A Framework for Visualizing Systems Engineering Research Coverage

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Outline

- Task Intent
- Approach
- Synthesis of an SE Research Framework
- Evaluating and Refining the SE Research Framework
- Applications of the Final SE Research Framework
- Summary

Research Intent

- To produce a framework for the identification and prioritisation of System Engineering and System of Systems Engineering research
  - The framework is intended to guide the initiation of future DSTO – DSIC research activities aimed at improving Australia's SE and SoSE capabilities
- Requirements
  - The framework needs to capture all aspects of the area that may be undertaken as part of a coordinated research program

Approach

- Iterative experiential approach
  - Frame the problem
  - Gather information
  - Synthesise a taxonomy
  - Design visualisation
  - Apply in various ways
  - Evaluate
  - Iterate

Framing the Problem

Thought about SE and SoS SE as a Capability (Cook, Nowakowski & Unewisse, 2012)

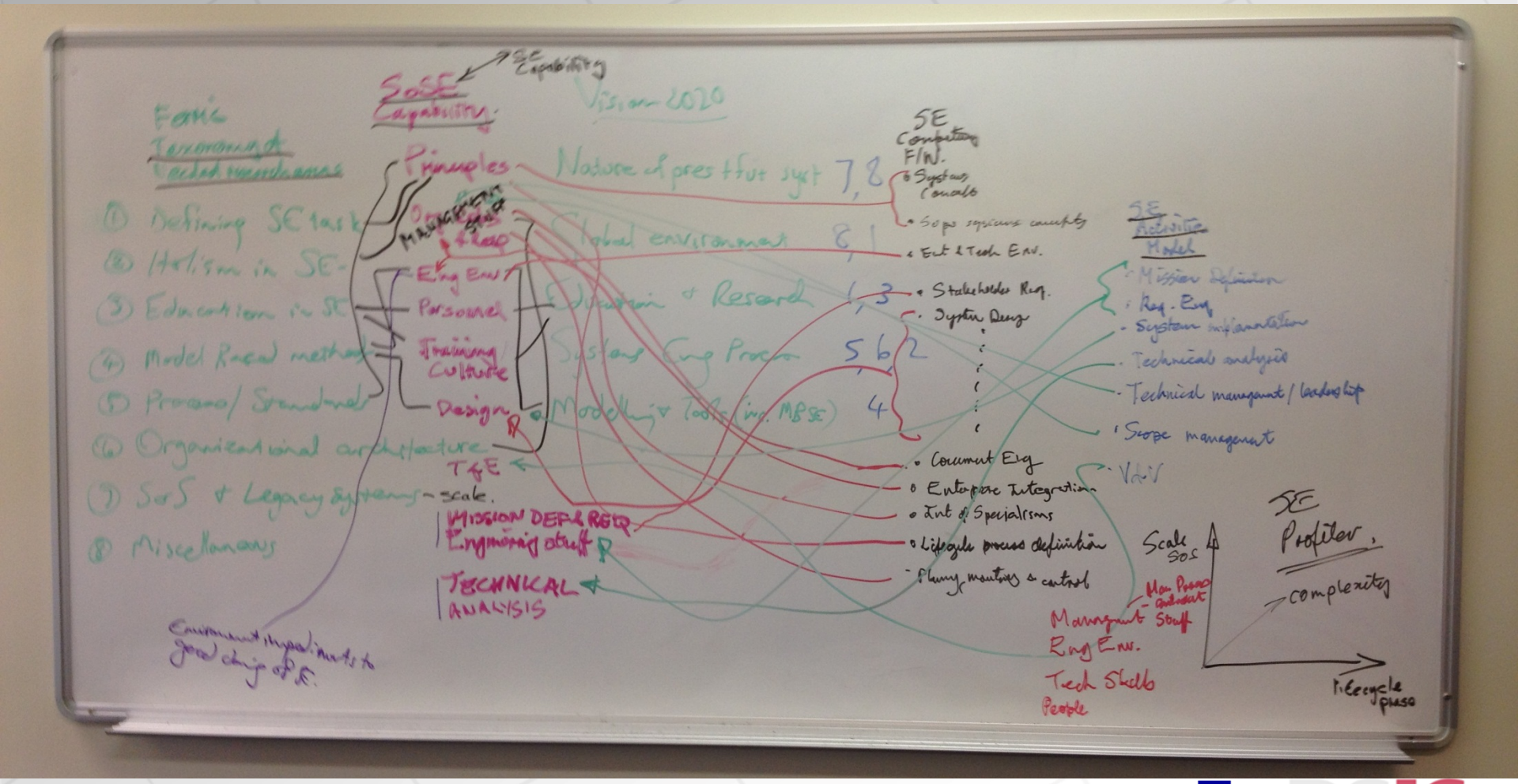
Gathering Information

- Research team gathered a number of SE research taxonomies and synthesised them in a workshop
  - SE activities framework devised by Honour & Valerdi (2006) from SE standards
  - Ferris' 2009 framework of research topics in systems engineering
  - The INCOSE (2006) Systems Engineering Vision 2020
  - The INCOSE (2010) Systems Engineering Competencies Framework

SE Research Framework
Expansion of SE Technical Capabilities
(Honour & Valerdi, 2006)

SE Categories	ANSI/EIA-632	IEEE-1220	ISO-15288	CMMI	MIL-STD-499C
Mission/purpose definition	Not included in scope	▪ Define customer expectations (Req Anlys)	▪ Stakeholder needs definition	▪ Develop customer requirements (Req Devlp)	Not included in scope
Requirements engineering	System Design ▪ Requirements definition	▪ Requirements analysis ▪ Track requirements and design changes	▪ Requirements analysis	▪ Req'ments development ▪ Requirements mgmt	▪ System requirements analysis and validation
System architecting	System Design ▪ Solution definition	▪ Synthesis	▪ Architectural design ▪ System life cycle mgmt	▪ Select product-component solutions (Tech sol'n) ▪ Develop the design (Tech sol'n)	▪ System product technical req'ments anlys/validation ▪ Design or physical solution representation
System implementation	Product Realization ▪ Implementation ▪ Transition to Use	Not included in scope	▪ Implementation ▪ Integration ▪ Transition	▪ Implement the product design (Tech sol'n) ▪ Product integration	Not included in scope
Technical analysis	Technical Evaluation ▪ Systems analysis	▪ Functional analysis ▪ Requirements trade studies ▪ Functional trade studies ▪ Design trade studies	▪ Requirements analysis	▪ Decision analysis and resolution	▪ Functional analysis, allocations and validation ▪ Assessments of system effectiveness, cost, schedule, and risk ▪ Tradeoff analyses
Technical management/ leadership	Technical Mgmt ▪ Planning ▪ Assessment ▪ Control	▪ Technical mgmt ▪ Track analysis data ▪ Track performance – project plans, tech plans ▪ Track product metrics ▪ Update specifications ▪ Update architectures ▪ Update plans ▪ Maintain database	▪ Planning ▪ Assessment ▪ Control ▪ Decision mgmt ▪ Configuration mgmt ▪ Resource mgmt ▪ Risk mgmt	▪ Project planning ▪ Project monitoring & control ▪ Measurement and analysis ▪ Process and product quality assurance ▪ Configuration mgmt ▪ Integrated project mgmt ▪ Quantitative project mgmt ▪ Risk mgmt	▪ Planning ▪ Monitoring ▪ Decision making, control, and baseline maintenance ▪ Risk mgmt ▪ Baseline change control and maintenance ▪ Interface mgmt ▪ Data mgmt ▪ Technical reviews/audits
Scope management	Acquisition & Supply ▪ Supply ▪ Acquisition	Not included in scope	▪ Acquisition ▪ Supply	▪ Supplier agreement mgmt	▪ Technical mgmt of subcontractors/vendors
Verification & validation	Technical Evaluation ▪ Requirements validation ▪ System verification ▪ End products validation	▪ Requirement verification ▪ Functional verification ▪ Design verification	▪ Verification ▪ Validation	▪ Verification ▪ Validation	▪ Design or physical solution verification and validation
In the standard, but not in agreement with other standards			▪ Operation ▪ Disposal ▪ Enterprise mgmt ▪ Investment mgmt ▪ Quality mgmt	▪ Organ'l process focus ▪ Organ'l process definition ▪ Organ'l training ▪ Organ'l process perf ▪ Causal analysis/resolution ▪ Organ'l innov/deploymnt	▪ Lessons learned and continuous improvement

