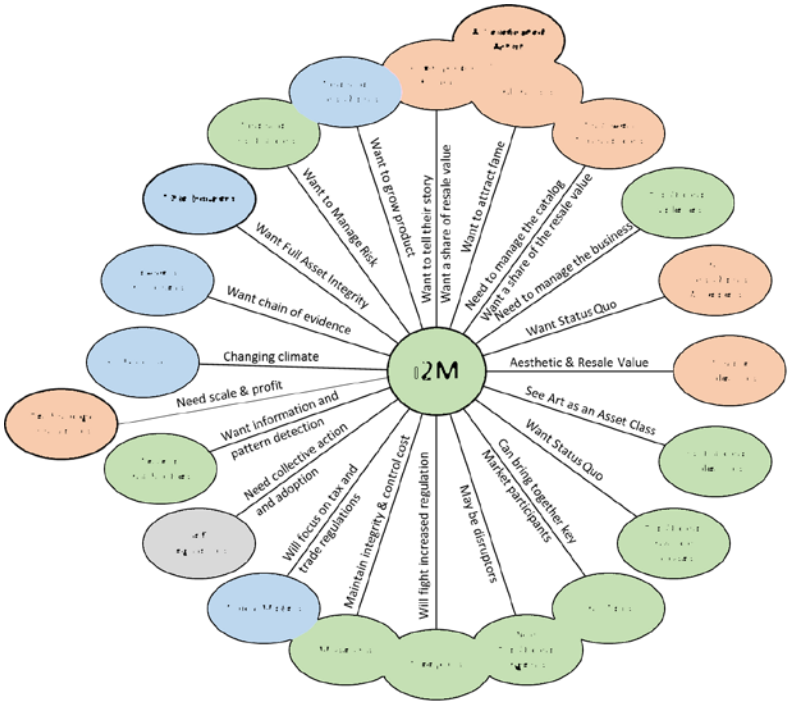
\+ Interactive Systemigram
Stakeholder Discussions of Misaligned Incentives
Stakeholder Discussions of System-Wide Enablers and Barriers

= Real-Time Incentive Alignment & **Real-Time System Change**

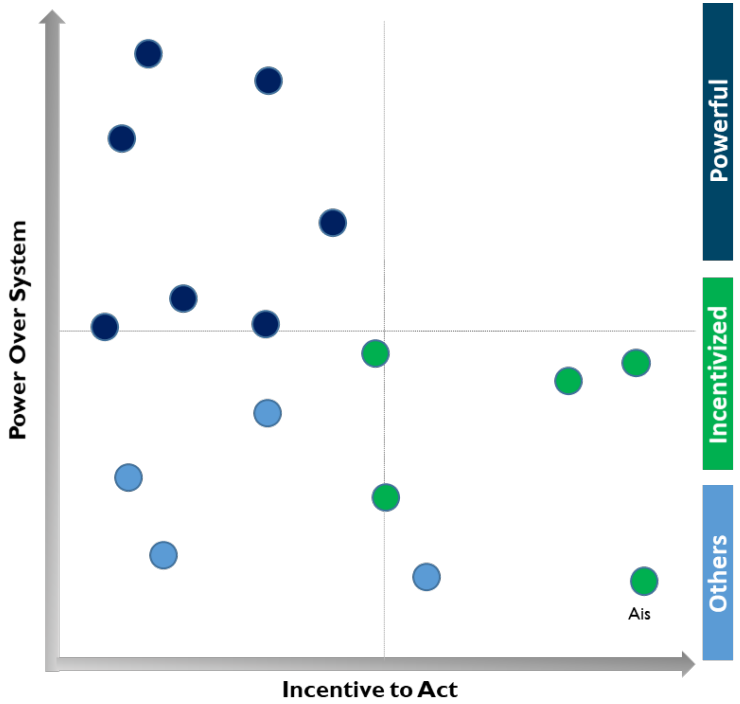
The tension between perceptions and facts often form the best starting place to understand the behaviors in a sociotechnical system

Mark Meier: Architecture Heuristics

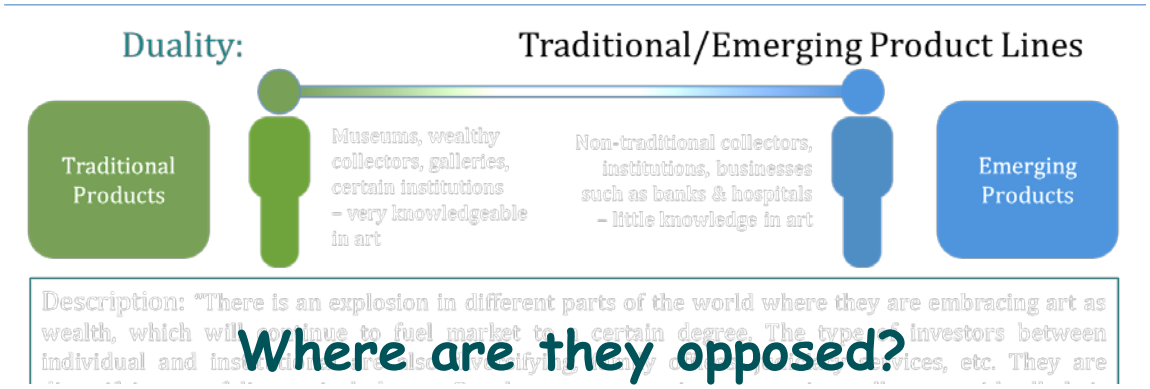
Stakeholder Analysis



What do they value?



How will they influence?



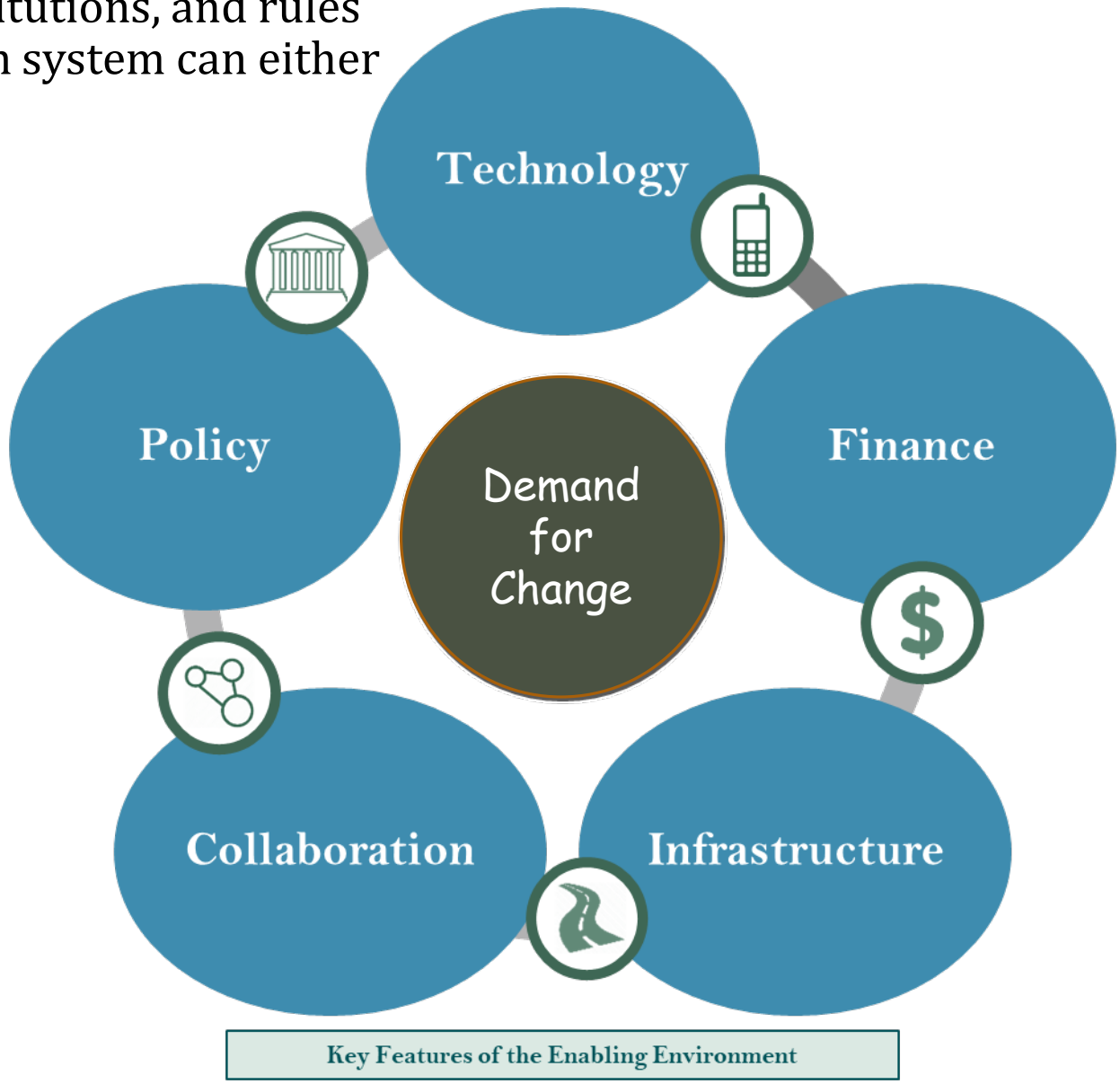
Where are they opposed?

