SYSTEMS ENGINEERING RESEARCH CENTER

STEVENS INSTITUTE of TECHNOLOGY
THE INNOVATION UNIVERSITY

VIRGINIA TECH

WRT-1040: Application of Digital Engineering Measures

Tom McDermott (Stevens), Kaitlin Henderson (Va Tech)
Alejandro Salado (U. Arizona)

Sponsor: OUSD(R&E)

WASHINGTON DC VIRTUAL
NOV. 2-4 2021
ANNUAL SPONSOR RESEARCH REVIEW

SERC task WRT-1040 Application of DE Measures

- Using background literature and interviews, develop causal models for candidate metrics.
- Select metrics to be measured based on causal relationships and sponsors' recommendations.
- Establish a measurement plan that combines quantitative and qualitative data, both from direct measurements and from personnel perceptions.
- Characterize organizations and projects (1 or 2) where the measurements will be conducted.
- Conduct sample measurement of benefits and analyze measurement results.

Agenda

- Motivation
- Previous work
- Causal Model
- DE Measurement Framework
- Validation Efforts
- Conclusions

Motivation

- As systems continue to increase in size and complexity, the industry moves towards a Digital Transformation
- DE aims to bridge business processes and integrate design data across all functional disciplines
- MBSE enables this collaboration for DE, and is an important part of the larger Digital Transformation
- There is little-to-no quantitative evidence of the value of MBSE at this point, the majority of the evidence is qualitative

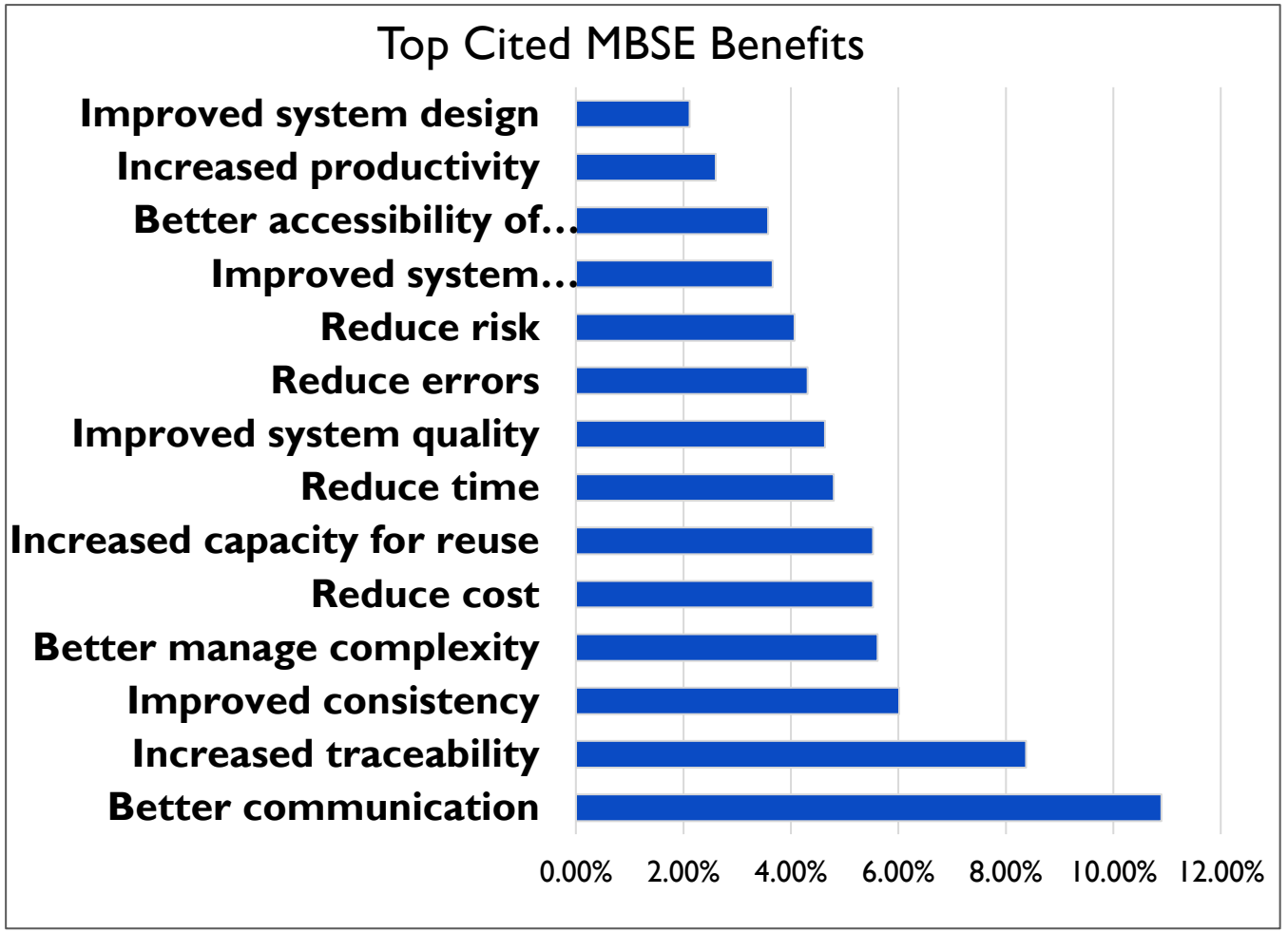
Previous Work

- MBSE Literature Review
- MBSE Maturity Benchmark Survey
- DE Metrics Study

https://sercuarc.org/results-of-the-serc-incose-ndia-mbse-maturity-survey-are-in/

MBSE Literature Review

- Systematic review of research and practice papers in major systems engineering journals and conference proceedings
- Benefits of MBSE claimed in papers were recorded and aggregated into 48 benefits



MBSE Maturity Benchmark Survey

- Survey to establish a current profile of MBSE use and expectations in the industry
  - Assess the observed and expected value of MBSE
  - Collect reports of enablers and barriers to MBSE adoption
- Results from the survey related to benefits aligned well with literature review results
- 37 factors were found to be enablers and/or obstacles to adoption

Top Enablers	Top Obstacles
Leadership Support	Organizational Culture
People willing to use MBSE tools	Workforce Knowledge/ Skills
Workforce Knowledge/ Skills	Leadership Support
Demonstrating Benefits/ Results	Awareness of MBSE Benefits

DE Metrics Study

- Identified 55 potential metrics across 5 categories
- Categories are linked to enterprise Digital Transformation objectives
- Derived from the MBSE Benchmark Maturity Survey and Literature Review
  - Top cited metrics =>

Metric Area	Metrics Category
Quality	Increased traceability
	Reduced defects/errors
	Reduced cost
Velocity/ Agility	Reduced time
	Improved consistency
	Better support for integration, Early V&V
	Increased capacity for reuse
User Experience	Multiple viewpoints of model
	Higher level support for automation
Knowledge Transfer	Better accessibility of information
	Better communication/ info sharing
Adoption	DE/MBSE methods and processes
	Training
	People willing to use DE/MBSE tools

DE Metrics Working Group

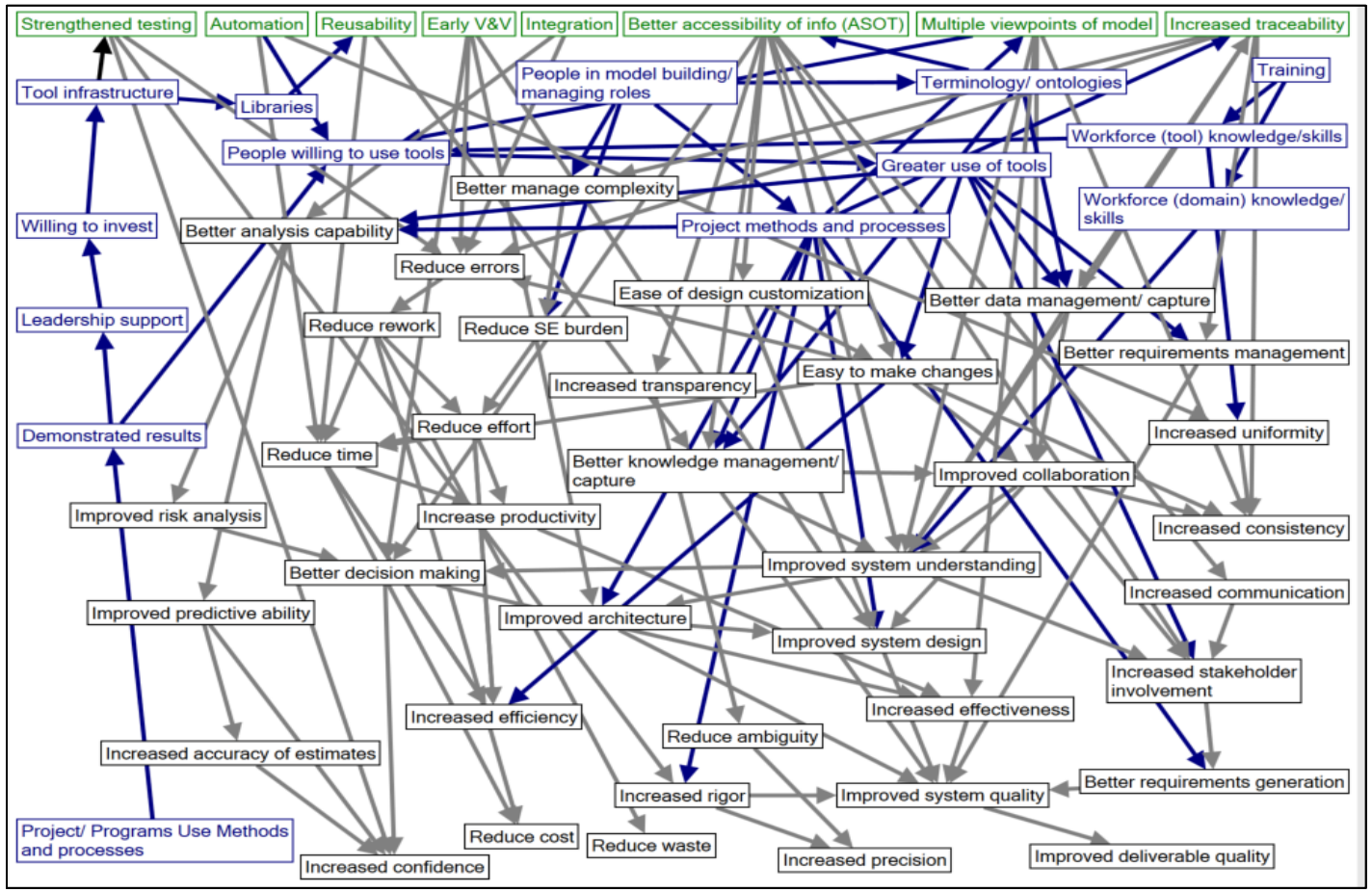
- Chartered to standardize DE metrics specification
- Based on the Practical Software Measurement (PSM) methodology
- Government/ Industry consensus-based

Chair: Joe Bradley
joseph.bradley@mainsailgroup.com

Causal Model: Methodology

- Based on precedence in the Performance Measurement field, a causal map was determined to be an effective method of selecting important measures
- Causal map consists of nodes and causal links between nodes
- Steps of methodology:
  - Select nodes
  - Develop causal links
  - Seek validation from SMEs