Comparing and Contrasting the Coverage of Source Material



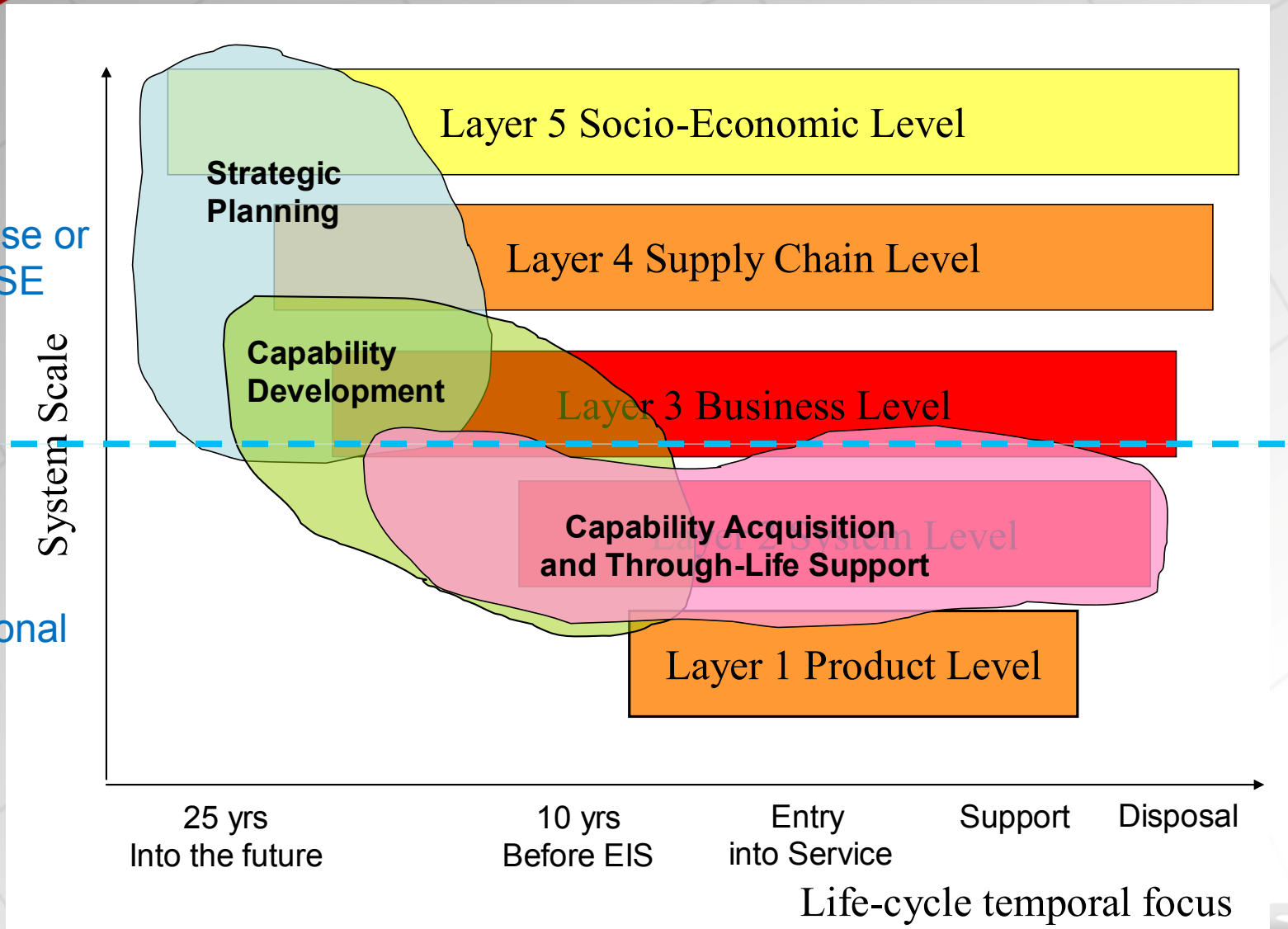
Result from the Initial Synthesis

- The capability-based approach covered most things
- Needed to add other technical SE skills not explicitly listed eg
  - Mission definition
  - Technical analysis including trade studies
- When discussing this framework with international peers it became clear that:
  - Domain-specific research areas need to be included as a separate category
  - We need to deal with scale/complexity: determines many characteristics of practice

Dealing with Scale

- It is seemingly universally recognised that SoSE is different from platform-level SE
- SoS SE uses different techniques and is more complex because of the scale of the work undertaken, the socio-technical nature of the problems, and the lack of direct control of the constituent systems
- The trend is to not dwell on definitions but to characterise the differences and profile the system of interest against scales ranging from traditional SE to SoS SE
  - See next three slides

Scale – Hitchins' Five-Layer Model
(Cook, 2003; Hitchins, 2007)

