International Council on Systems Engineering
A better world through a systems approach

Achieving Harmony in System Design:

Balancing Optimal Performance Across the Engineering Specialities in a Solution

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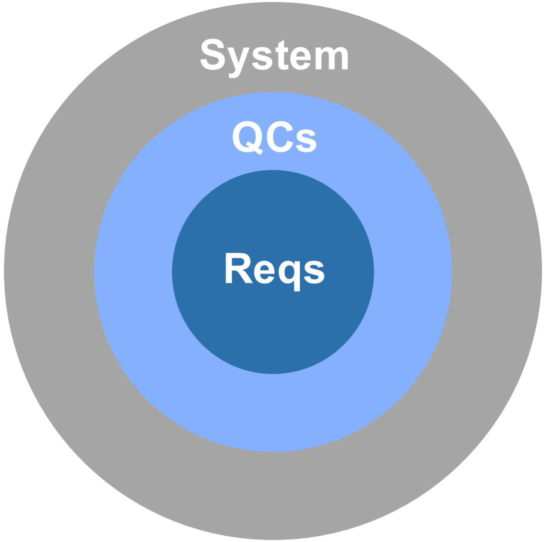
What are Engineering Specialities (ESs)?

- Definitions –
  - "A cluster of interests, including but not limited to such areas as availability, maintainability, reliability, safety, human factors, & usability. These "ilities" requirements are referred to as "critical quality characteristics"" (ISO/IEEE 24748-1)
  - "**Quality Characteristics (QC):** an inherent characteristics of a product, process, or system related to a requirement" (INCOSE SE Handbook)
- QC approaches are typically known as Engineering Specialities (ESs)
- Often ESs are those disciplines that are NOT considered "mainstream " engineering disciplines
  - Examples of "mainstream" engineering disciplines - systems engineering, software engineering, chemical engineering, mechanical engineering, electrical engineering, etc



Engineering Specialities, including "ilities"

- Accessibility
- Accountability
- Adaptability
- Administrability
- Affordability
- Agility
- Availability
- Capability
- Composability
- Configurability
- Compatibility
- Demonstrability
- Deployability
- Durability

- Connectivity
- Cybersecurity
- Ecodesign
- Human Systems Integration
- Industrialisation
- Life Cycle Costs

- Executability
- Extensibility
- Evolvability
- Fidelity
- Flexibility
- Functionality
- Integrability
- Interoperability
- Interpretability
- Maintainability
- Manageability
- Mobility
- Modifiability

- Performability
- Portability
- Practibilty
- Practicality
- Predictability
- Producibility
- Recoverability
- Reliability
- Repeatability
- Responsibility
- Reusability
- Scalability
- Serviceability

- Logistics Eng
- Modularity
- Resilience
- Robustness
- Safety Eng
- Security Eng

- Supportability
- Suitability
- Survivability
- Tailorability
- Testability
- Traceability
- Trainability
- Transportability
- Trustability
- Understandability
- Upgradability
- Usability
- Verifiability
- Vulnerability