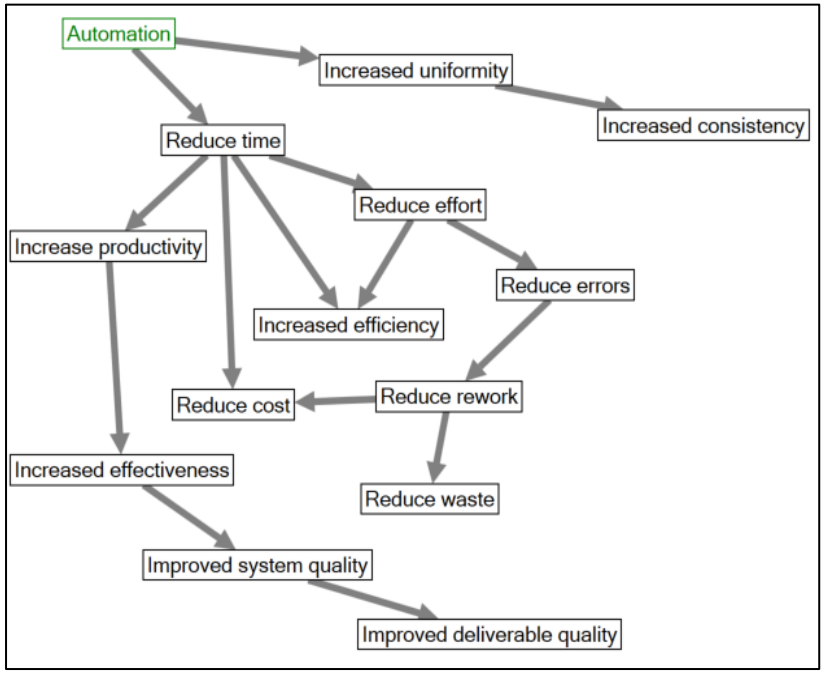
Causal Map



Strengthened testing
Higher level support for Automation
Reusability
Early V&V
Higher level support for Integration
Better accessibility of info (ASOT)
Multiple viewpoints of model
Increased traceability

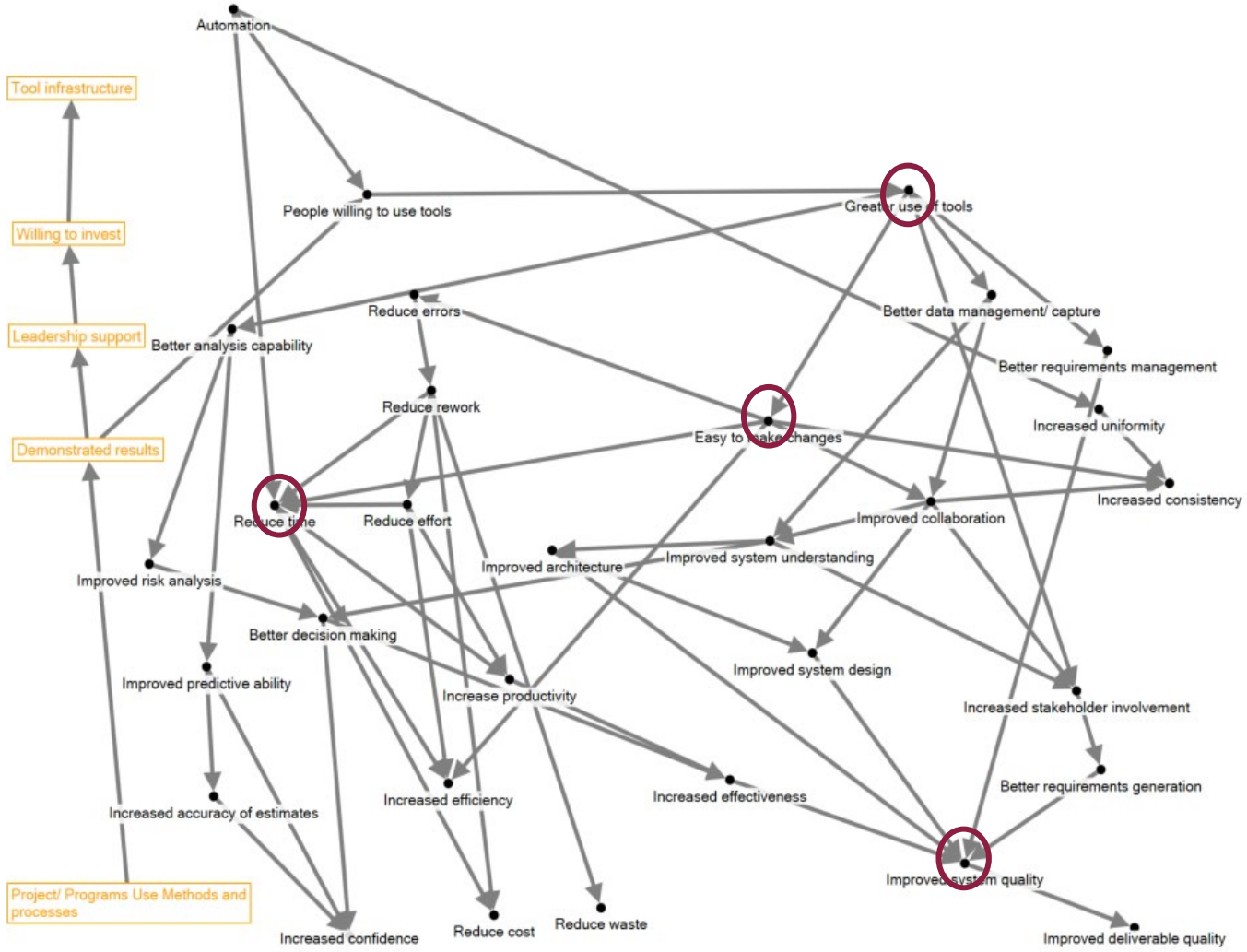
SME Validation

- Members of Digital Engineering Metrics Working Group provided feedback verbally after being walked through the map



Example breakdown of causal map for presentation to SMEs

Causal Map Analysis



Visual analysis key nodes:

- Greater use of tools
- Easy to make changes
- Reduce time
- Improved system quality
- Reduce rework
- Improved collaboration
- Reduce effort
- Improved system understanding

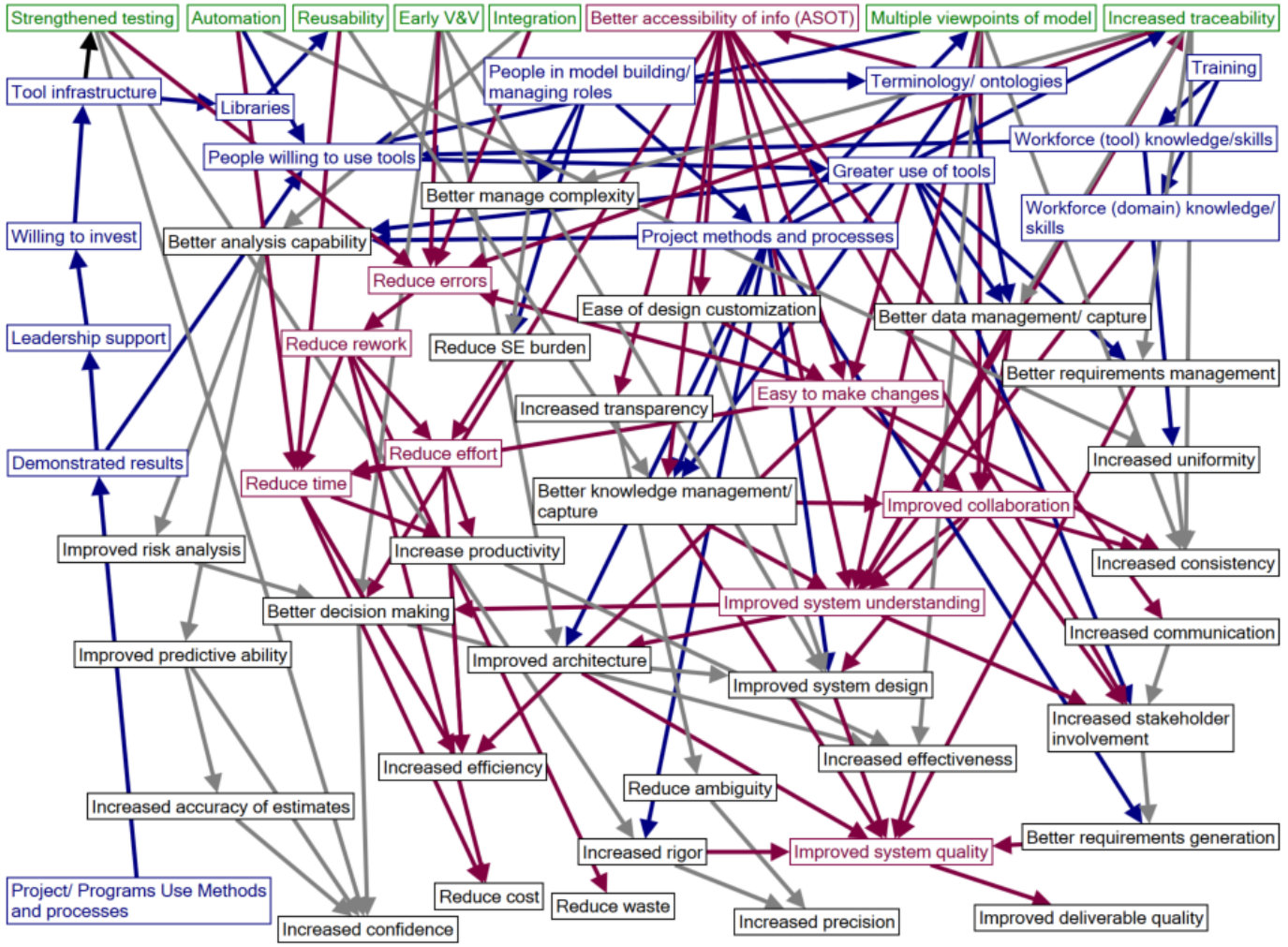
Causal Map Analysis

Eigenvector Centrality		PageRank	
Better accessibility of info (ASOT)	0.0659	Better accessibility of info (ASOT)	2.2002
Improved collaboration	0.0624	Project methods and processes	2.0069
Improved system understanding	0.0576	Reduce time	1.8383
Better knowledge management/ capture	0.0494	Improved system understanding	1.7941
Project methods and processes	0.0493	Improved system quality	1.7559
Increased stakeholder involvement	0.0401	Improved collaboration	1.7101
Easy to make changes	0.0397	Easy to make changes	1.6249
Multiple viewpoints of model	0.0367	Better knowledge management/ capture	1.4082
Improved system design	0.0345	Reduce errors	1.3660