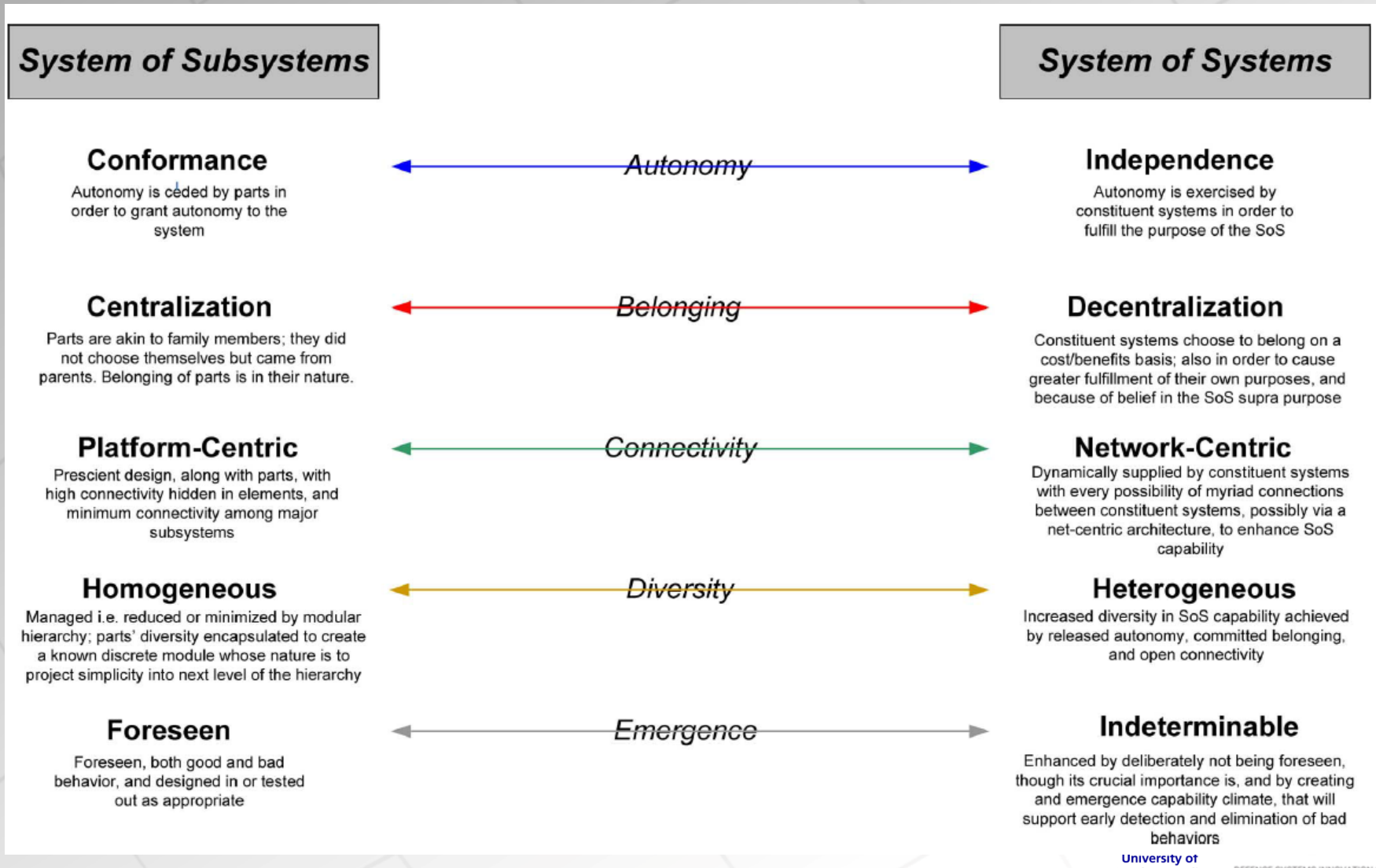


Differences between Systems and Systems of Systems as they apply to Systems Engineering

	Systems Engineering	Systems of Systems Engineering
Management and Oversight		
System	Physical engineering	Socio-technical management and engineering
Stakeholder Involvement	Clear set of stakeholders	Multiple levels of stakeholders with mixed and possibly competing interests
Governance	Aligned management and funding	Added levels of complexity due to management and funding for both SoS and systems; SoS does not have control over all constituent systems
Operational Environment		
Operational focus (goals)	Designed and developed to meet common objectives	Called upon to meet new SoS objectives using systems whose objectives may or may not align with the SoS objectives
Implementation		
Acquisition/Development	Aligned to established acquisition and development processes	Cross multiple system lifecycles across asynchronous acquisition and development efforts, involving legacy systems, developmental systems, and technology insertion
Process	Well established	Learning and adaptation
Test and evaluation	Test and evaluation of the system is possible	Testing is more challenging due to systems' asynchronous life cycles and given the complexity of all the parts
Engineering and design considerations		
Boundaries and interfaces	Focuses on boundaries and interfaces	Focus on identifying systems contributing to SoS objectives and enabling flow of data, control and functionality across the SoS while balancing needs of the systems. OR Focus on interactions between systems Difficult to define system of interest
Performance and Behaviour	Performance of the system to meet performance objectives	Performance across the SoS that satisfies SoS use capability needs while balancing needs of the systems
Metrics	Well defined (e.g. INCOSE handbook)	Difficult to define, agree, and quantify

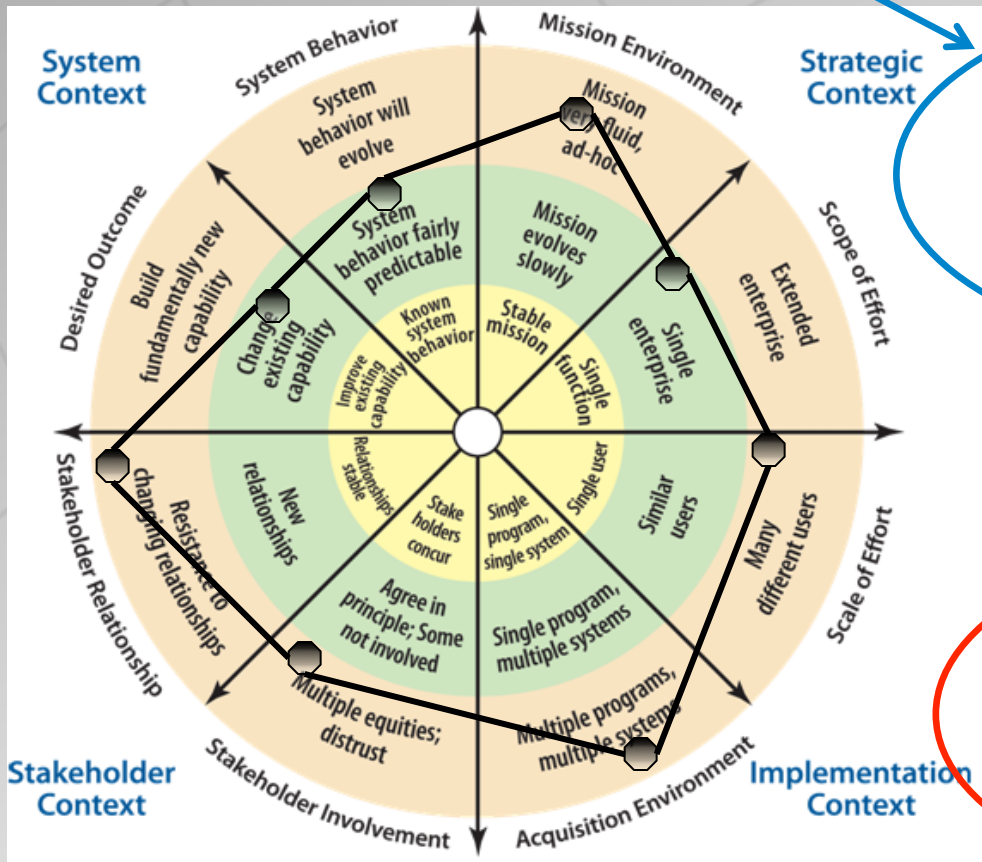
Differences between Traditional Systems and SoS as they Apply to SE
(Barot et al, 2012)

Distinguishing Characteristics of SoS (Gorod et al, 2008)



Mitre Profiler (Stevens, 2011)

Traditional Project SE



- **Traditional program domain**
  - *Well-bounded problem*
  - *Predictable behavior*
  - *Stable environment*
- **Transitional domain**
  - *Systems engineering across boundaries*
  - *Influence vs. authority*
- **Messy frontier**
  - *Political engineering (power, control…)*
  - *High risk, potentially high reward*
  - *Foster cooperative behavior*

SoSE Area

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Approach to Dealing with Scale

- Solution: Use one model but each layer of interest will need a unique instantiation of research topics.