Innovation System Analysis

The players, resources, institutions, and rules that comprise an innovation system can either enable or block innovation.

+ Key Enablers to Innovation

- Key Barriers to Innovation



Key Features of the Enabling Environment

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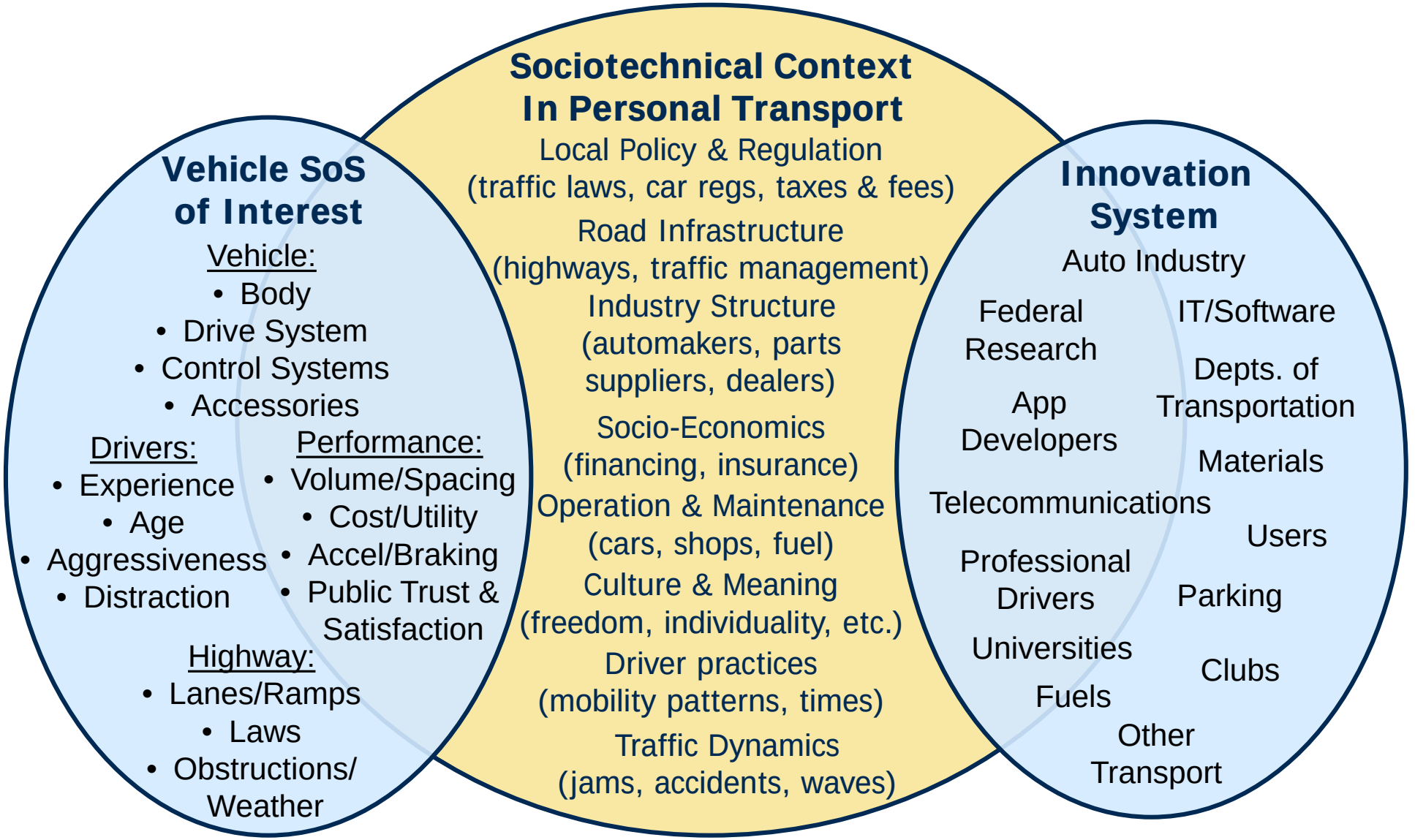
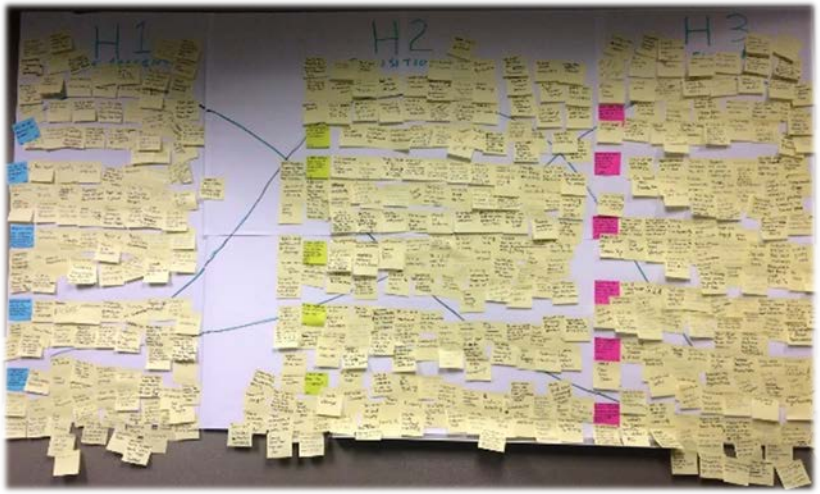
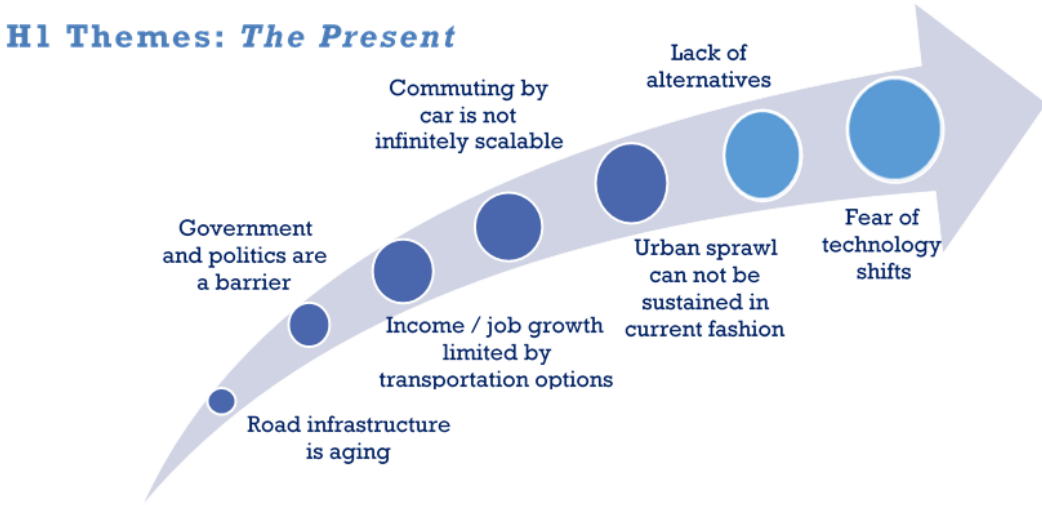
3-System Model for Transportation