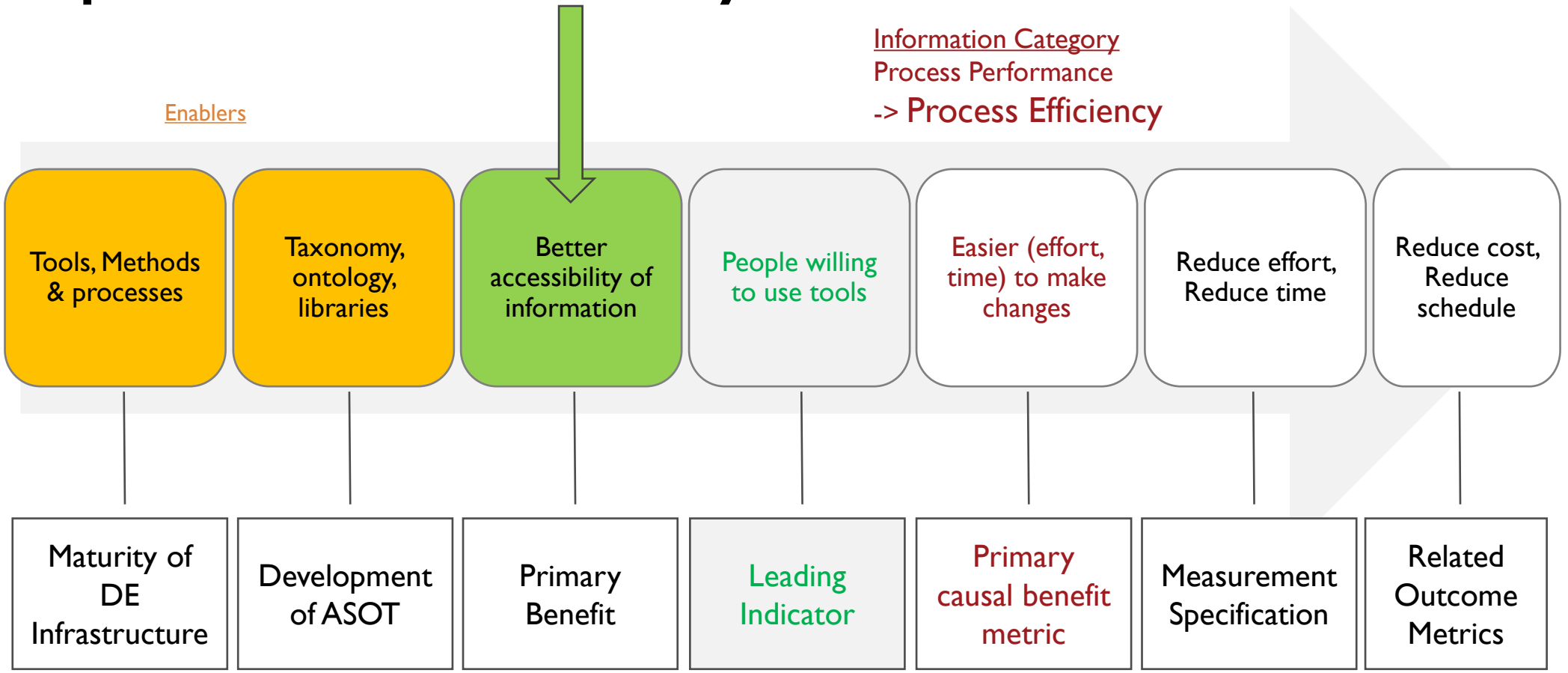
Nodes ranked based on number of links	
In-Degree	***Out-Degree***
Improved system quality	Better accessibility of information
Improved system understanding	Project methods and processes
Improved system design	Easy to make changes
Improved collaboration	Multiple views of model
Increased consistency	Greater use of tools
Increased stakeholder involvement	Terminology/ ontologies
Reduce errors	Early V&V

Top Metric Candidates

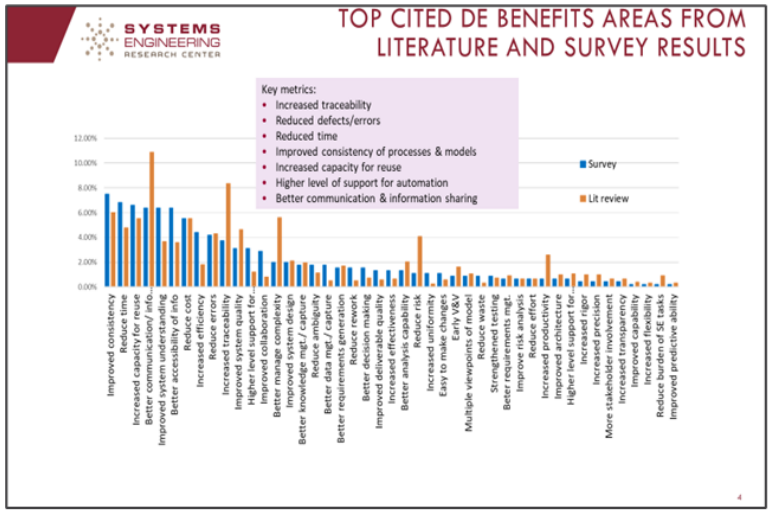
- Accessibility of information
- Collaboration
- System understanding
- Ease of making changes
- Time
- Rework
- Effort
- System quality (defects)

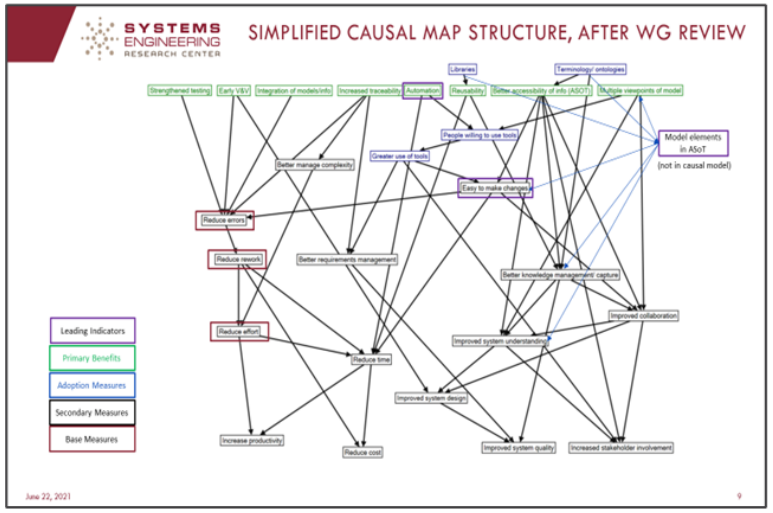


Example Causal Pathway



Transition Framework



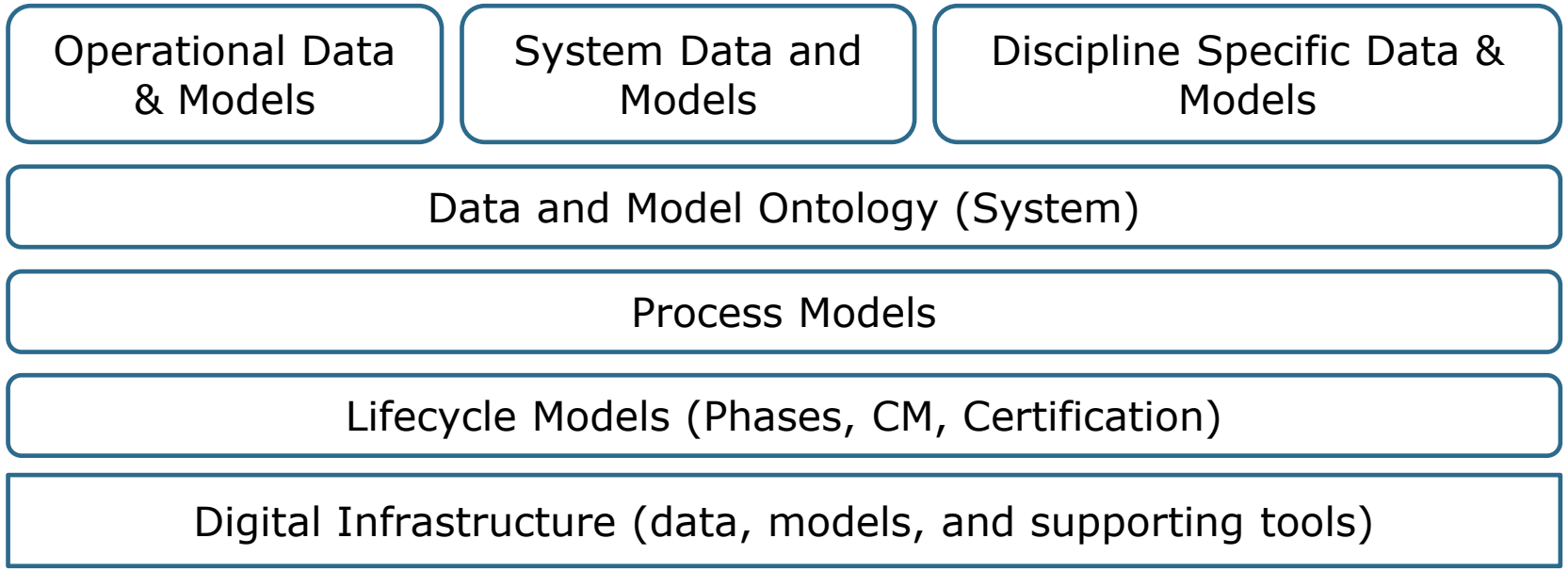


The PSM DE measurement framework builds on research from DoD SERC and definition of measures based on information needs relative to traditional development

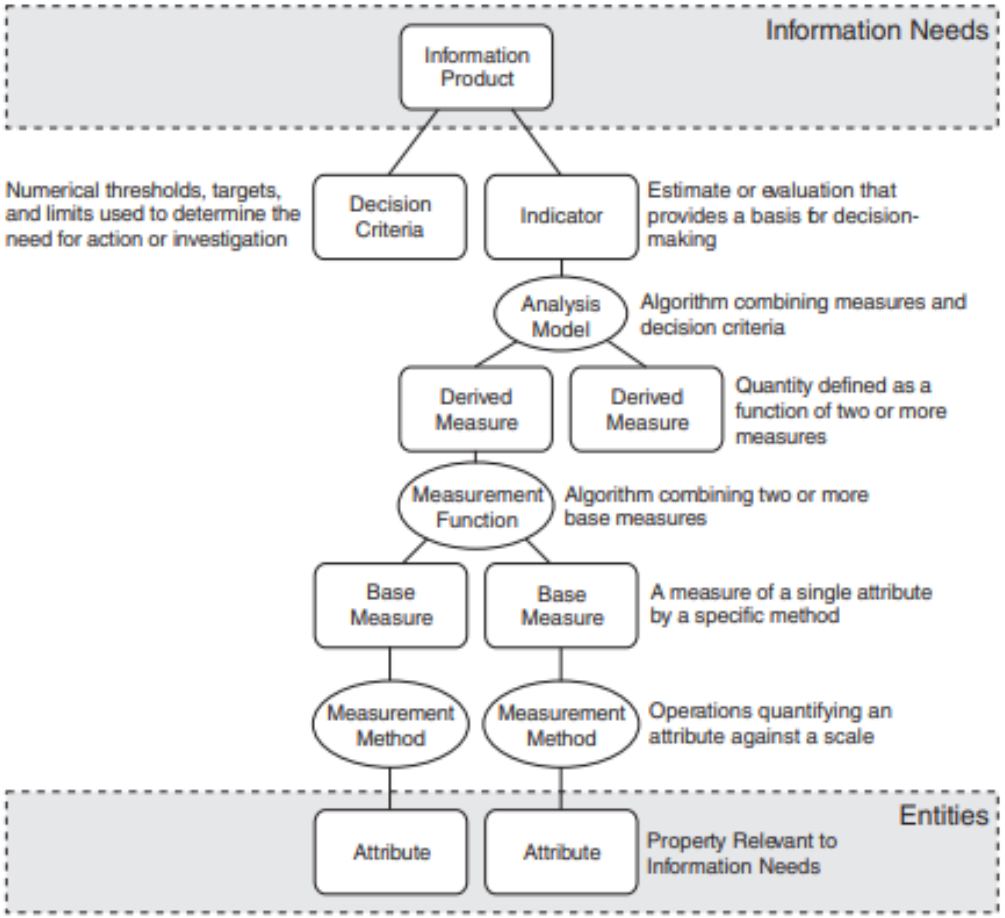
Information Categories	Measurable Concept	Potential Measures	Priority
Size and Stability	Functional Size and Stability ***	Architectural completeness: System element coverage and traceability (% of functions allocated to system model elements)	M
Product Quality	Defect Detection and Rework (Functional Correctness)	Defect detection and removal profiles Defect containment vs. escape ratios across life cycle activities Defect saves - defects found that would have impacted a later design phase (particularly saves in requirements or architecture phases that would have effected the deployed product) Defect detection pre-drawing release vs. post-drawing release	H
	Model Review Efficiency	# of digital model review item discrepancies (RIDs) # of defect saves # of approvals completed in the review # of post-review actions Action item closure times, rates	M
	Defect Detection and Rework (Functional Correctness)	Defect rework effort across life cycle activities Time and effort to assess change impacts using digital models relative to [illegible] onal method	H