Initial Framework

Research Areas	Example Inclusions
SE Enablers	Systems science and underlying principles Agreed approach and processes
SE Infrastructure	Software tools, test beds, generic models, physical infrastructure, etc.
Organisational Aspects	Leadership, cultural alignment, team design, roles and responsibilities
SE Skills and Competencies	Mission/purpose definition Requirements engineering System architecting System implementation Technical analysis Technical management/leadership Scope management Verification and validation
Education and Training	Individual & organisational
Domain-specific technical aspects	Research topics specific to particular application domains

Evaluating and Iterative Refining the SE Research Framework

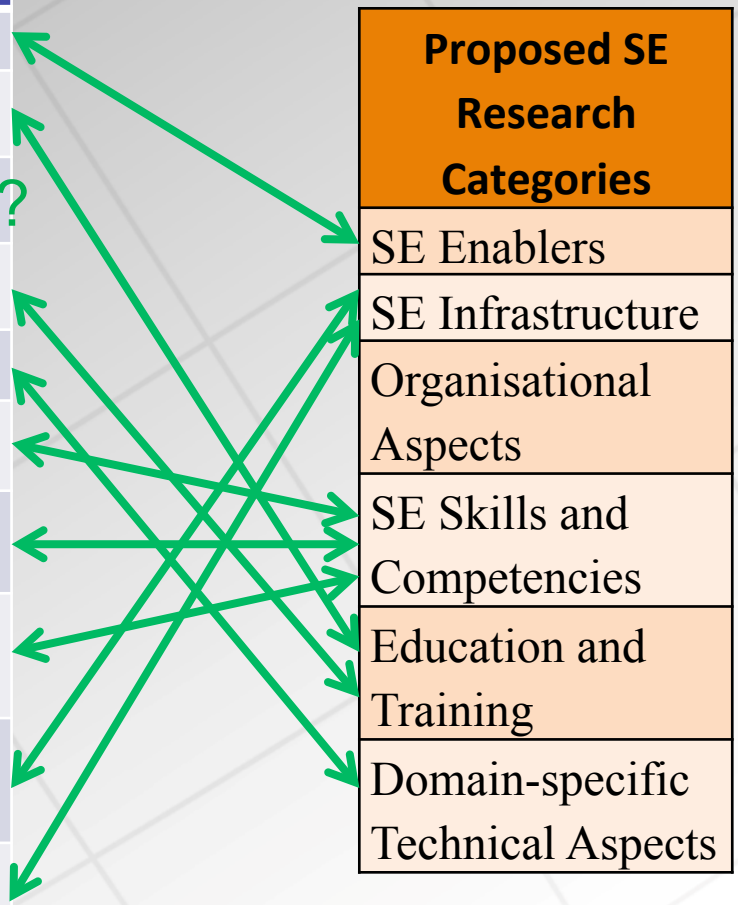
- Achieved by mapping SE research topic lists onto the proposed framework
  - US DoD SE Research Agenda
  - INCOSE SoS WG Pain Points
  - Kalawsky's Grand Challenges
  - T-AREA SoS
  - INCOSE WG Structure

Mapping of US Research Thrusts onto Proposed SE Research Framework

(Baldwin, 2012)

Thrust	Project
Human Capital Development	BKCASE
	SE Capstone Registry
	Workforce Evolution
	Experience Accelerator
Trusted Systems	System-Aware Security
SE Transformation	Tradespace and Affordability
	Expedited Systems Engineering
Enterprises/SoS	Multi-Level Modeling of Socio-Technical systems
	SoS Analytic Workbench
	SoS Agent-Based Models

?



Not completely mapped

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A Refined Framework

- SE Enablers
  - Systems science and underlying principles
  - Agreed approach and processes
- SE Technical Capabilities
  - Mission definition, requirements engineering, architectural design, systems implementation, T&E, etc
- SE Infrastructure
  - Tools, testbeds, models, etc
- Organisational Aspects
  - leadership, cultural alignment, team design, roles and responsibilities
- Workforce Development
  - SE Competencies definitions and skills development
  - Education and Training: individual & organisational
- Domain-specific technical aspects

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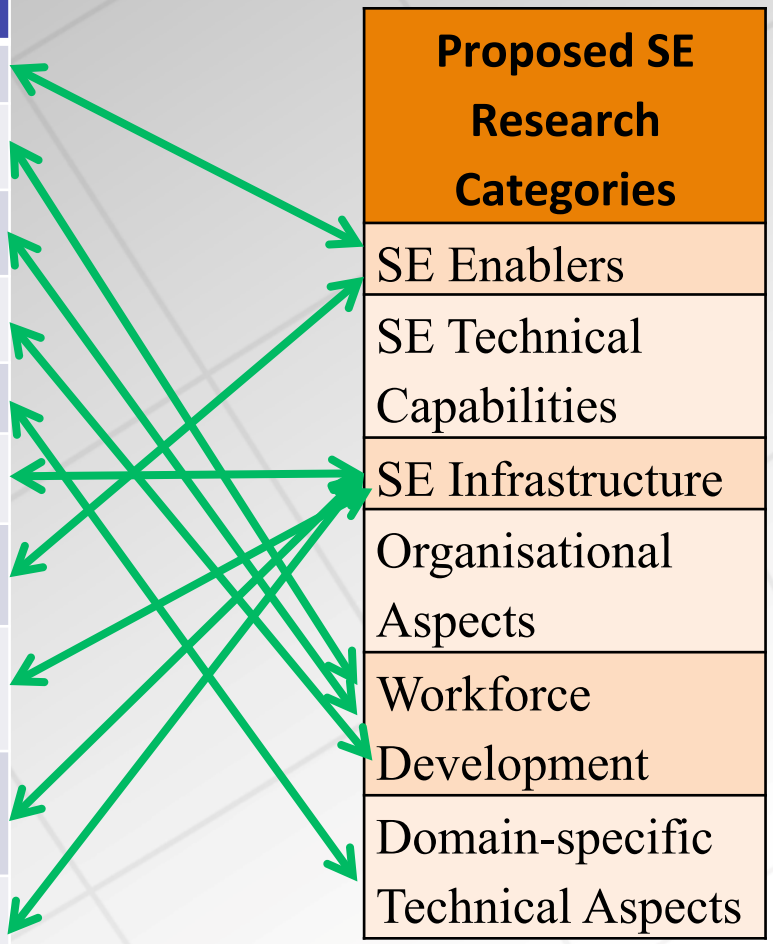