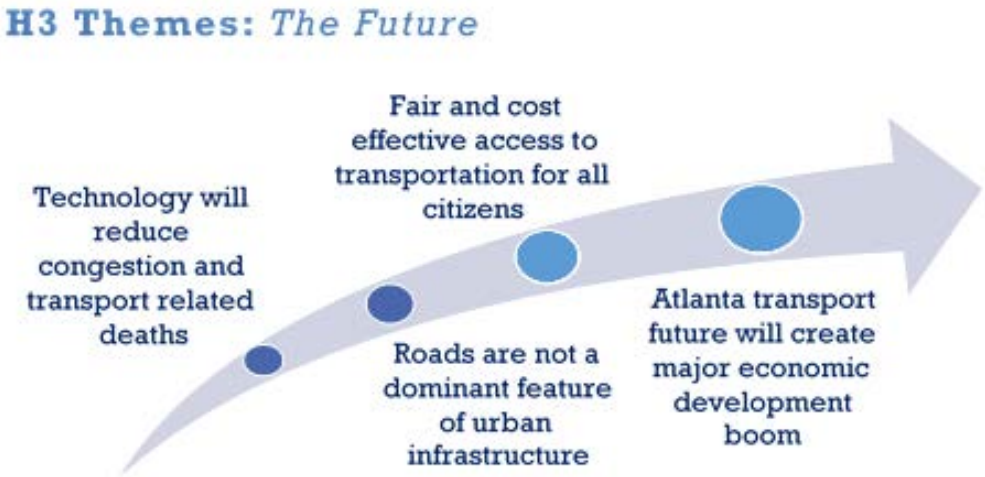


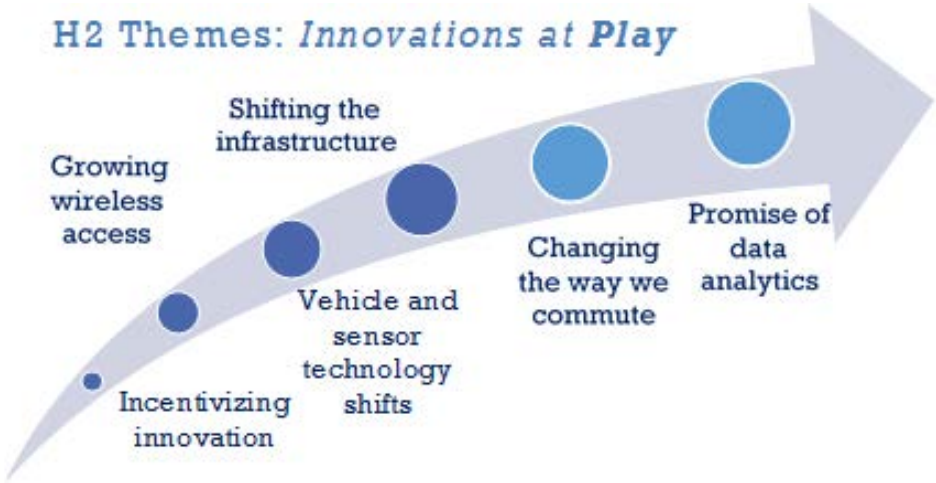
Three Horizons Workshop

Case study: Internet of Things & Transportation in Atlanta

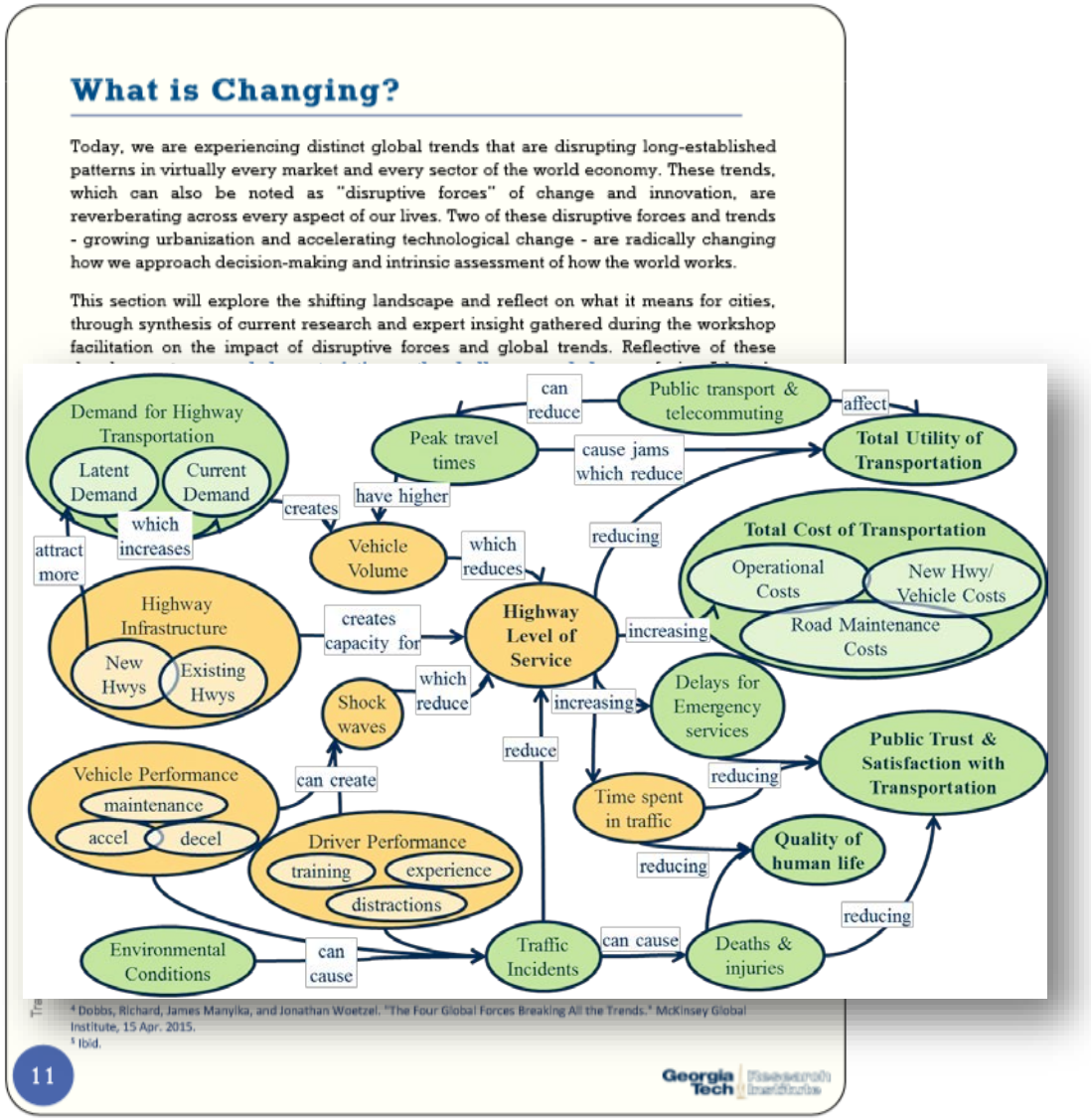








Systemigram for Highway Transportation Improvements



- Systemigram (Boardman & Sauser) is used to map the SoS interrelationships
- Narrative form expresses emergence
- Diagrammatic form expresses structure
- Interrelationships captured to equivalent measures of change