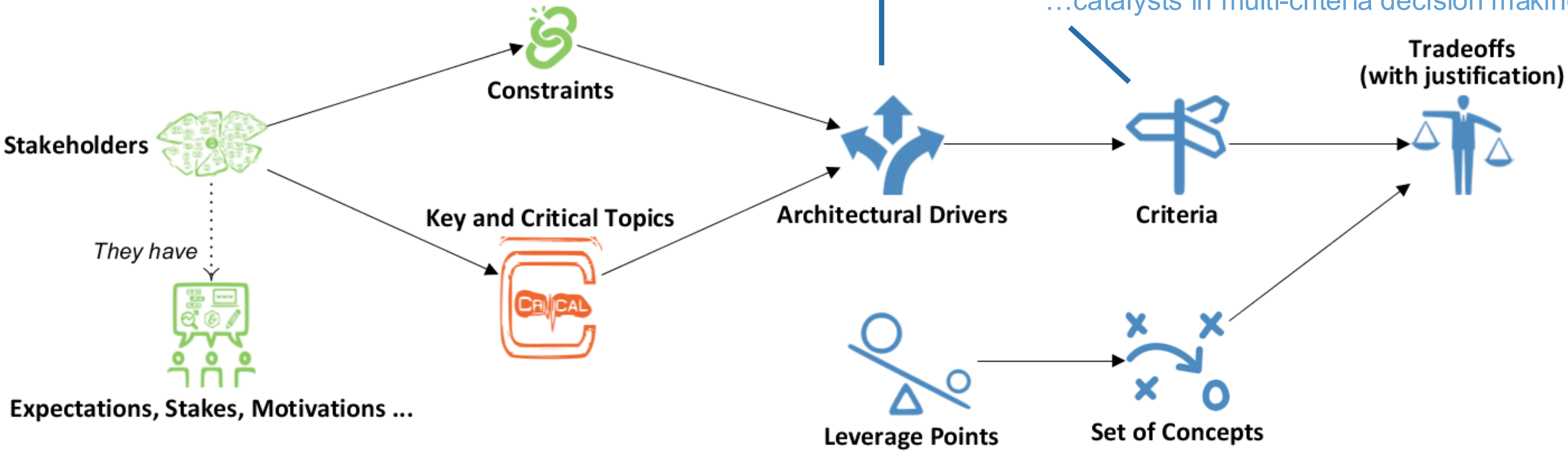
New specialities continue to emerge

Importance of Engineering Specialities

- Engineering Specialities are often…

…key factors influencing, shaping, or constraining the design of a system's architecture

…catalysts in multi-criteria decision making



…"places within a complex system where a small shift in one thing can produce big changes in everything"

Source:

1. Diagram adapted from Thales Advanced Architecting training material
2. For understanding more about leverage points see Donella Meadows, Leverage Points: Places to Intervene in a System (http://donellameadows.org/wp-content/userfiles/Leverage_Points.pdf)

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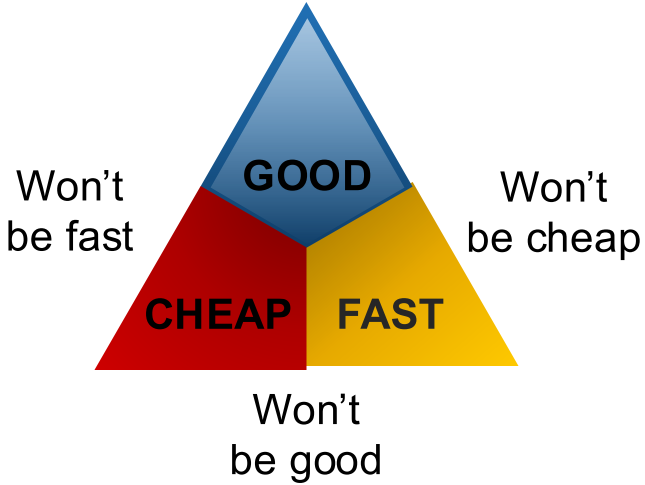
Dilemma – Optimising vs Balancing

How do you avoid hidden technical debt?



How do you target the most valuable Engineering Specialities?

How do you provide balance across the identified valuable Engineering Specialities?

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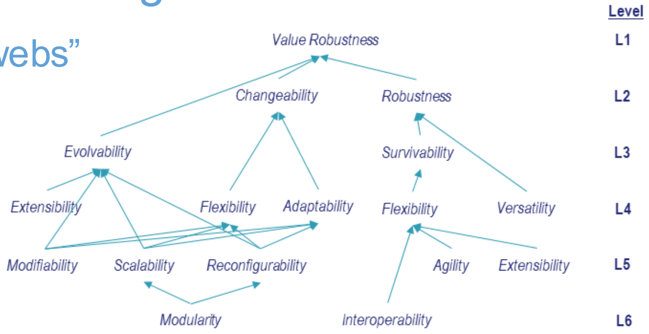
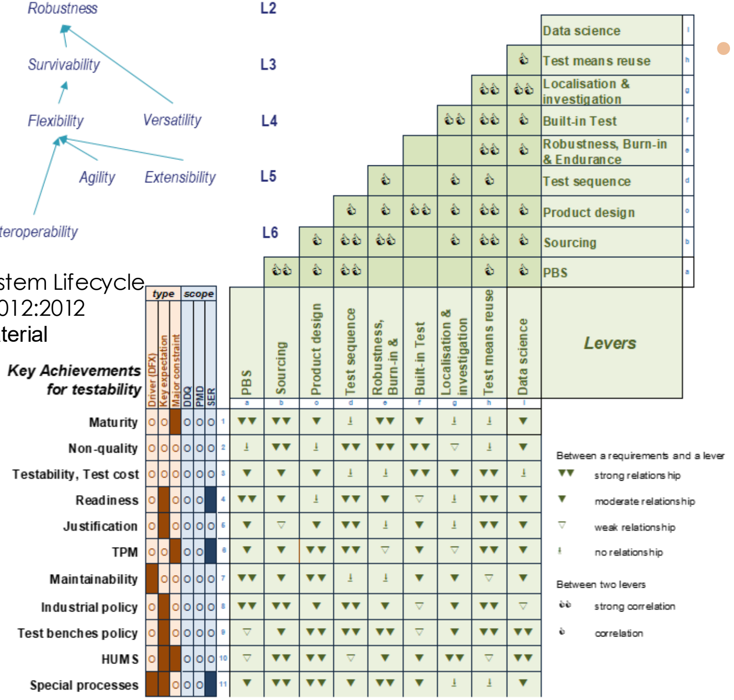
What Next?