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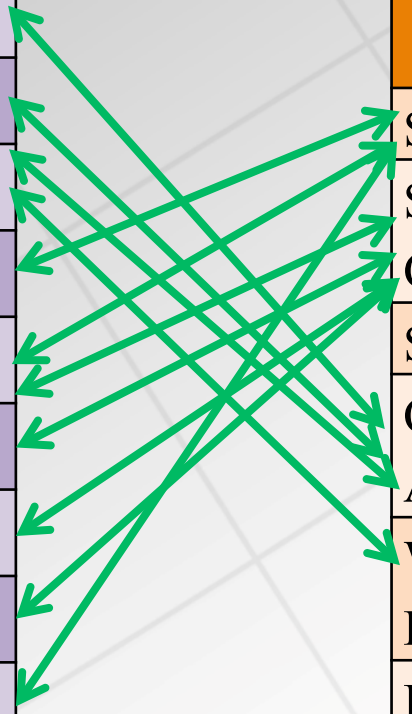
SoS WG Survey of Pain Points
(Dahmann, 2012)

INCOSE SoS SE WG Pain Points
SoS Authorities and funding
CS perspectives
Leadership
SE Processes
Emergence
SoS Interdependencies
Capabilities and requirements
Testing validation and Learning
SoS Thinking Principles



Proposed SE Research Categories
SE Enablers
SE Technical Capabilities
SE Infrastructure
Organisational Aspects
Workforce Development
Domain-specific Technical Aspects

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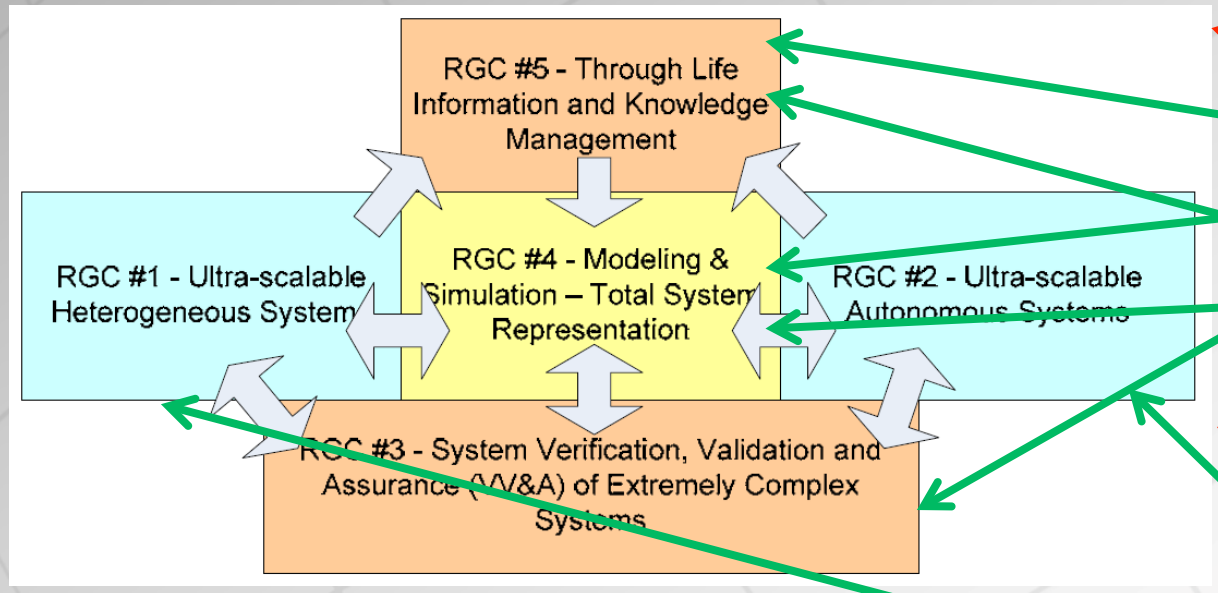
Mapping Kalawsky's Grand Challenges onto Refined SE Research Framework

(Kalawsky, 2009)



Proposed SE Research Categories
SE Enablers
SE Technical Capabilities
SE Infrastructure
Organisational Aspects
Workforce Development
Domain-specific Technical Aspects

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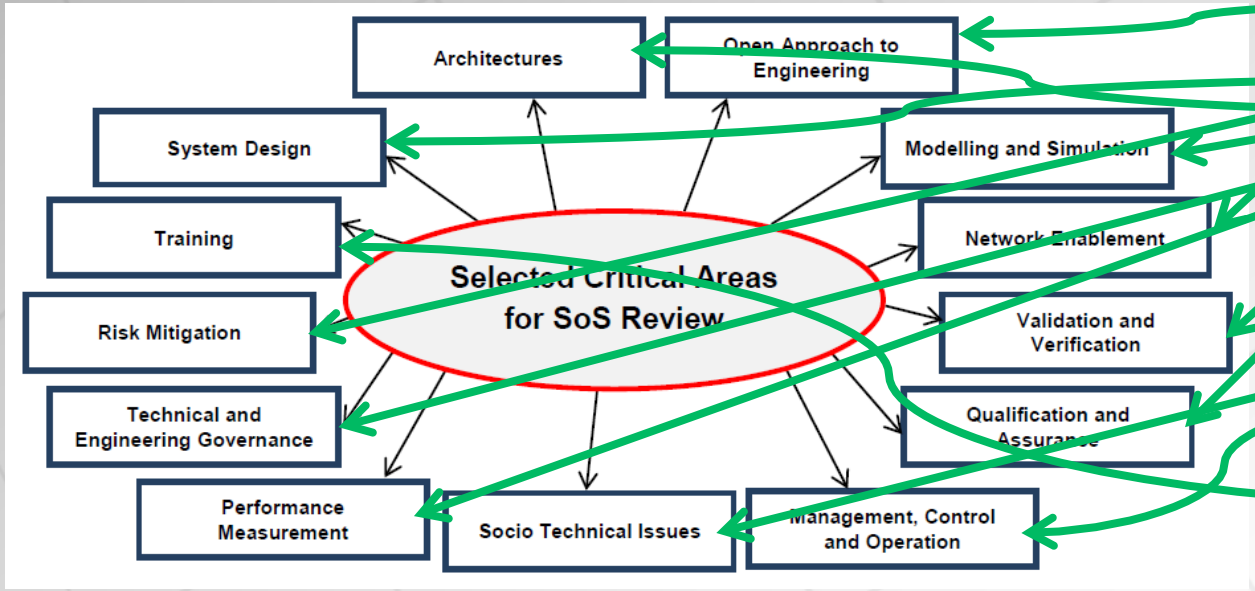
Mapping T-AREA SoS Key SoS Importance Areas onto Refined SE Research Framework (Barot et al, 2012)



Proposed SE Research Categories
SE Enablers
SE Technical Capabilities
SE Infrastructure
Organisational Aspects
Workforce Development
Domain-specific Technical Aspects