Self-Driving Cars: Transition Matrix (Geels)

GLOBAL KNOWLEDGE INITIATIVE

(Broad) Systems Context of focus for transition pathway

MICRO ←---------- MESO ----------→ MACRO

	Current State	Signals of Change to the Future State	Future State	Signals of Change to the Future State	Additional Future State
Macro Scale Trends	• Rapid increases in Automation • Sharing Economy • Growth in Machine Learning Tech		• Local laws/incentives shift to encourage automated car use • Automakers move from sales to service		Additional transition states if needed
Macro Scale Events	• Relocation to Urban Hubs • Examples of Fragile Road Infrastructure		• Driverless Car Disasters • Traffic gets better, or worse? • Commercial goods transport models		
Enablers	• Low cost sensors Broad Information Access • Advances in Machine Learning	• Initiatives to Attract Innovators • Gradual feature introduction	• Vehicle-to-Vehicle • Smart roads • New transport layouts	• Shift in highway patterns • Car sharing clubs	
Barriers	• Existing laws and regulations • Relative immaturity of technology • Fear of Tech	• Carmakers jumping to change	• Loss of jobs • Pushback for freedom to drive • Cars used as terror weapons	• Tech safety record • Insurance models • Job creation	
Institutional/ Organizational Landscape	Local government, carmakers, insurers, commuters, etc.	• Local laws allow • Venture capital	Fed Highway transition, urban planners, car ownership co-ops	• Growing comfort with automation • Localities outlaw drivers	
Example Programs and Involved Actors	Google Car, Gov't funds for studies, increasing R&D capital, Local government Initiatives	• Google Car • Tesla AutoPilot • Zoox Robotic Taxi	Local DoT tolls incentives to change patterns, taxi models change, Commercial vehicle shifts	• New transport hub models reflect urban hubs	

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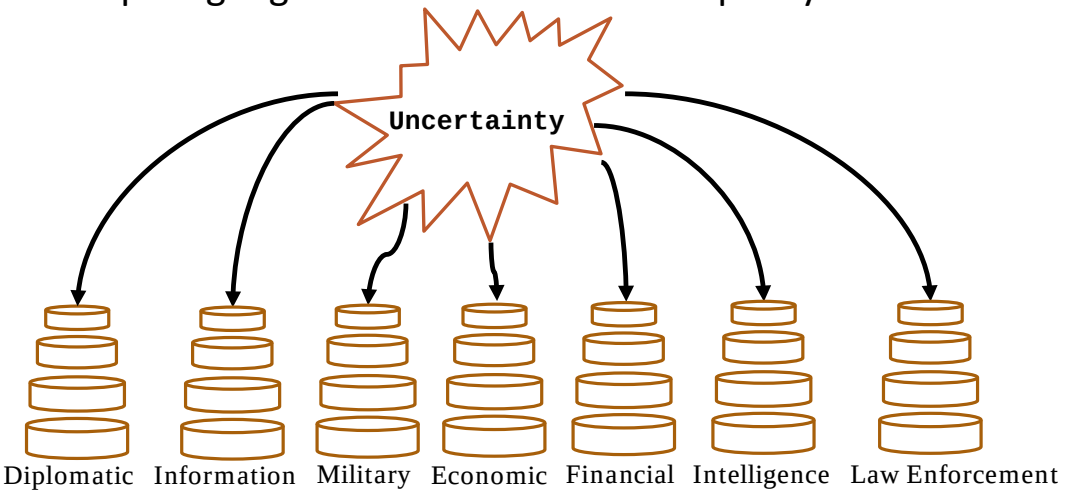
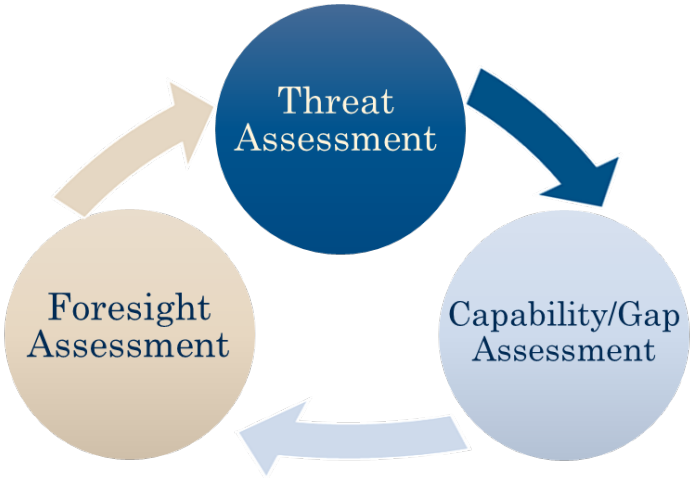
Introduction to the Context

- The novelty of the approach does not rest in a single analytic method, tool, or a unique dataset.
- *First year* focused on identifying conceptual tools, and documenting and testing them. *Second year* focuses on bridging the qualitative tools to quantitative tools.
- Create a "playbook" for decision- making strategy and conducting research, designed to address complex problem spaces
- Improved methods to address problems that grapple with uncertainty.
- Develop language and tools that connect policy domain with engineering and tech domain.

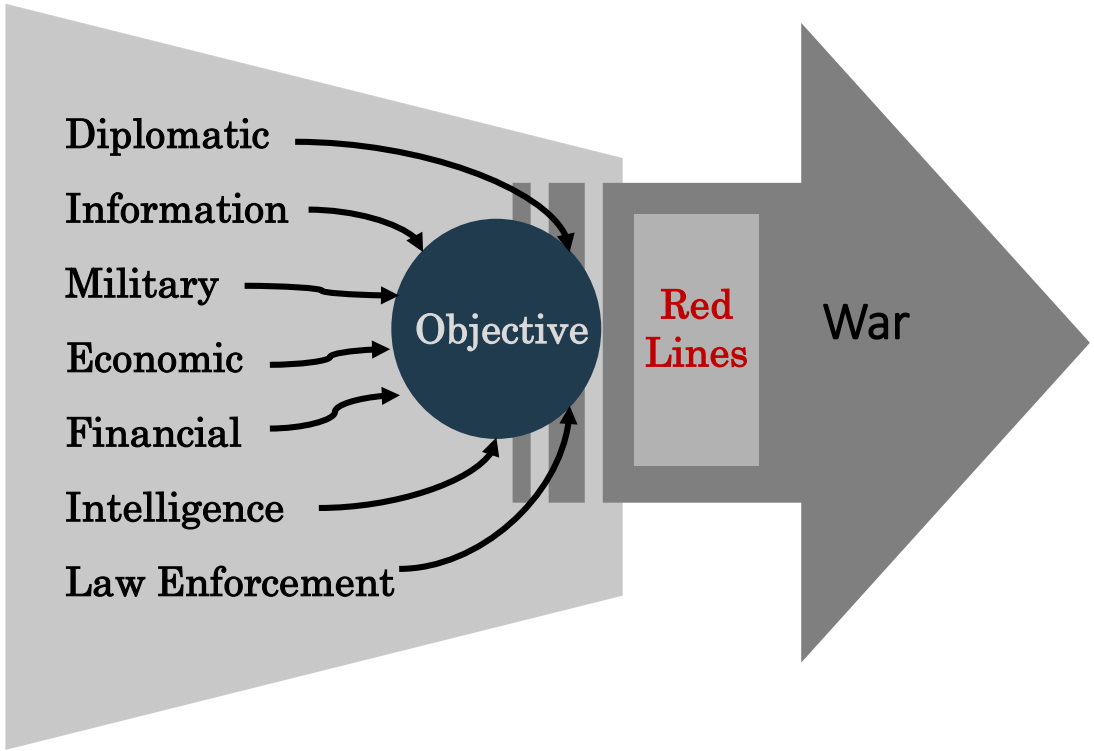


Policy planners, strategists, or military doctrine tend to categorize complex systems into silos, in attempt to reduce complexity via scientific approaches, reductionism, and structure. This breaks down relationships, behaviors, interactions, destroys linkages across space and time, and through over-simplification promises a false reduction of uncertainty.[1]



Context: Gray Zone Conflict

Gray Zone warfare:
The ***purposeful***, ***aggressive***, ***ambiguous***, and ***integrated*** use of multiple elements of power to achieve political or economic objectives, by a state or non-state actor, exceeding the threshold of normal national competition yet falling below the level of major interstate war.