- Consider using methods such as…
  - "ilities webs"



Sources:
1. Investigating Relationships & Semantic Sets amongst System Lifecycle Properties (Ilities) De Weck, Rhodes & Ross MIT ESD-WP 2012:2012
2. HoQ diagram from Thales Advanced Architecting training material

  - Houses of Quality (HoQs)



- But what is the impact on the overall System mission(s)

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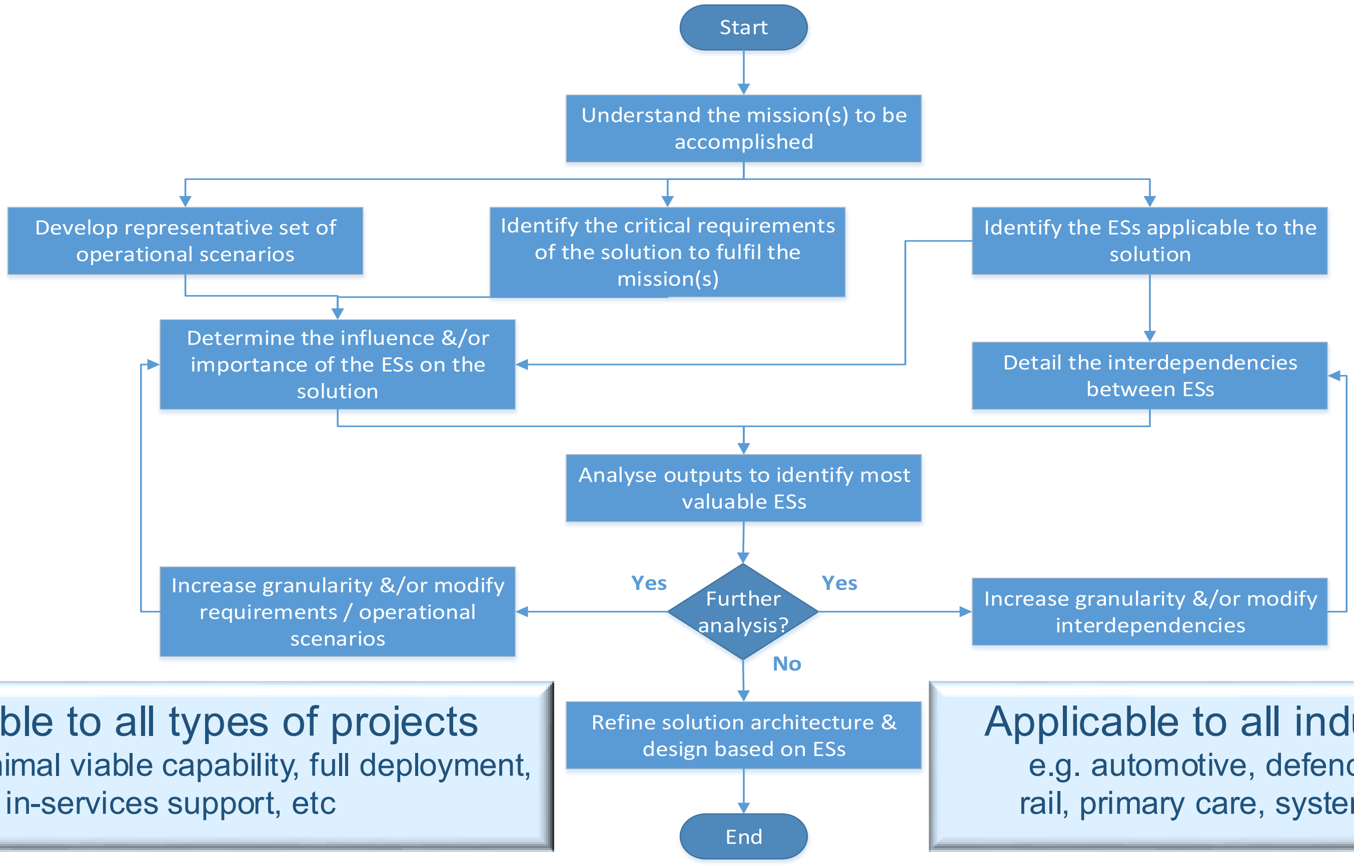
Back to Basics from the ES Perspective