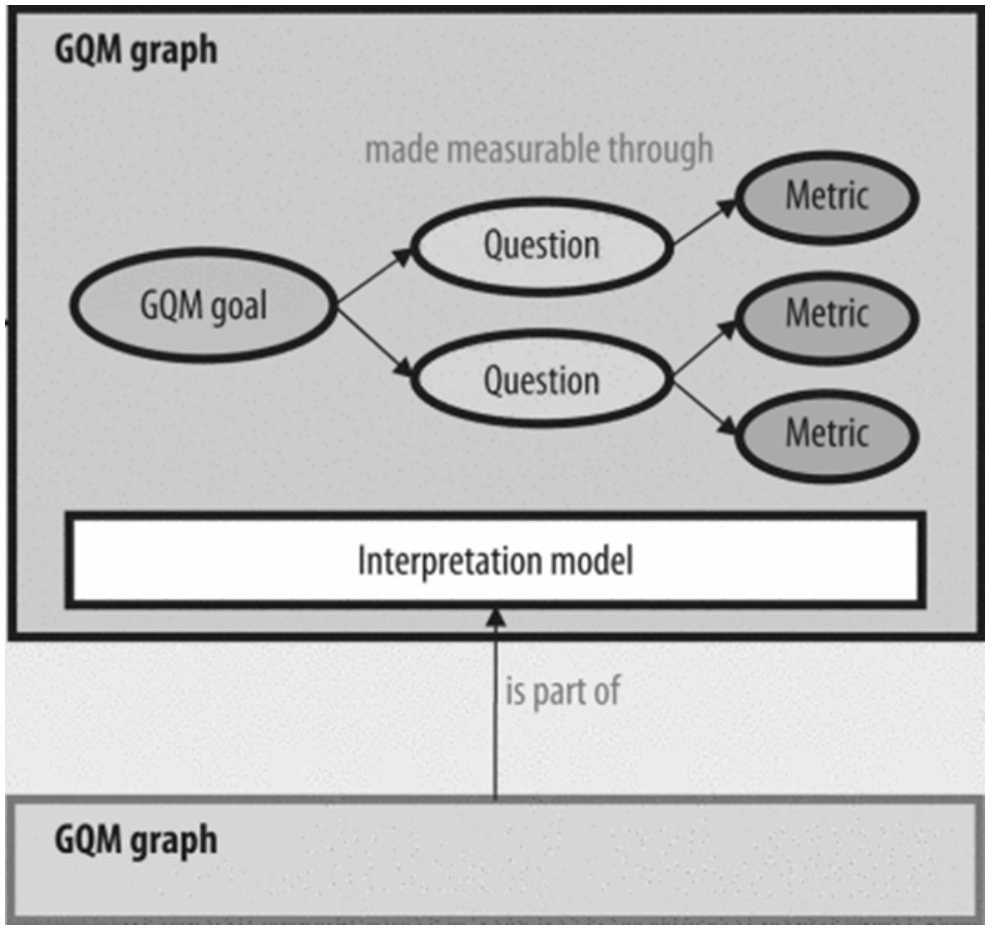
DE Work Decomposition

- Decomposition of the DE process flow is generally associated with models and underlying data, and the digital infrastructure supporting them. All are important concepts in the measurement approach and have related specifications.