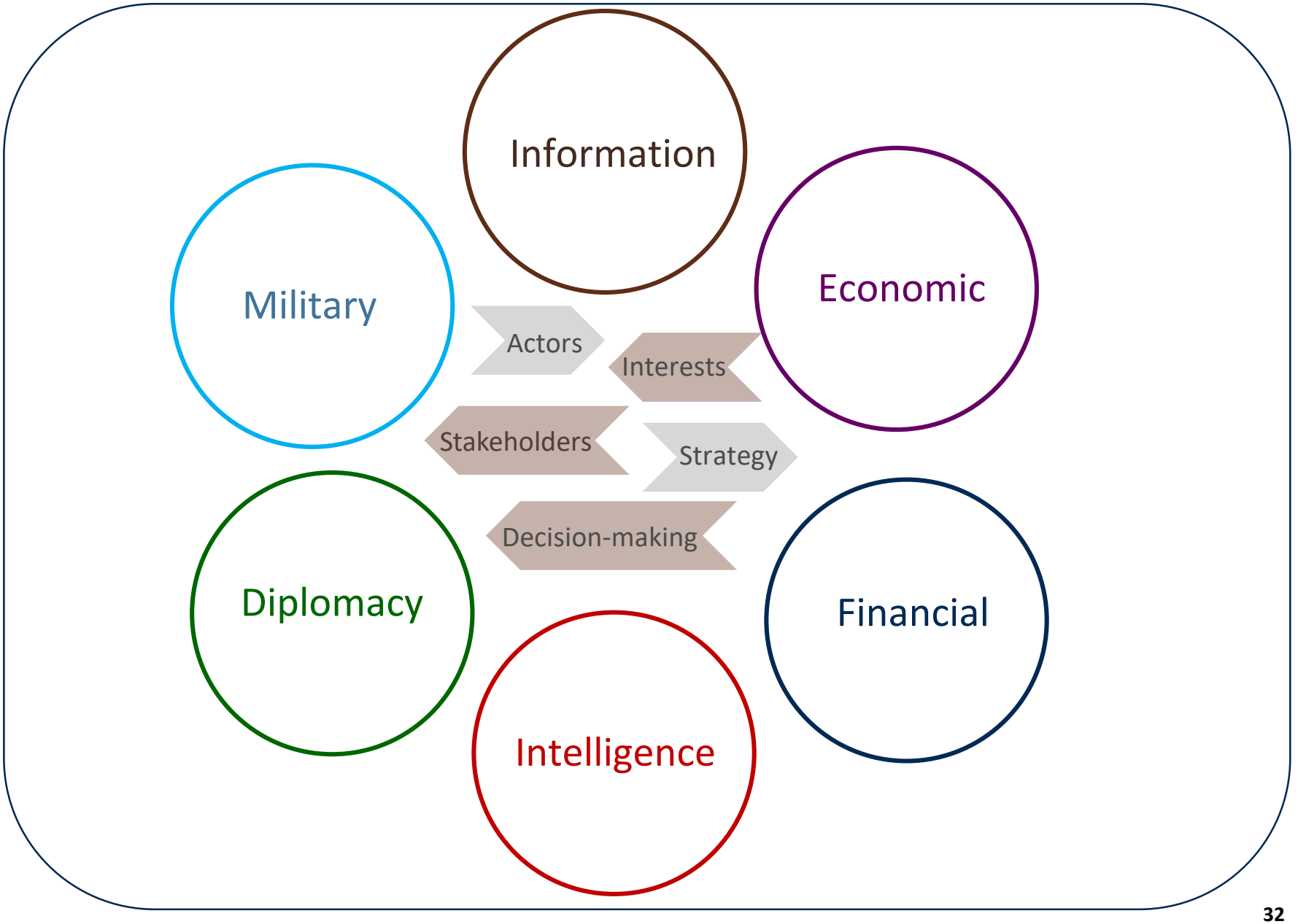


"War below the lines"

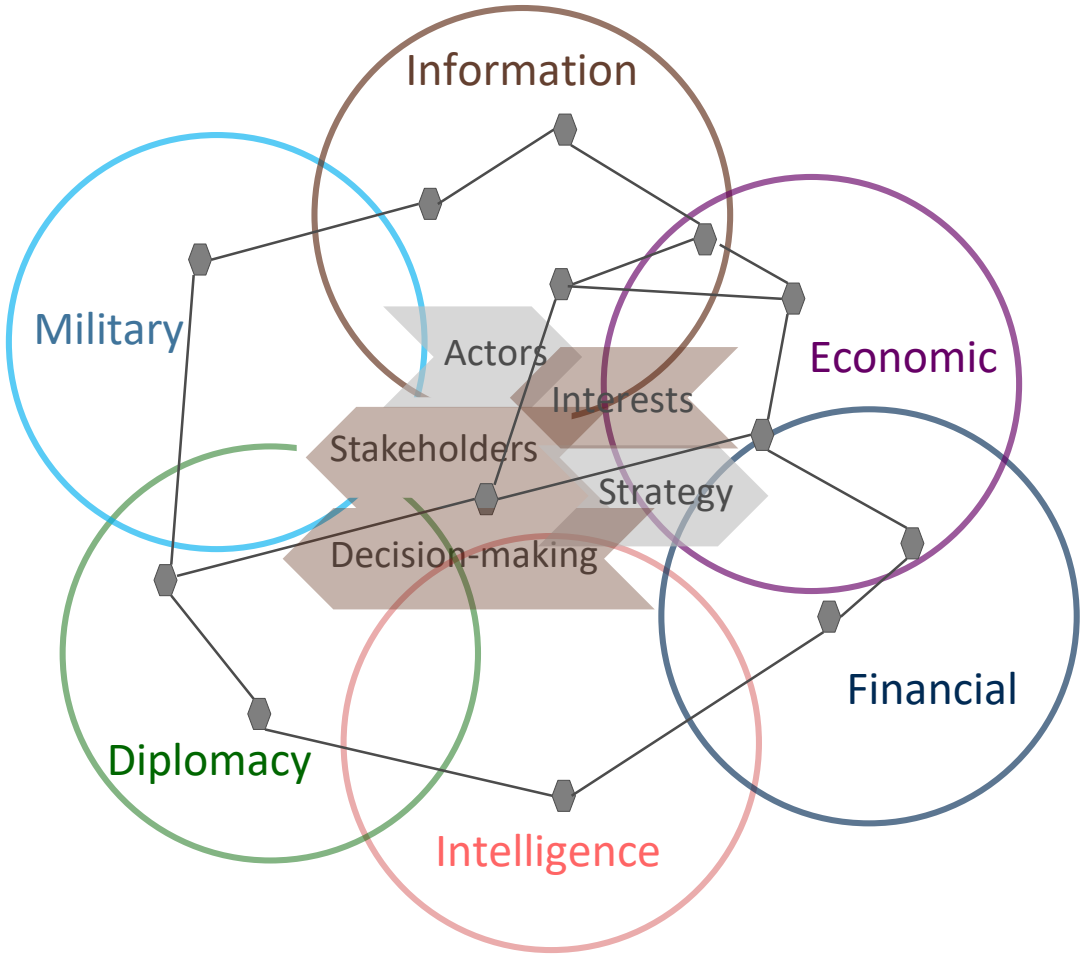
Case Study: Moldova & Georgia

- Gaps in understanding links between Russian leadership's *stated objectives* vs. Russia's *actual foreign and security behavior*
- Both countries are gray zone conflict areas
- Russia's intervention in Ukraine pretext for Moldova & Georgia?
- Results capture emerging trends in the complex system that may not be obvious without a systemic analysis and capture gaps in existing literature, or predictive models of system performance.