Applicable to all types of projects
e.g. R&D, minimal viable capability, full deployment, in-services support, etc

Applicable to all industries/domains
e.g. automotive, defence, healthcare, etc
rail, primary care, systems of systems, etc

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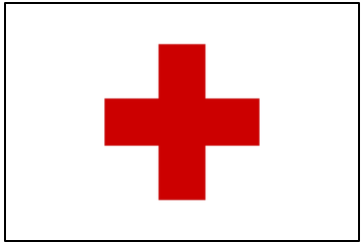
Examples - Case Studies (CS)

- CS1 – Drone Countermeasures (DCM)
  - Provides counter-drone capability to effectively defend against drone strikes. Also includes AI assistance for onboard diagnostics, detection patterns, & access restrictions based on biometrics
  - Identified ESs for "balancing" e.g. -
    - Safety
    - Security
    - EMI/EMC
    - Reliability
    - Supportability
    - Human Factors
    - Operational training
    - Performance

- CS2 – Mobile Medical Unit (MMU)
  - Provide a self-contained, transportable facility equipped to provide medical services in various locations, especially where permanent healthcare infrastructure is limited or unavailable. It includes solar & generator hybrid systems for off-grid operations, AI assistance for diagnostics for remote triage, & predictive maintenance for onboard equipment
  - Identified ESs for "balancing" e.g. –
    - Security
    - Safety
    - Reliability
    - Portability
    - Performance
    - Testability
    - Human Factors
    - Maintainability



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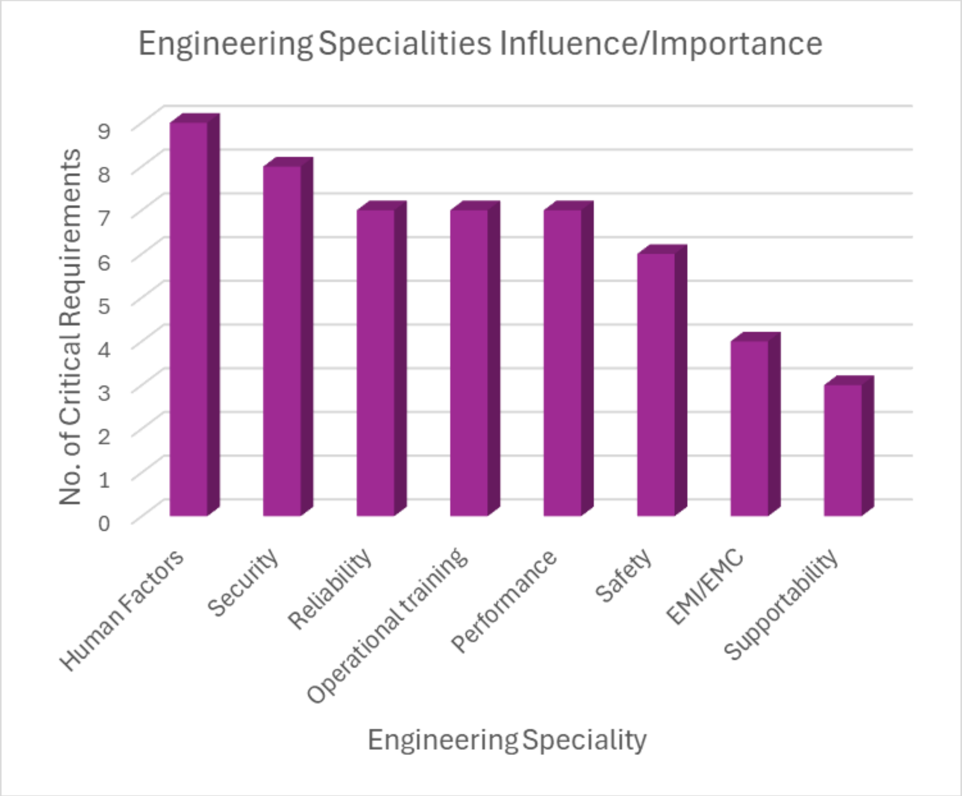
CS1 – DCM ES & Critical Requirements

- Subset of critical requirements –
  - Accurate area coverage
  - Time to detect
  - Time to react to “kill”
  - Threat accuracy
  - Kill accuracy
  - Restricted access to the counter-drone system
  - Availability of counter-drone system
  - Mobility of counter-drone system
  - Scalability of counter-drone system