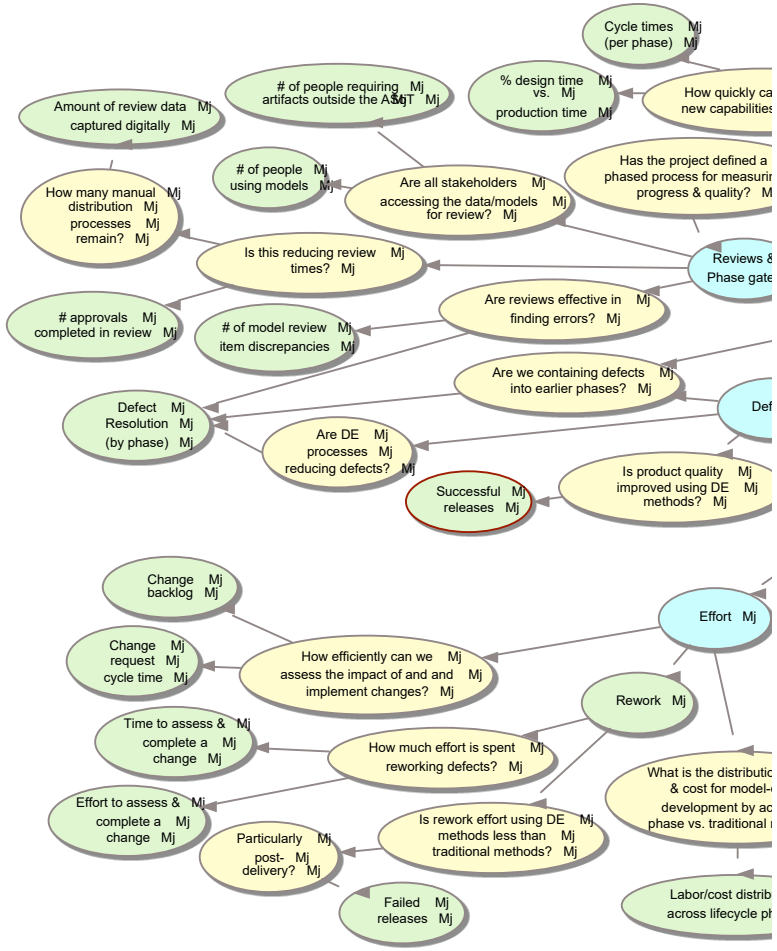


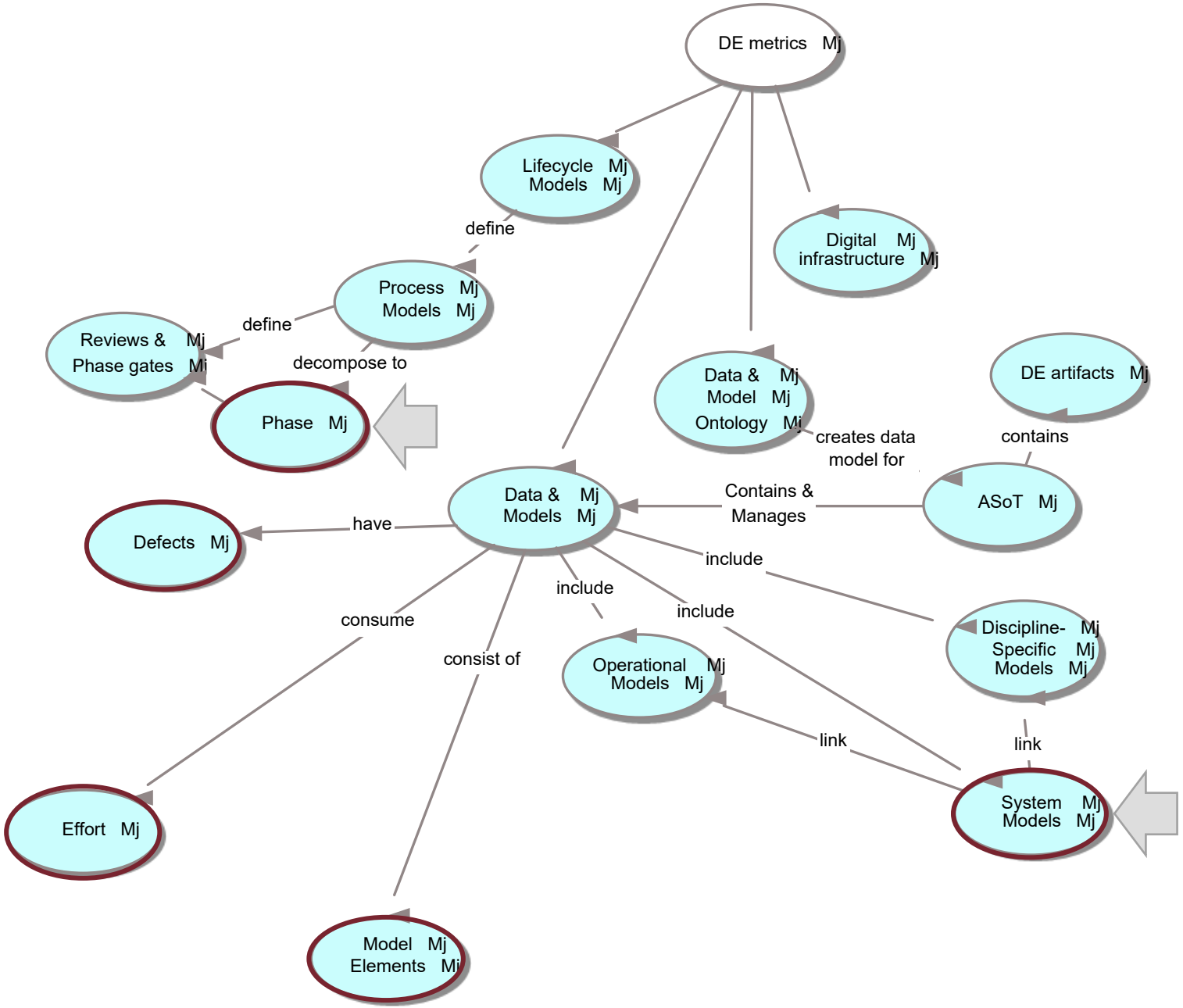
PSM Framework - GQM Framework



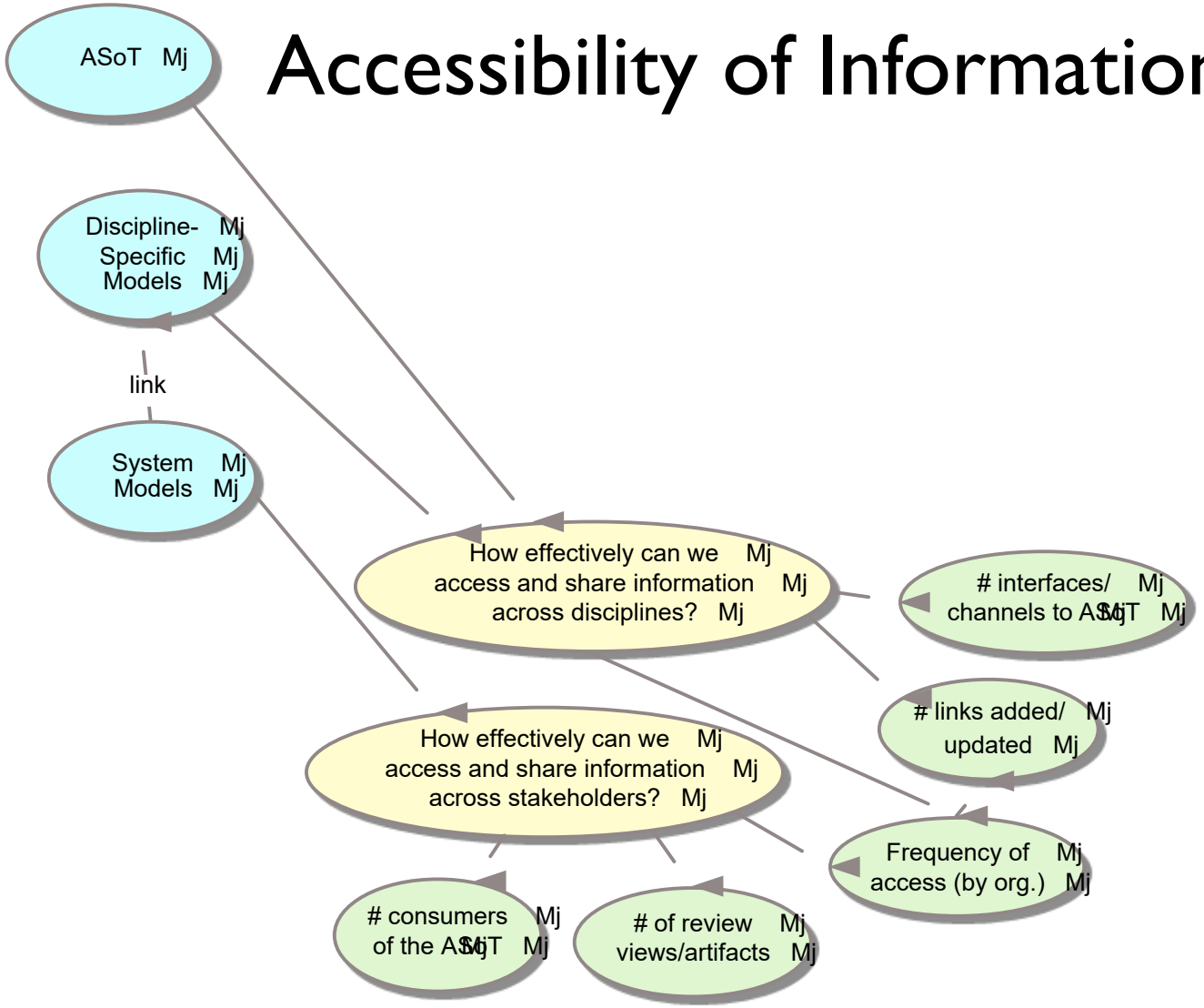


Mapping the DE Framework





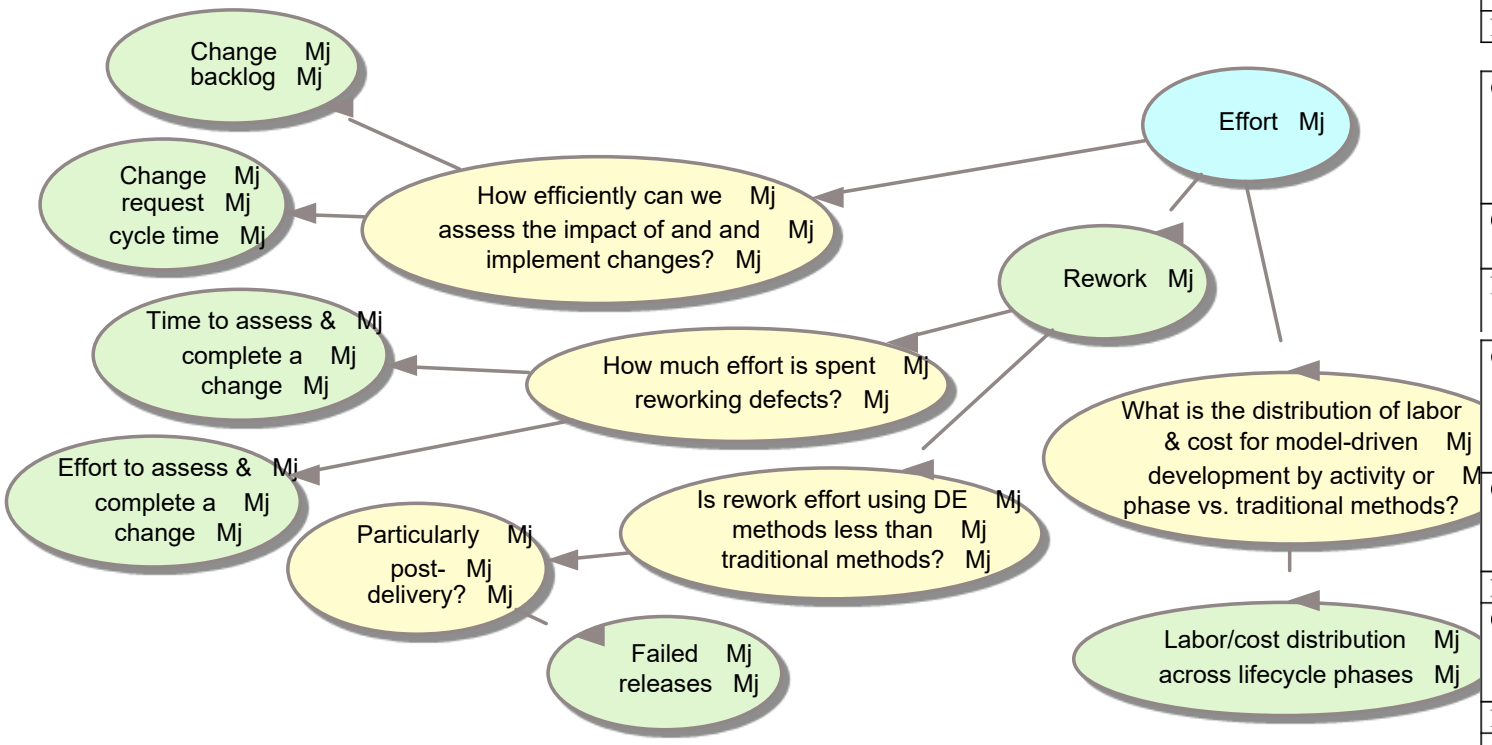
Accessibility of Information



Goal	Purpose Issue Object (process) Viewpoint	Improve The quality of Collaboration Between stakeholders For everyone involved in the system
Question		How effectively can we access and share information across stakeholders?
Metrics		# consumers of the ASOT # of review views/artifacts Frequency of access (by org)
Question		How effectively can we access and share information across disciplines?
Metrics		# interfaces/ channels to ASOT # links added/ updated Frequency of access (by org)

	Issue Object (process) Viewpoint	The accessibility of Information for everyone involved in the system
Question		Are all stakeholders accessing the data/models for review?
Metrics		# of people using models # of people requiring artifacts outside the ASOT
Question		How effectively can we access and share information across stakeholders?
Metrics		# consumers of the ASOT # of review views/artifacts Frequency of access (by org)
Question		How effectively can we access and share information across disciplines?
Metrics		# interfaces/ channels to ASOT # links added/ updated Frequency of access (by org)

Effort – Rework – Easy to make changes



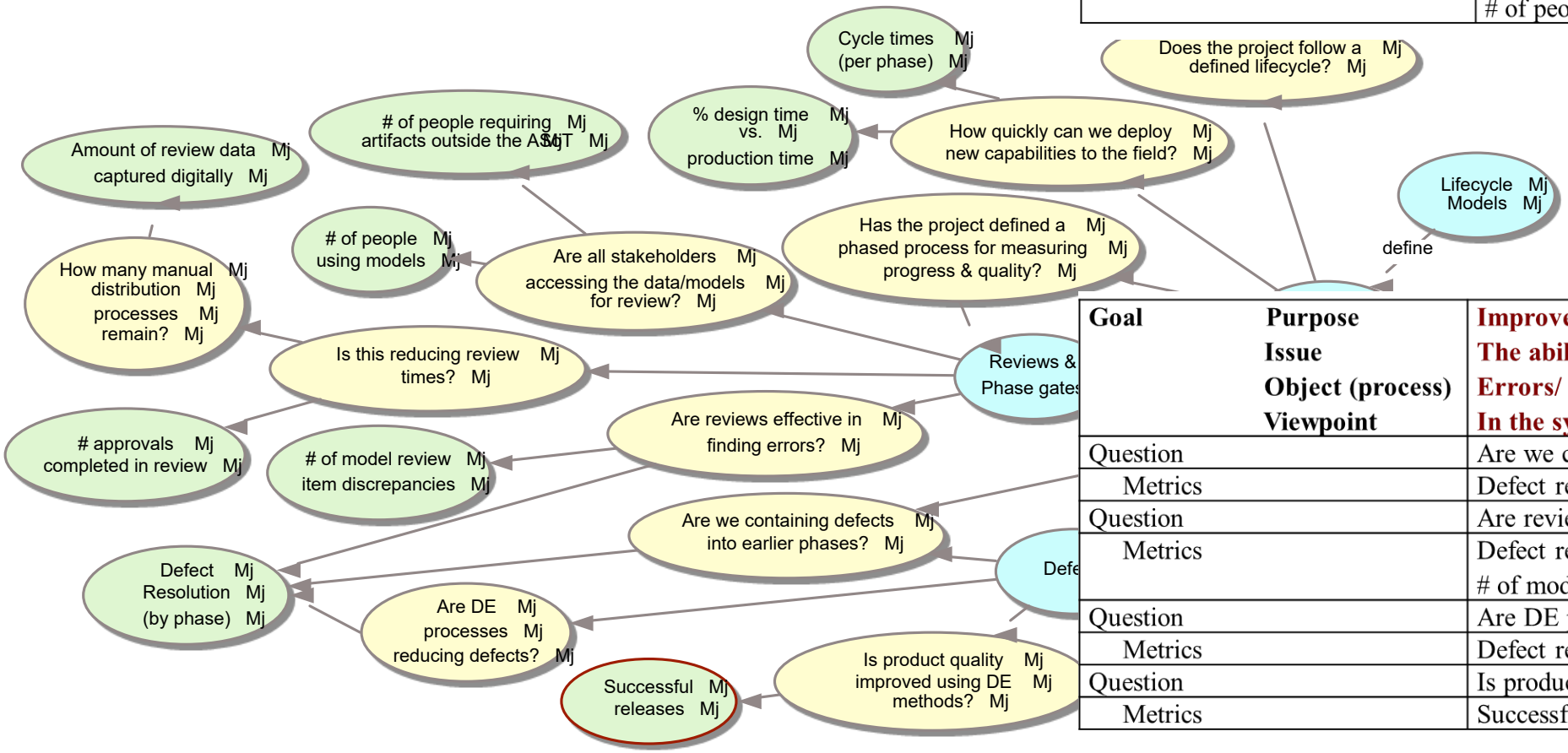
Goal	Purpose Issue Object (process) Viewpoint	**Reduce** **The amount of** **Rework to correct errors/ defects** **In the system**
Question		Are we containing defects into earlier phases?
Metrics		Defect resolution (by phase)
Question		How much effort is spent reworking defects?
Metrics		Time to assess and complete a change Effort to assess and complete a change
Question		Is rework effort using DE methods less than traditional methods (particularly post-delivery)
Metrics		Failed releases