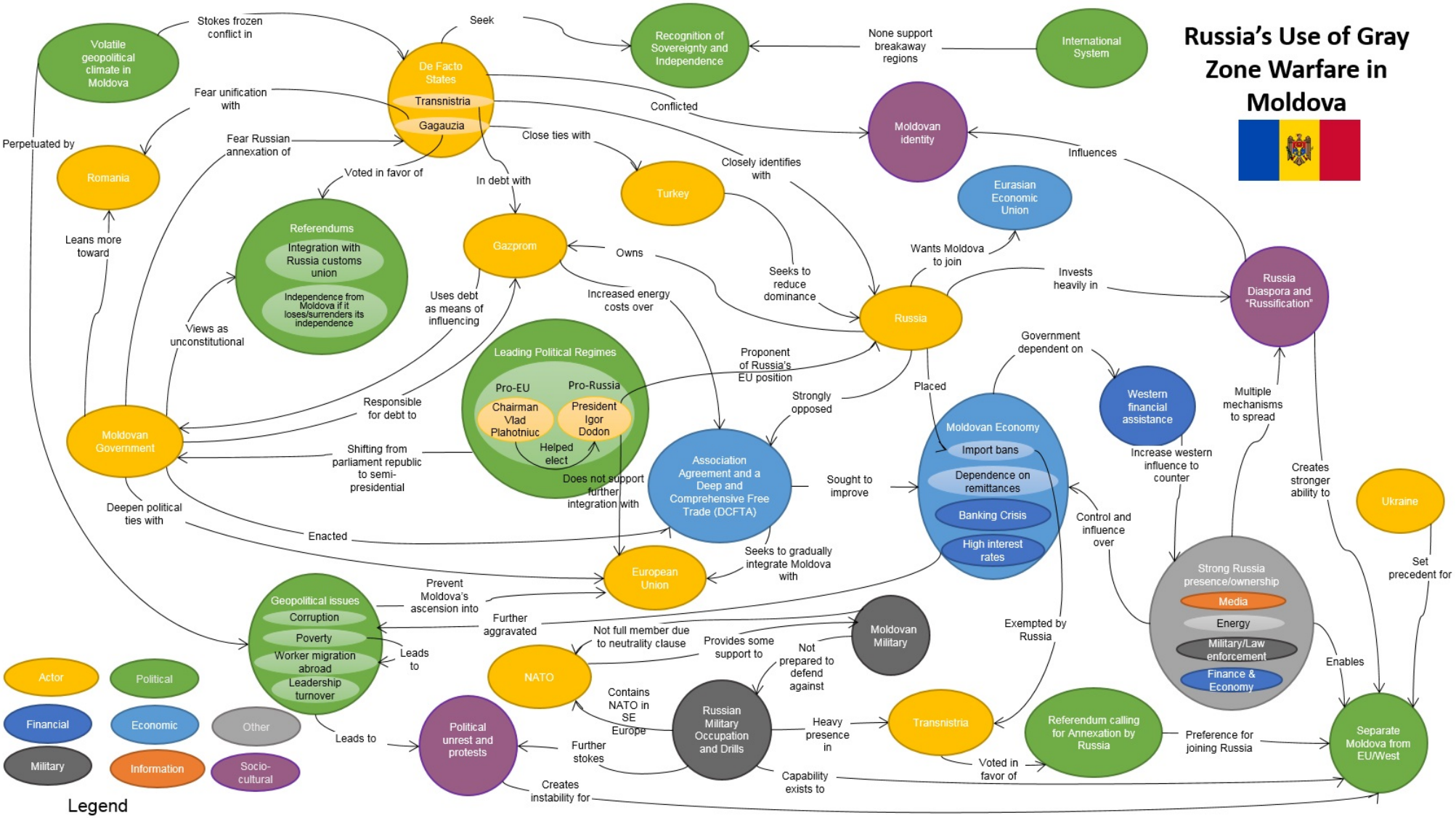
Gray Zone Conflict: Complex system analysis



Gray Zone Conflict: Complex system analysis



Example Diagram (Systemigram)