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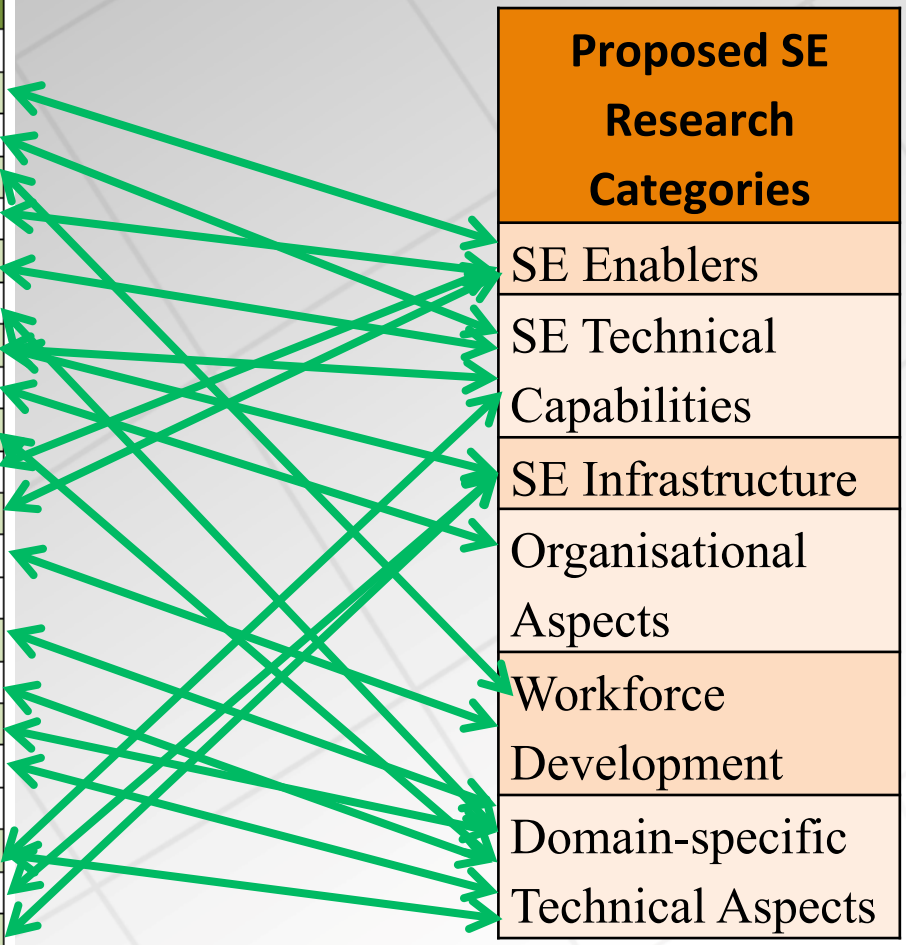
Mapping INCOSE Working Groups onto Refined SE Research Framework – Part 1 of 2

(INCOSE, 2012)

INCOSE SE Working Group List (Part 1)
KNOWLEDGE
Agile Systems and Systems Engineering
Architecture
Competency
Complex Systems
Decision Analysis
Intelligent Enterprises
Knowledge Management
Process Improvement
Resilient System
Systems Engineering Effectiveness
Systems Science
Training
INDUSTRY
Biomedical
Infrastructure
Net-centric Operations
SE in VSME
TECHNOLOGY
Autonomous System Test & Evaluation
Tools Database
Tools Integration & Interoperability



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Mapping INCOSE Working Groups onto Refined SE Research Framework – Part 2 of 2 (INCOSE, 2012)

INCOSE SE WORKING GROUP LIST (PART 2)
GOVERNMENT
Anti-terrorism International
Defense Systems
Global Earth Observation System of Systems
Power & Energy Systems
Space Systems
Transportation
ACADEMIA LIAISON
Motor Sports
PROCESSES
Affordability
Cost Engineering
Human Systems Integration
In-Service Systems
Lean Systems Engineering
Life Cycle Management
Measurement
Model-based Concept Systems Engineering
Object-Oriented SE Method
Reliability Engineering
Requirements
Risk Management
System of Systems
System Safety Integration
Systems Security Engineering
Verification & Validation

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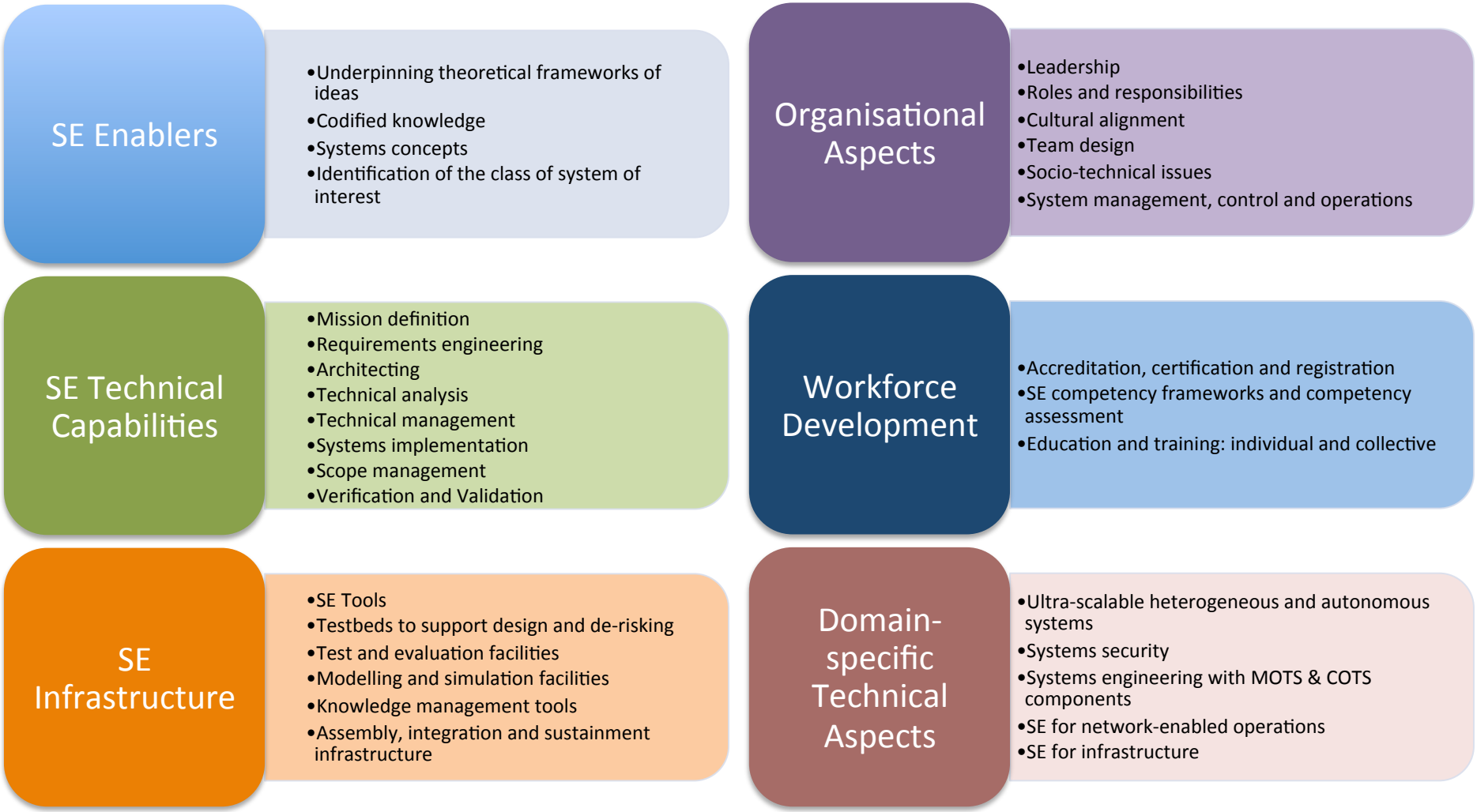
Interim SE Research Framework (Showing Example Second Level Decomposition)