Goal	Purpose Issue Object (process) Viewpoint	**Increase** **The ease of** **Making changes to system information** **For all stakeholders**
Question		How efficiently can we assess the impact of and implement changes?
Metrics		Change backlog Change request cycle time

Goal	Purpose Issue Object (process) Viewpoint	**Reduce** **The amount of** **Effort required to create and maintain the system** **For users and developers**
Question		What is the distribution of labor and cost for model-driven development by activity of phase vs. traditional methods
Metrics		Labor/cost distribution across lifecycle phases
Question		How much of the DE design and development process can be automated to reduce effort and shorten cycle times?
Metrics		# or % of DE tasks automated
Question		How much effort can be saved through automation?
Metrics		Savings in effort

Reviews – Defects

Goal	Purpose Issue Object (process) Viewpoint	Improve The understanding of The system For all users and stakeholders
Question		How many people are trained to the appropriate levels for DE based on role?
Metrics		Training metrics
Question		Are all stakeholders accessing the data/models for review?
Metrics		# of people using models # of people requiring artifacts outside the ASOT



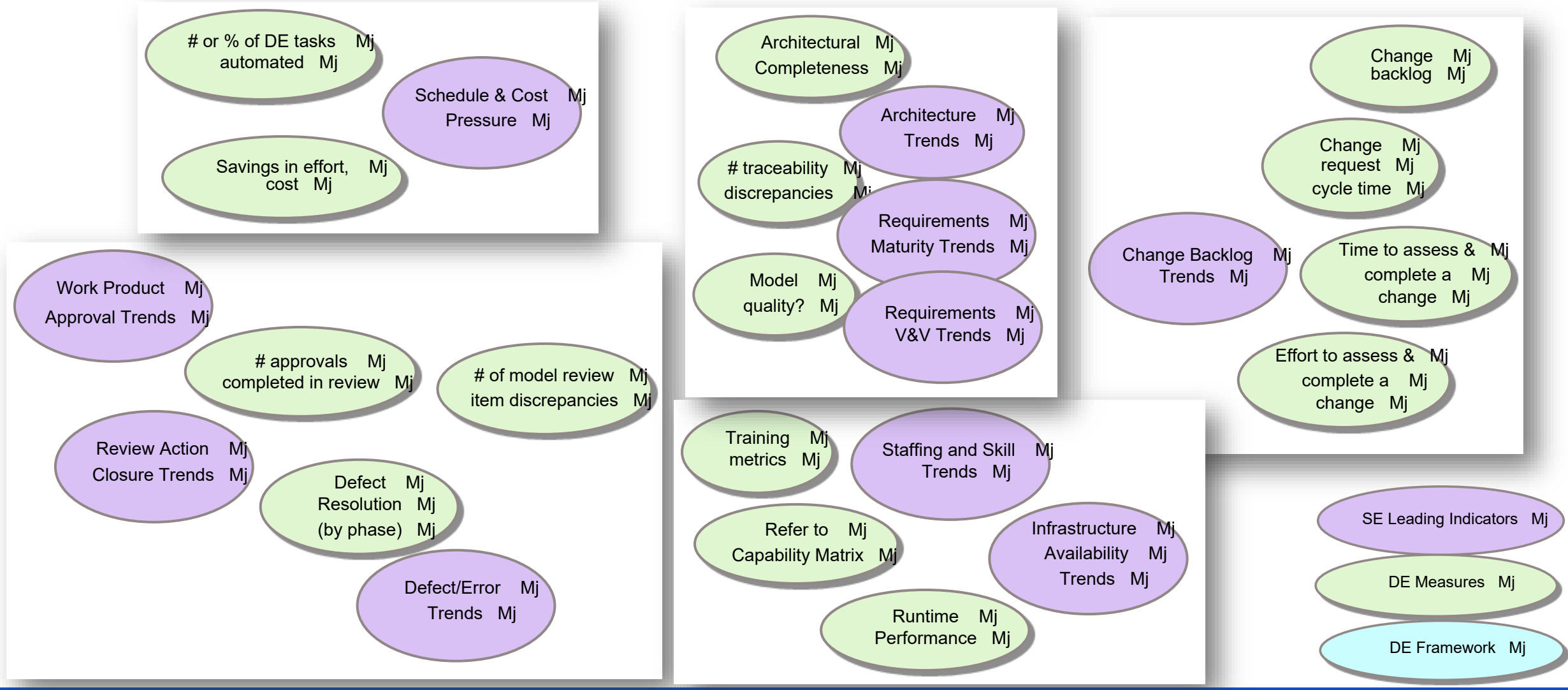
Goal	Purpose Issue Object (process) Viewpoint	Improve The ability to detect Errors/ defects In the system
Question		Are we containing defects into earlier phases?
Metrics		Defect resolution (by phase)
Question		Are reviews effective in finding errors?
Metrics		Defect resolution (by phase) # of model review item discrepancies
Question		Are DE processes reducing defects?
Metrics		Defect resolution (by phase)
Question		Is product quality improved using DE methods?
Metrics		Successful releases

Validation Efforts

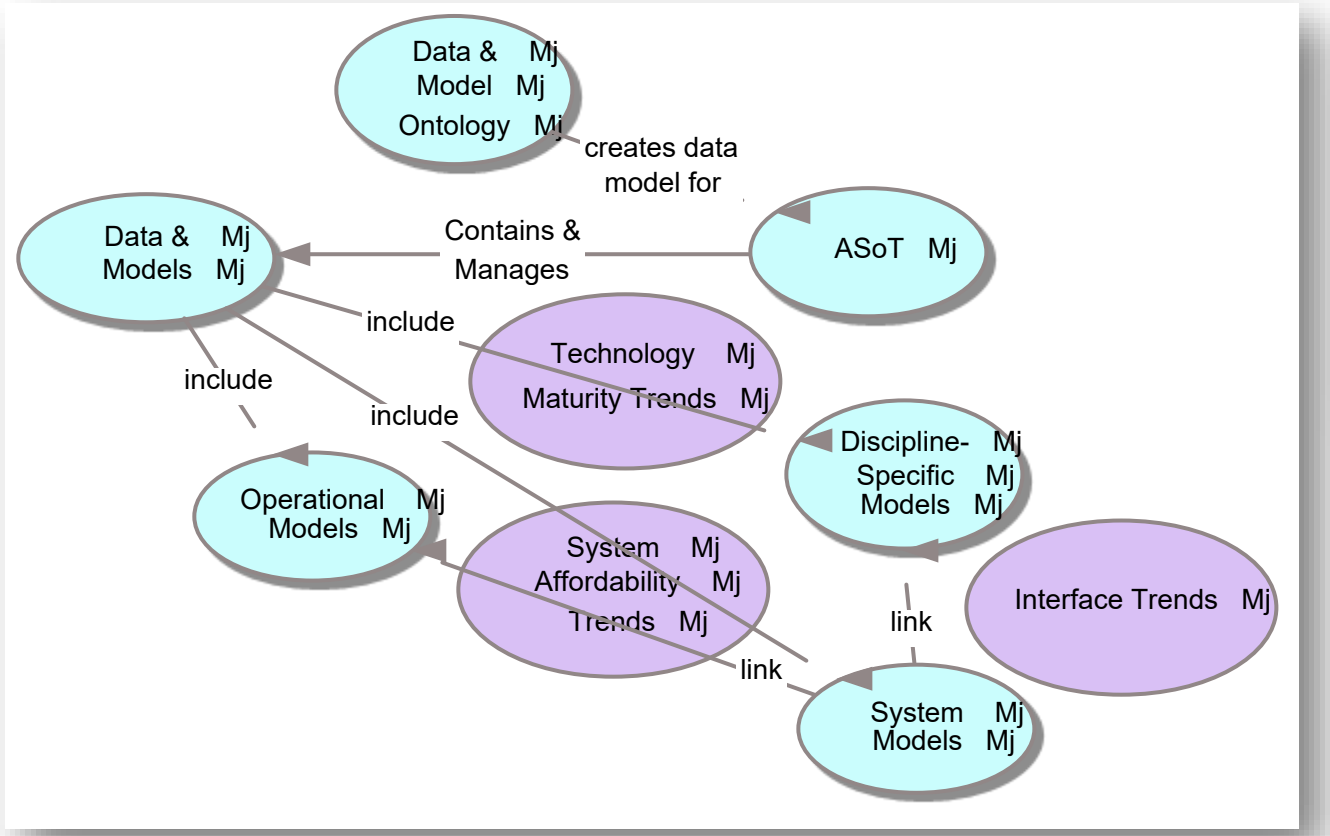
- Relation to Previous Systems Engineering Measurement Efforts
  - INCOSE/PSM/MIT Systems Engineering Leading Indicators Guide V2.0
- (Limited) Literature Review Validation
  - Submarine Warfare Federated Tactical Systems (SWFTS)
- Program Office discussions (ongoing)
- DE/MBSE Tool Capability Survey (ongoing)

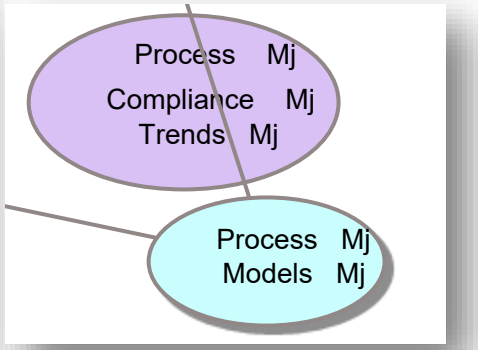
- Transition: SE Modernization Program

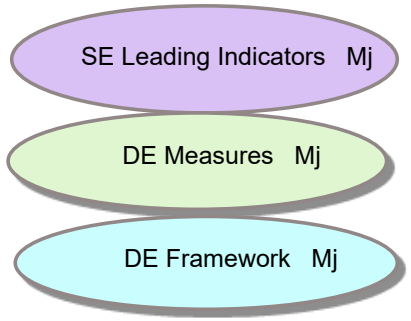
Link to Systems Engineering Leading Indicators