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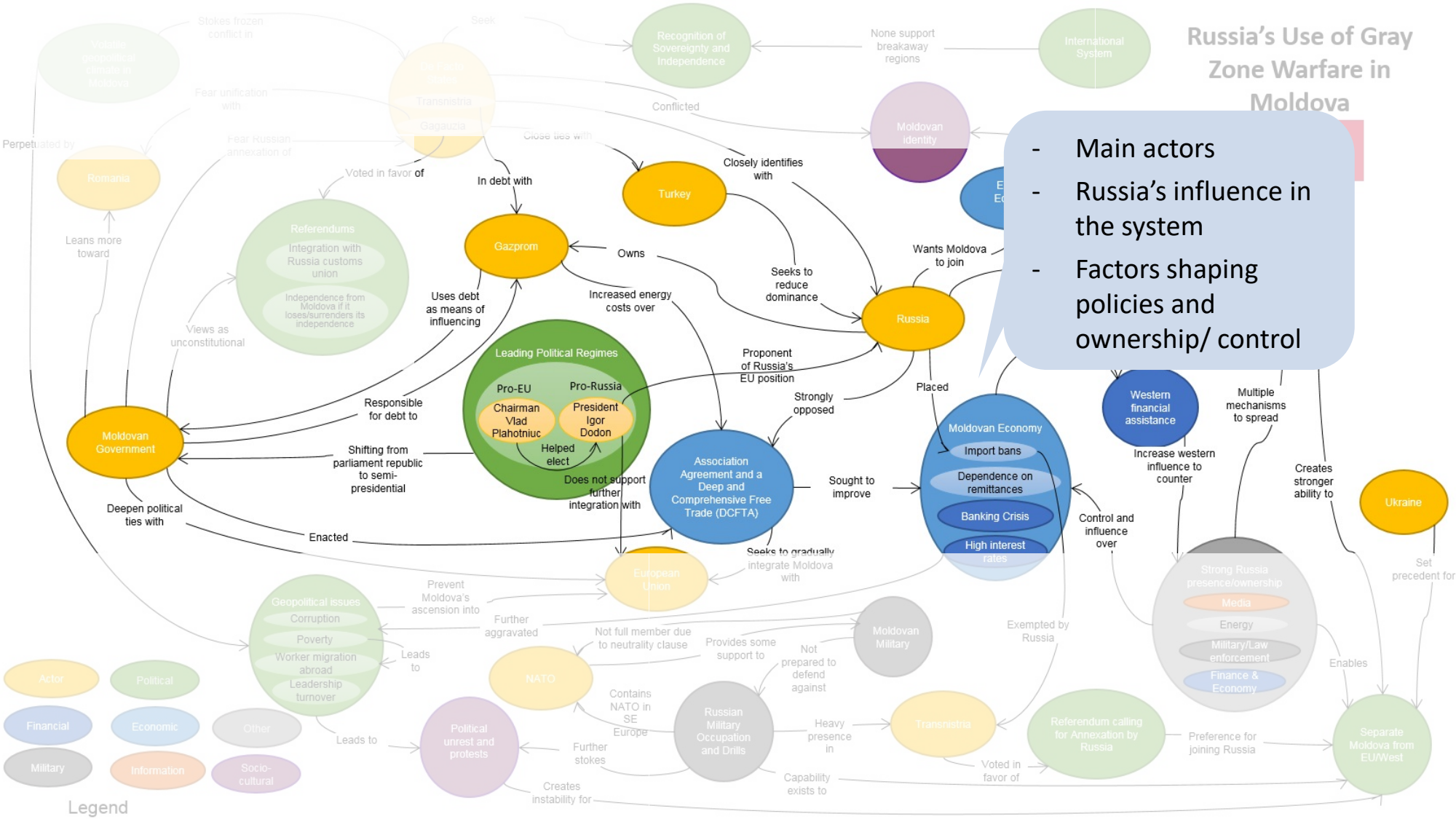
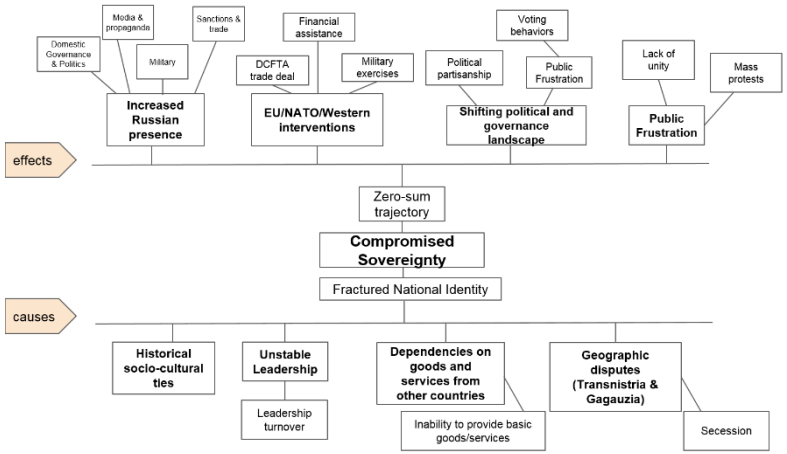
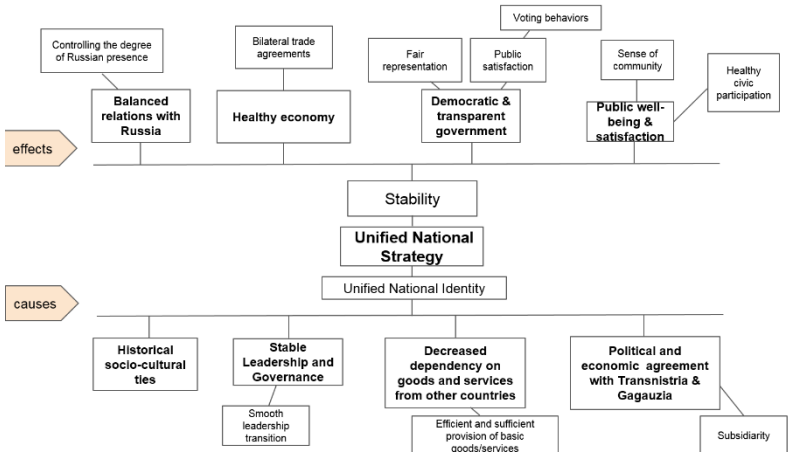


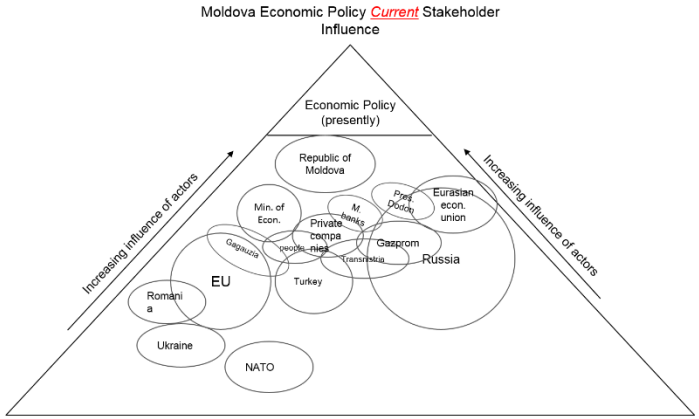
Other tools tested

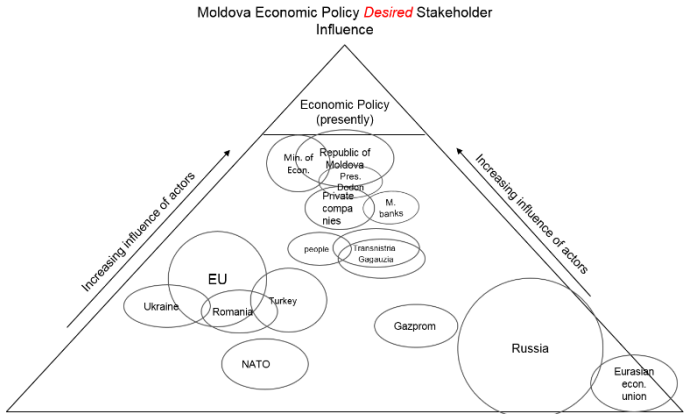
Problem and objectives tree





Stakeholder influence map



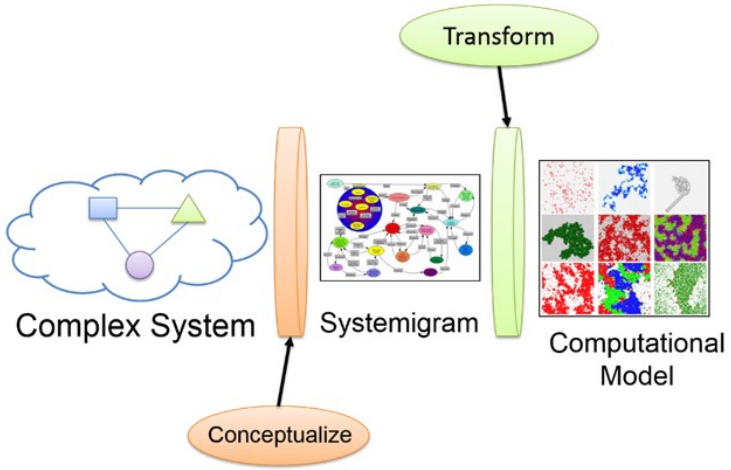


OUTLINE

- Introduction
- The 3-Systems Model
- Introduction to the Toolset
- Case study #1: Transportation & IoT
- Case study #2: Gray Zone Conflict
- **Current Research**
- Wrap up and Next Steps
- Conclusion

Current Research

- Transforming systemigrams into quantitative models
- Growing number of coding software and data tools to automatically extract stakeholders, sentiments, and events from multi-lingual databases and media publications on daily/real-time bases.