Using the Research Framework

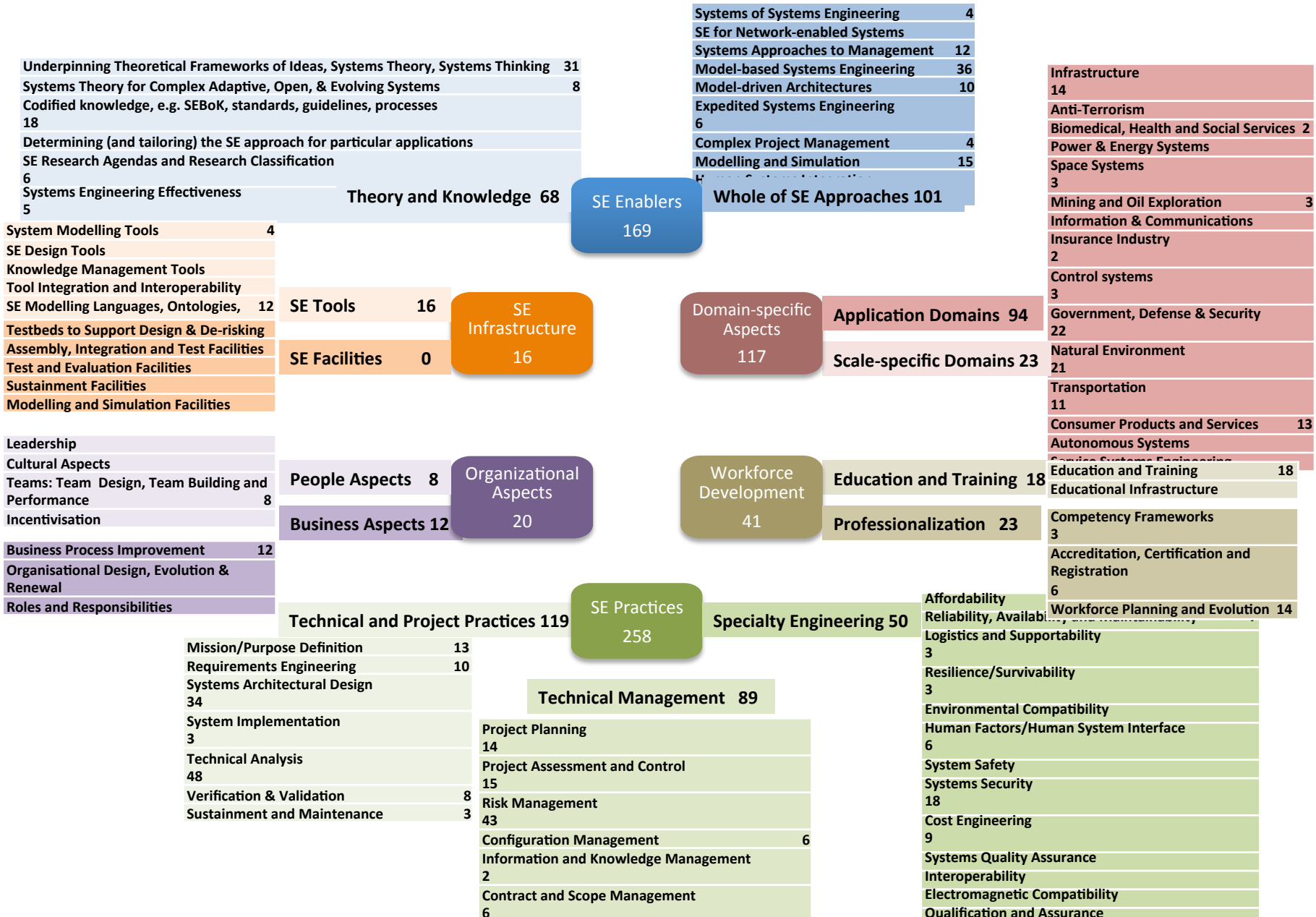
- Can be used at any of the three level described
- Could use one or more posters to represent the required information: SE + SoSS; Aust vs International; etc.
- Could use colour-coded markers to compare and contrast coverage
- Could also use say colour density or asterisks to indicate intensity of effort, etc

Further Evaluation through Application

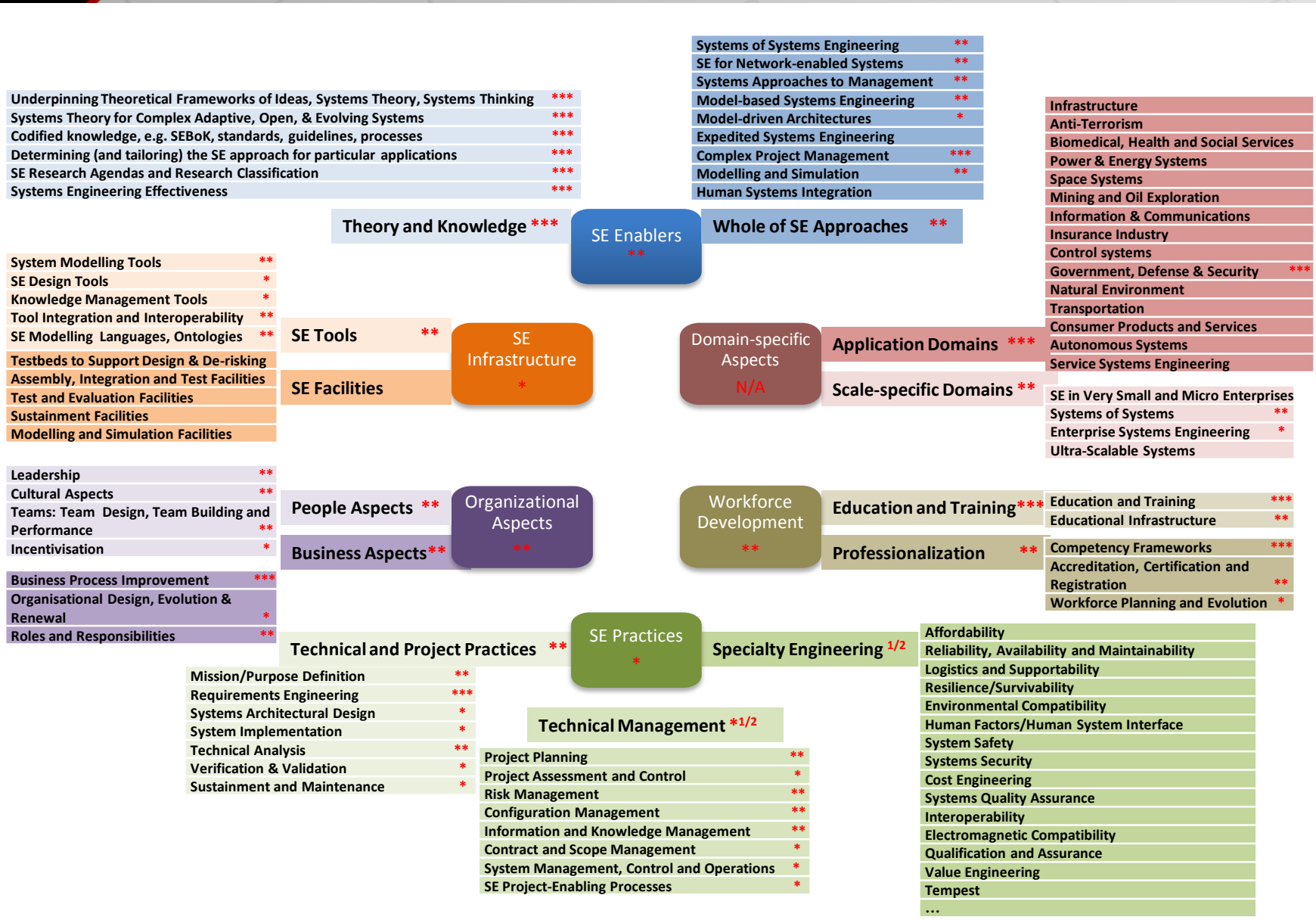
- Started to classify papers from *System Engineering*