Link to Systems Engineering Leading Indicators







Submarine Warfare Federated Tactical Systems (SWFTS)

Case Study Validation

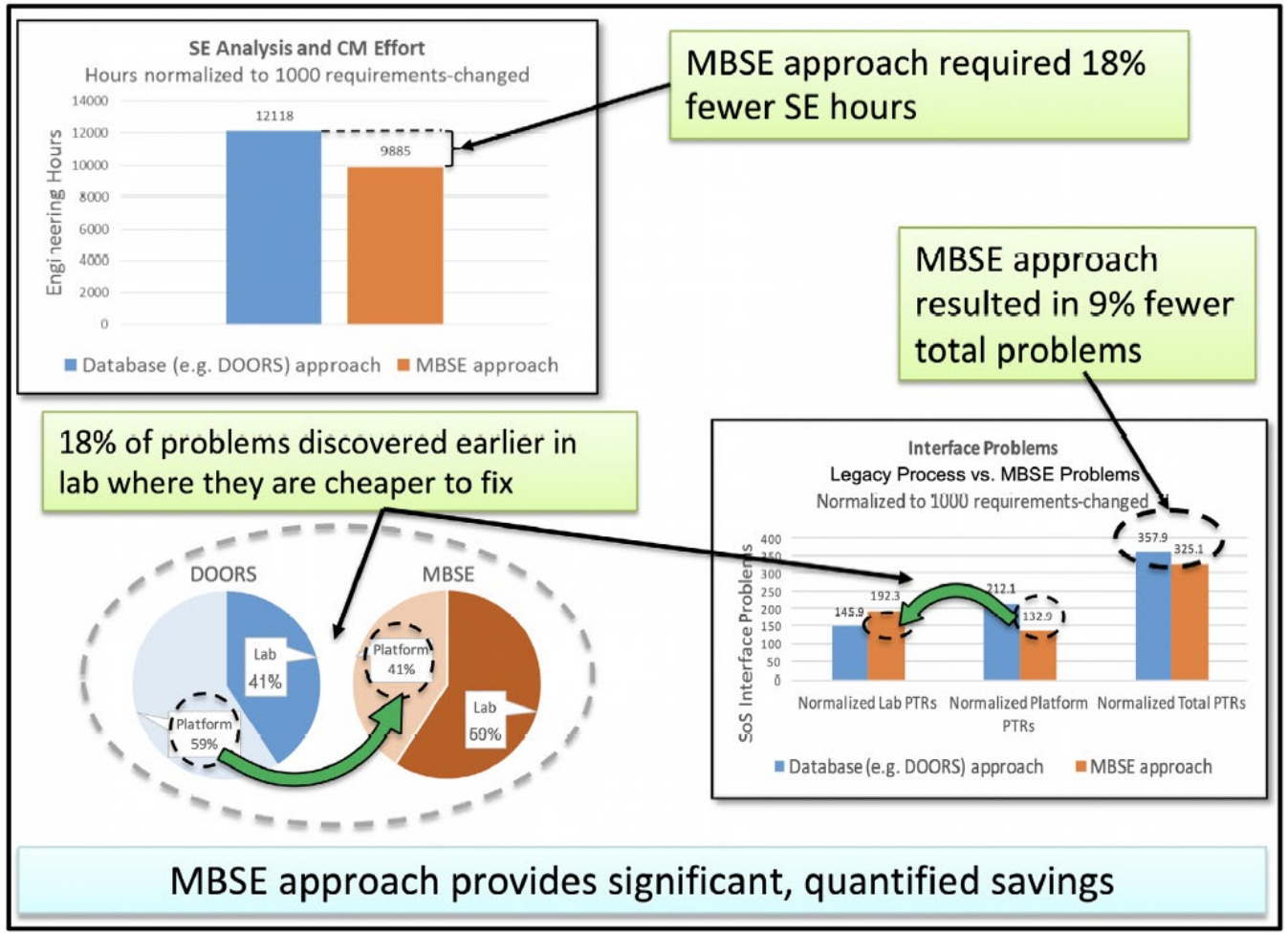
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Technology Insertion Baseline Development																							
TI00 Baseline	00	00	00	00																			
TI02 Baseline					02	02	02																
TI04 Baseline						04	04	04															
TI06 Baseline								06	06	06													
TI08 Baseline										08	08	08											
TI10 Baseline												10	10	10									
TI12 Baseline														12	12	12							
TI14 Baseline																14	14	14					
TI16 Baseline																		16	16	16			
TI18 Baseline																				18	18	18	
Platform Fielding (Class and # of hulls)																							
Los Angeles (50)						02	02	04	04	06	06	08	08	10	10	12	12	14	14	14	14	18	18
Virginia (27)						02	02	02	02	02	02	02	08	10	10	12	12	14	16	16	16	16	16
Seawolf (3)								04	04	04	04	04	08	08	08	08	08	12	12	12	12	16	16
SSGN (4)								04	04	04	04	04	10	10	10	10	10	10	10	10	10	10	18
SSBN (14)																			16	16	16	16	18
Collins (6)											06	06	06	06	10	10	10	10	14	14	14	14	18

VIRGINIA Class initial interface baseline

Common Baseline migration to cover all submarine classes as a product family

DOORS-based Commonality initiative

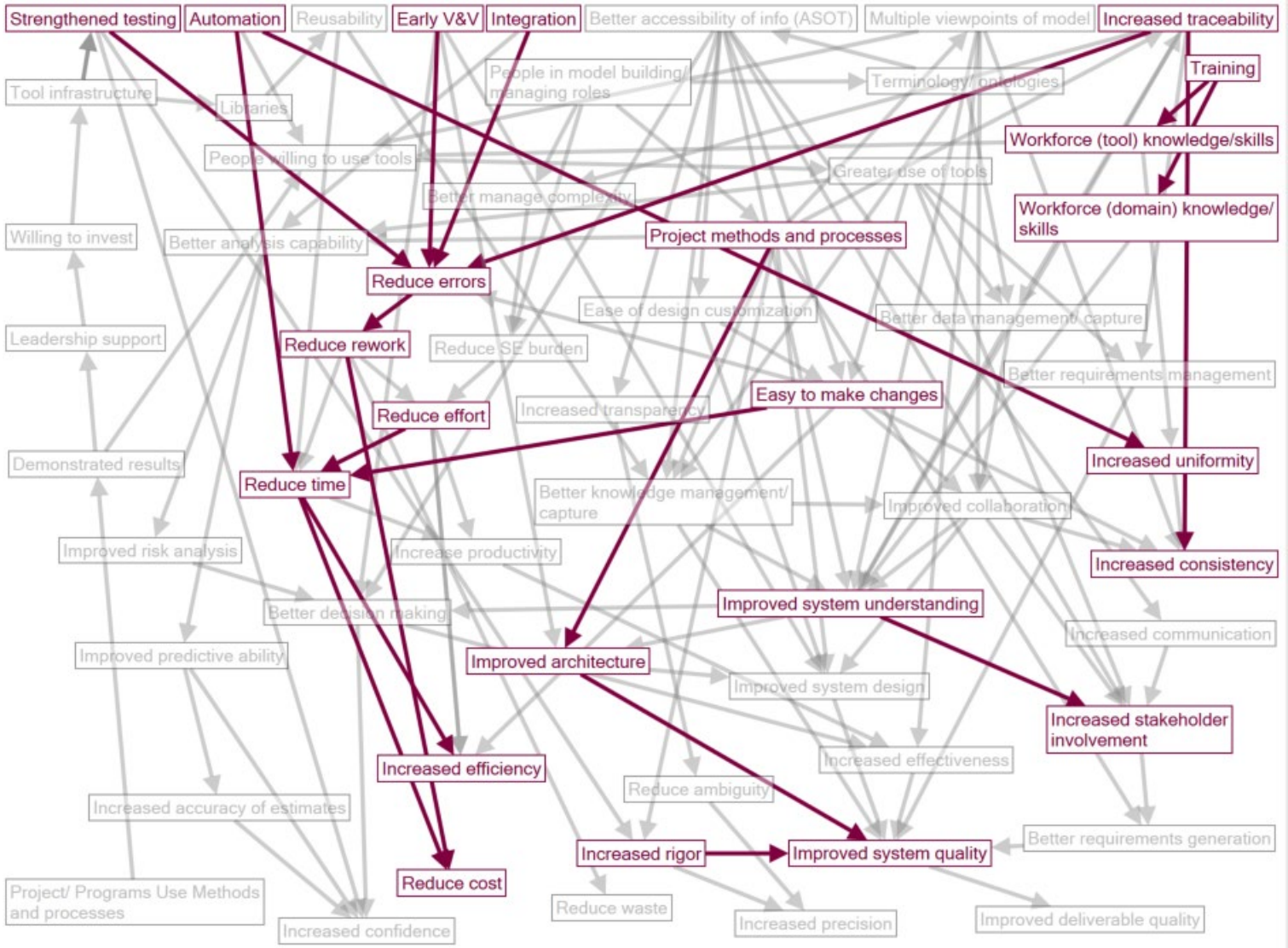
MBSE initiative



Rogers III, E. B., & Mitchell, S. W. (2021). MBSE delivers significant return on investment in evolutionary development of complex SoS. Systems Engineering.

Model Validation (n=1)

- Application of MBSE to Submarine Warfare Federated Tactical Systems (SWFTS) program
- Measured monetary and operational benefits



Rogers III, E. B., & Mitchell, S. W. (2021). MBSE delivers significant return on investment in evolutionary development of complex SoS. Systems Engineering.