- Probe and test hypotheses against assumptions with conceptual tools and multilingual text-analytic techniques (using GDELT).
- Identify emergent correlations of sentiments and events behavior.
- Explore additional toolset computational & quantitative linkages: systems dynamics, social network, discreet event simulation, statistical modeling
- **Research objective: The goal is a new generation of management planning and decision analysis tools that combines qualitative and quantitative approaches.**

The GDELT Database

- Global Database of Events Language and Tone
  - www.gdeltproject.org
- Contains events extracted from online news sources
- An Event contains:
  - two actors
  - the action
  - source url of a news article
  - geographic information
  - temporal information
- A source of recent news articles on the web
- Commonly used in computational database of society level behavior
- Events coded into Conflict and Mediation Event Observations (CAMEO) system, while capturing the world media through machine coding in near real-time

13	THREATEN
130	Threaten, not specified below
131	Threaten non-force, not specified below
1311	Threaten to reduce or stop aid
1312	Threaten to boycott, embargo, or sanction
1313	Threaten to reduce or break relations
132	Threaten with administrative sanctions, not specified below
1321	Threaten to impose restrictions on political freedoms
1322	Threaten to ban political parties or politicians
1323	Threaten to impose curfew
1324	Threaten to impose state of emergency or martial law
133	Threaten political dissent, protest
134	Threaten to halt negotiations
135	Threaten to halt mediation
136	Threaten to halt international involvement (non-mediation)
137	Threaten with violent repression
138	Threaten to use military force, not specified below
1381	Threaten blockade
1382	Threaten occupation
1383	Threaten unconventional violence
1384	Threaten conventional attack
1385	Threaten attack with WMD
139	Give ultimatum

CAMEO Event Code 13 (THREATEN), with lower-level codes

Node 1	Node 2	Link	Actor 1 Code	Actor 1 Name	Actor 2 Code	Actor 2 Name	Event Code
Russia	Opposing Political Regimes: President Igor Dodon	Developing closer ties to	RUS	RUSSIA	MDA	DODON	019: Express accord
			RUS	RUSSIA	MDA	DODON	030: Express intent to cooperate
			RUS	RUSSIA	MDA	DODON	032: Express intent to engage in diplomatic cooperation
Russia	Moldova Economy: Import bans	Implemented to prevent EU export deception	RUSGOV	RUSSIA	MOLGOV	MOLDOVA	163: Impose embargo, boycott, or sanctions
			RUS	RUSSIA	MDA	MOLDOVA	163: Impose embargo, boycott, or sanctions
			RUSGOV	RUSSIA	IGOEUREEC	EUROPEAN UNION	163: Impose embargo, boycott, or sanctions
Russia	Moldovan migrants	Clearing entry for more	RUS	RUSSIA	MDA	MOLDOVAN	075: Grant asylum
			RUSGOV		MOLLAB	MIGRANT WORKER	073: Provide humanitarian aid
			RUSGOV		MOLLAB	MIGRANT WORKER	080: Yield
			RUS	RUSSIA	CVL	MIGRANT WORKER	075: Grant asylum
			RUS	RUSSIA	CVL	MIGRANT WORKER	073: Provide humanitarian aid

Adapting Systemigrams to GDELT/CAMEO coding

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Wrap-up & Next Steps

- Being empowered with the appropriate toolset will enable decision-makers to analyze how best to intervene in ever-changing complex systems.
- This research seeks to further develop a threat analysis framework by establishing formal documented research methods to effectively combine conceptual and computational tools.
- Probed and test hypotheses and techniques against assumptions with conceptual tools and multilingual text-analytic techniques (using GDELT)
- Identify emergent correlations of sentiments and events behavior
- The end-product will capture current features and possible evolution of gray zone conflict & other complex problem spaces for more foresightful decision-making strategy.
- In the latter phases of the research, the goal is to explore new and additional datasets and tools that can emerge from this research.

Conclusion

- Few truly directed or acknowledged SoS
- Need tools to capture more complex views of SoS emergence
- Applied to a diverse set of SoS:
  - Modeling innovation for small farm enterprises in Sub-Saharan Africa
  - Modeling the USAID Global Drug Delivery system for prioritizing change
  - Modeling intelligent transportation systems
  - Modeling urban agriculture innovation
  - Modeling defense industry skill retention
  - Modeling Russian “Grey Zone” tactics
  - Modeling the Global Art Marketplace for fraud/forgery prevention
  - Modeling the Impact of Digital Engineering on DoD Acquisition

http://globalknowledgeinitiative.org/initiative/analyzing-systems-to-maximize-impact/

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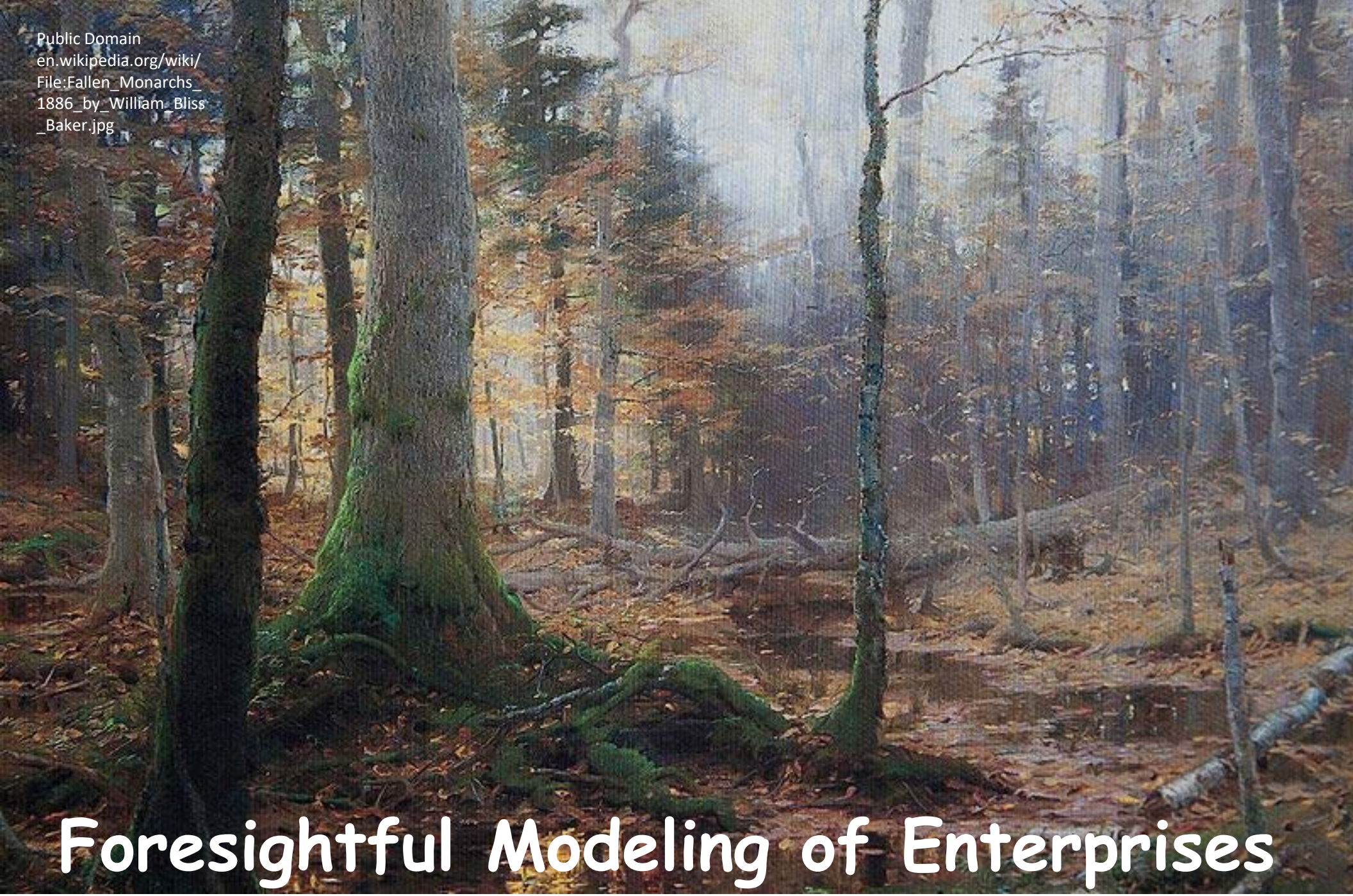
System of Systems Engineering Collaborators Information Exchange (SoSECIE)
June 26, 2018



Foresightful Modeling of Enterprises

Better able to observe, to perceive and understand internal and external change, to align goals and purpose, and to respond holistically. *Tom McDermott, 8 May 2018*