- Restructured framework again to:
  - Introduce a third level of decomposition to ease classification of SE papers
  - Incorporate newer ideas from IEC/ISO 15288
  - Include ideas from INCOSE IS review classification

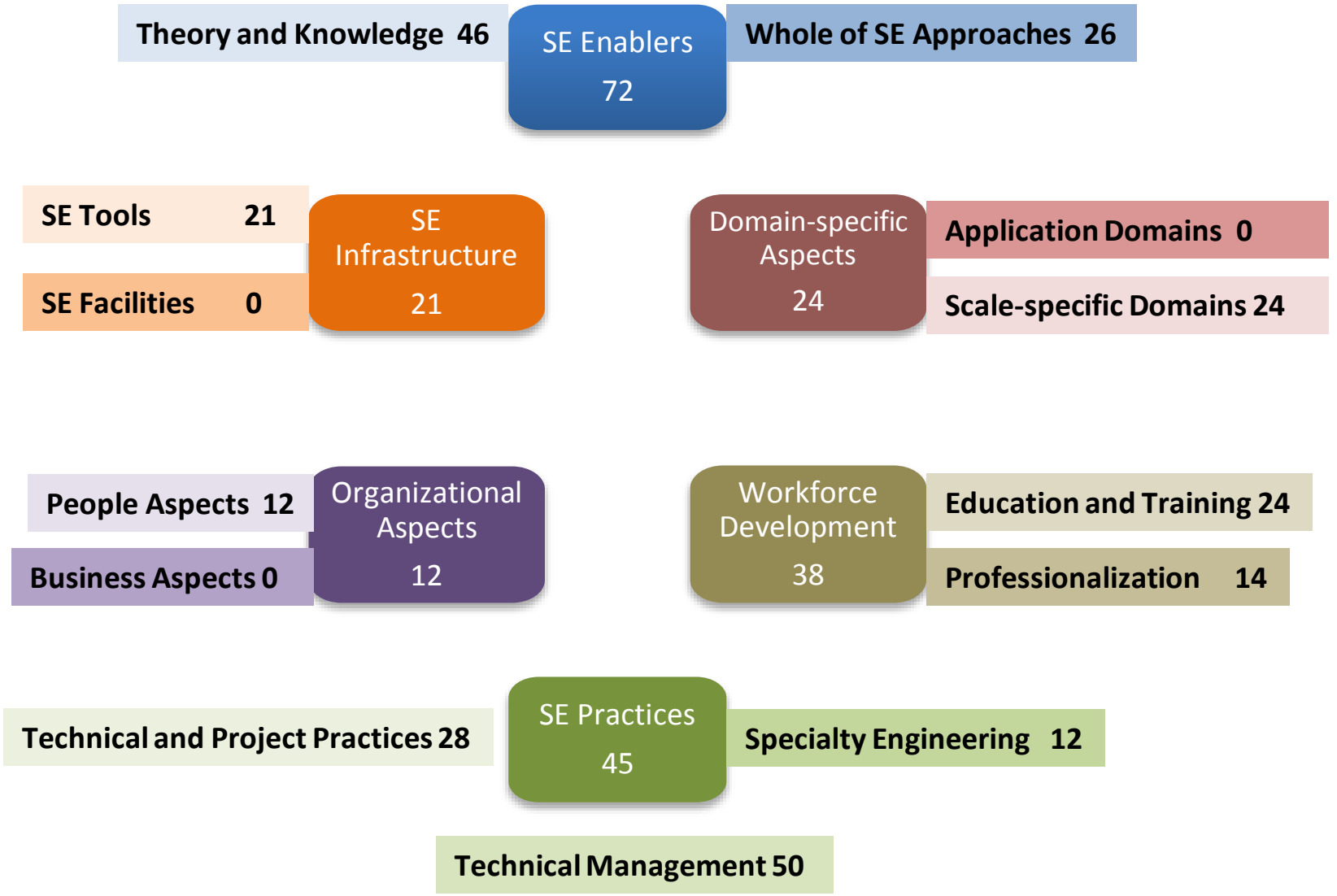
The Latest Iteration of the SE Research Visualization Framework Showing the Coverage of 104 SE Papers



A Visualisation of SoSE Research Needs



Visualisation of a Research Agenda



Summary

- Have synthesised an SE Research Visualisation Framework from the literature to cover Defence SE and SoS SE research areas
- Evaluated and refined the framework against international SE research agendas
- The proposed framework covers the field well with adequate resolution for a variety of purposes
- The framework appears to be fit for purpose

- It would be useful to think about how best to represent international research comparisons

Additional Material
Expansion of SE Research Areas

SE Research Framework
Expansion of SE Enablers

- SE Enablers
  - Underpinning Theoretical Frameworks of Ideas, eg Systems Science, Complexity Science, Management Science
  - Codified Knowledge: eg, SEBoK, Standards, Guidelines, Processes, SE literature
  - Systems Practices: eg, SE, SoS SE, Systems Thinking, Management Interventions, Systems Architecting, Agile SE, Lean SE,
  - Systems Concepts: eg, Network Enablement, Open Approach to Engineering
  - Identification of the class of the system of interest and appropriate systems engineering methodologies to tackle the problem in hand

SE Research Framework
Expansion of SE Infrastructure

- SE Infrastructure
  - SE Tools
  - Testbeds to support Design and De-risking
  - Test & Evaluation Facilities
  - Modelling and Simulation
  - Knowledge Management
  - Assembly, Integration and Sustainment Infrastructure

SE Research Framework
Expansion of Organisational Aspects

- Organisational Aspects (for creating, using, and sustaining the system)
  - Leadership
  - Organisational Design and Evolution
  - Cultural Alignment
  - Team Design
  - Roles and Responsibilities
  - Incentivization
  - Organisational renewal
  - Socio-technical issues
  - System Management, Control and Operations

SE Research Framework
Expansion of Workforce Development

- Workforce Development
  - Accreditation, Certification and Registration
  - SE Competency Frameworks and Competency Assessment
  - Education and Training: individual & organisational

SE Research Framework
Expansion of Domain-specific Technical Aspects

- Domain-specific technical aspects
  - System life-cycle affordability
  - Ultra-scalable Heterogeneous Systems
  - Ultra-scalable Autonomous Systems
  - Systems Security
  - Systems Engineering with MOTS & COTS components
  - SE for Network-enabled Operations
  - SE for Infrastructure
  - SE for Urgent Operational Requirements
  - Obsolescence Management