Further Validation Efforts

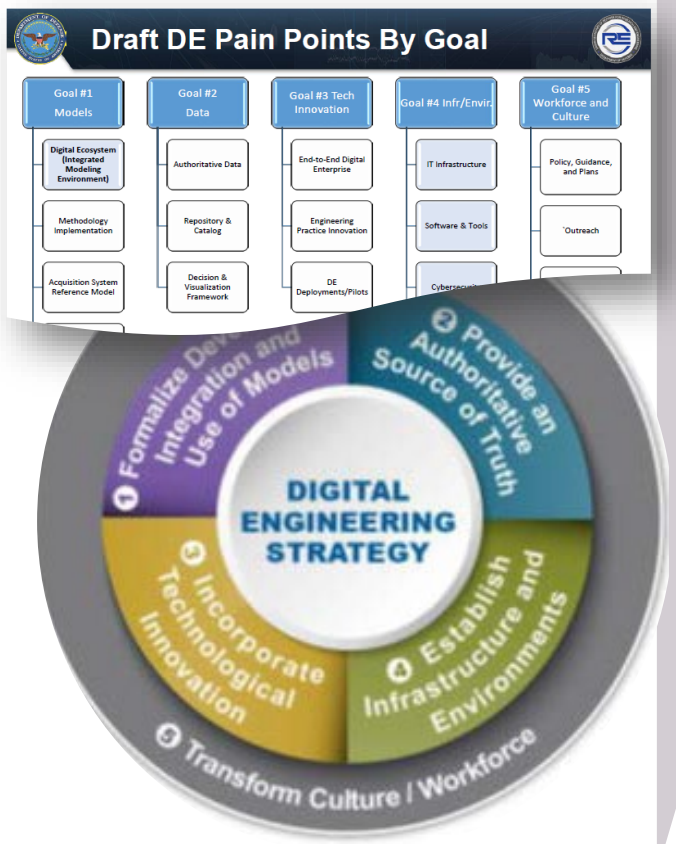
- Program Office discussions (ongoing)
- DE/MBSE Tool Capability Survey (ongoing)

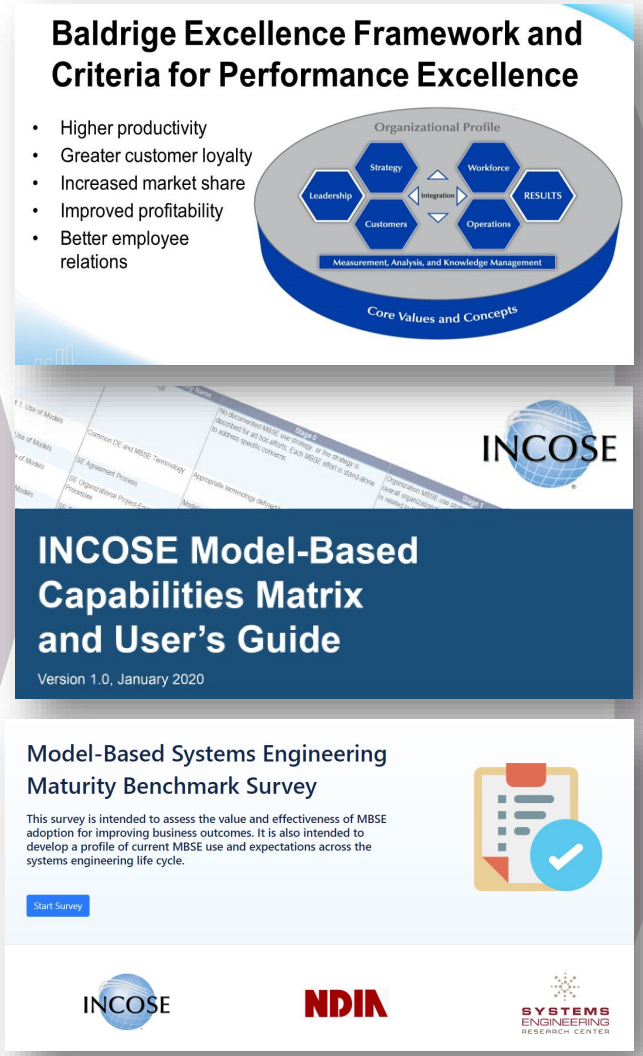
- Transition: SE Modernization Program

Questions?

Backup slides

SERC Research Program on DE Metrics





Metrics Framework:
Digital Engineering Value, Benefits, and Adoption

Metrics Application

Summary DE Success Measures Framework

Models are used to inform enterprise and program decision making

An enduring, authoritative source of truth is used over the lifecycle

Use technological innovation to improve engineering practices

Infrastructure and environments support improved communication and collaboration

Transform culture and workforce engineering across the lifecycle

Quality:
- Reduce Errors/Defects
- Improve System Quality
- Improve Traceability
- Reduce Cost

Knowledge Transfer:
- Better access to information
- Better communication/ info sharing
- Collaboration

Velocity/Agility:
- More Reuse
- Improve Consistency
- Increase Efficiency
- Support Integration
- Reduce Time

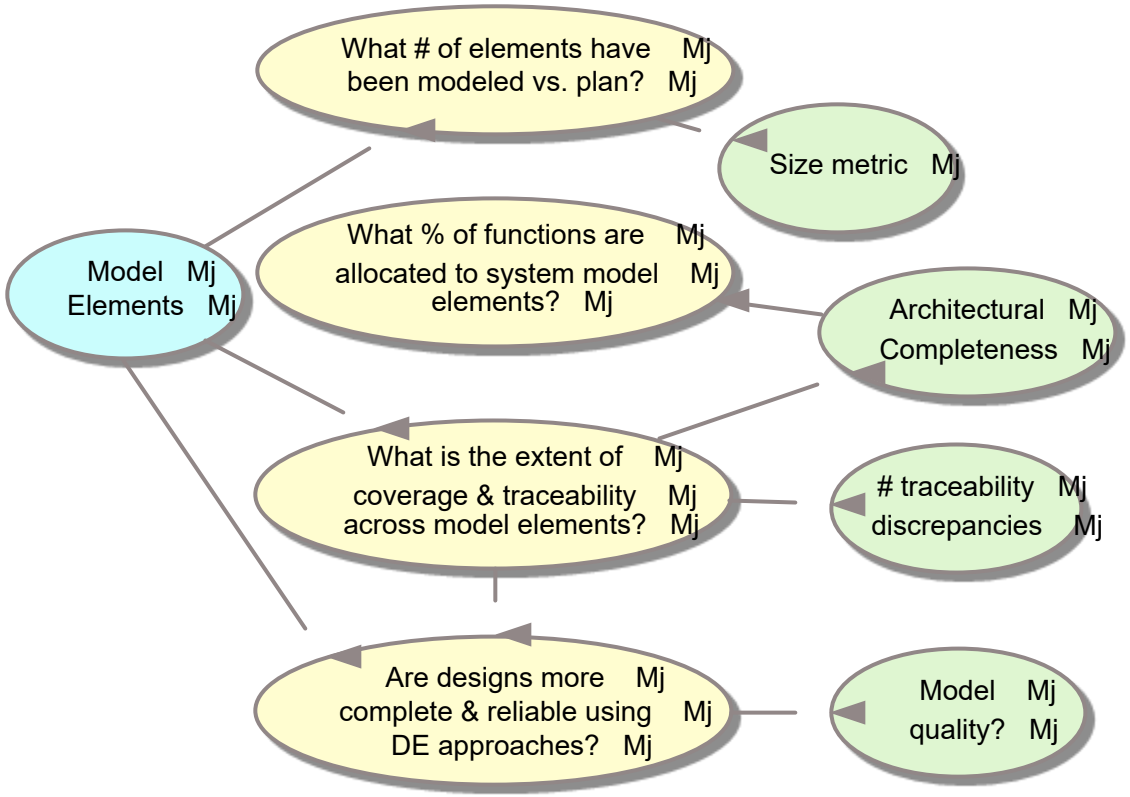
User Experience:
- Manage Complexity
- Improved System Understanding
- Automation

Adoption:
- Methods/Processes
- Roles/Skills
- Training/Tools
- Leadership support
- Change Mgmt Process
- Resources

Direct Benefits

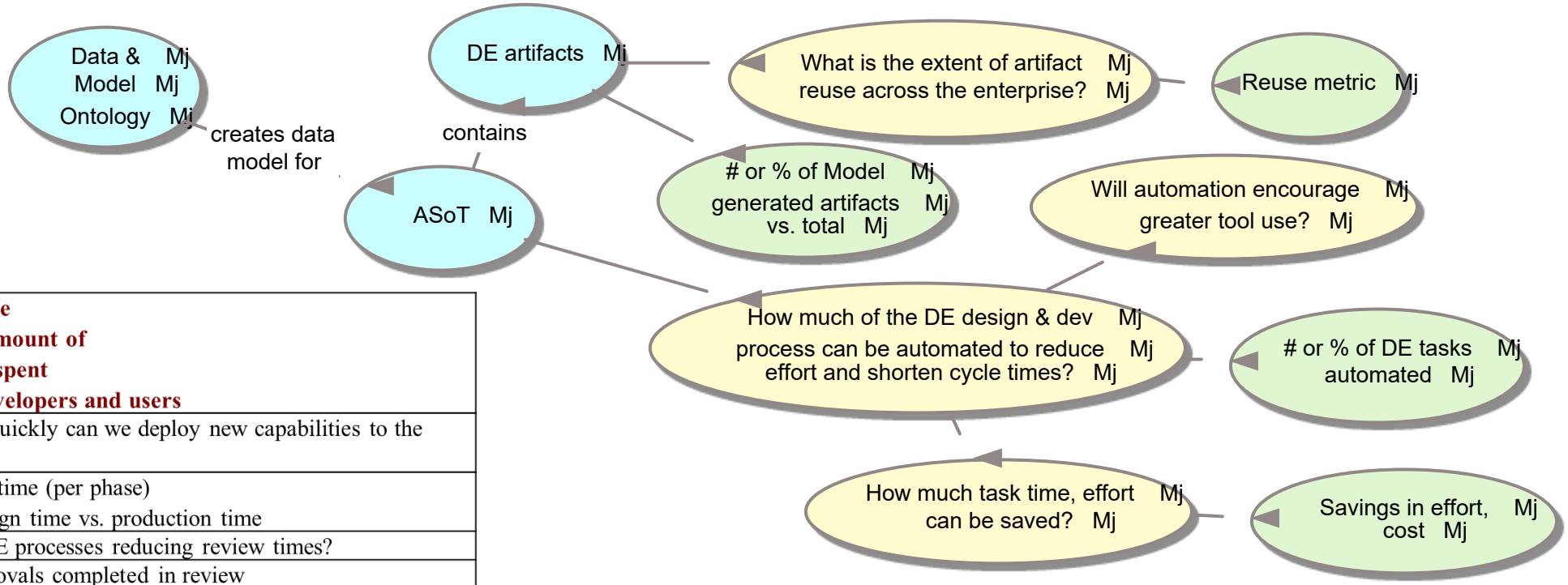
Direct Benefits	Definition
Higher level support for automation	Use of tools and methods that automate previously manual tasks and decisions
Early V&V	Moving tasks into earlier development phases that would have required effort in later phases
Reusability	Reusing existing data, models, and knowledge in new development
Increased traceability	Formally linking requirements, design, test, etc. through models
Strengthened testing	Using data and models to increase test coverage in any phase
Better accessibility of information (ASOT)	Increasing access to digital data and models to more people involved in program decisions
Higher level support for integration	Using data and models to support both the integration of information and system integration tasks
Multiple viewpoints of model	Presentation of data and models in the language and context of those that need access

Improve Quality – Increased Traceability



Goal	Purpose Issue Object (process) Viewpoint	Improve The quality of Traceability across elements Of the system
Question		What # of elements have been modeled v. planned?
Metrics		Size metric
Question		What % of functions are allocated to system model elements?
Metrics		Architectural completeness
Question		What is the extent of coverage and traceability across model elements?
Metrics		Architectural completeness # traceability discrepancies
Question		Are designs more complete and reliable using DE approaches?
Metrics		Model quality? Inconsistencies across stakeholders?

Automation & Reuse



Goal / Purpose / Issue / Object (process) / Viewpoint	Reduce / The amount of / Time spent / By developers and users
Question	How quickly can we deploy new capabilities to the field?
Metrics	Cycle time (per phase) % design time vs. production time
Question	Are DE processes reducing review times?
Metrics	# approvals completed in review Amount of review data captured digitally
Question	What is the extent of artifact reuse across the enterprise?
Metrics	Reuse metric
Question	How much of the DE design and development process can be automated to reduce effort and shorten cycle times?
Metrics	# or % of DE tasks automated
Question	How much task time can be saved due to automation?
Metrics	Savings in cost (labor hours)

Digital Infrastructure for Collaboration