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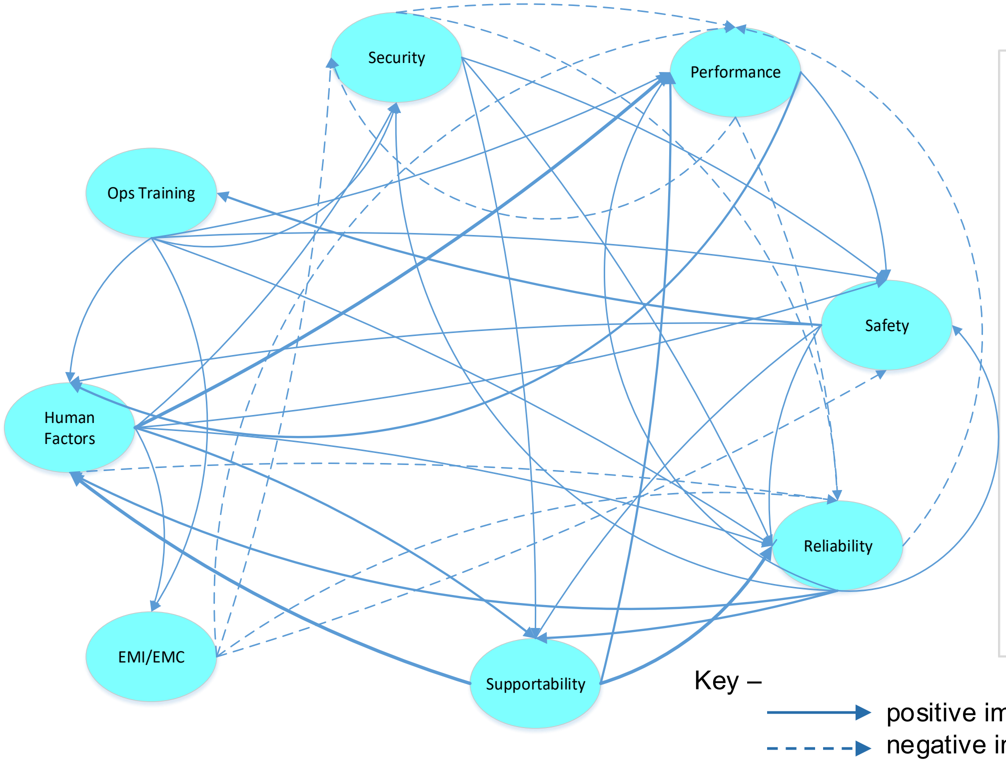
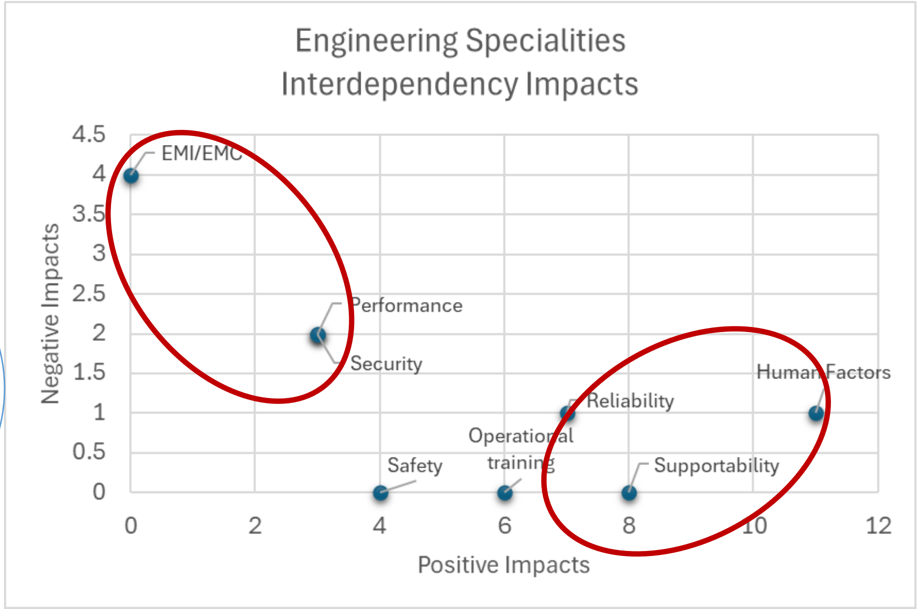
CS1 – DCM ES Interdependencies



Engineering Specialities Interdependency Network



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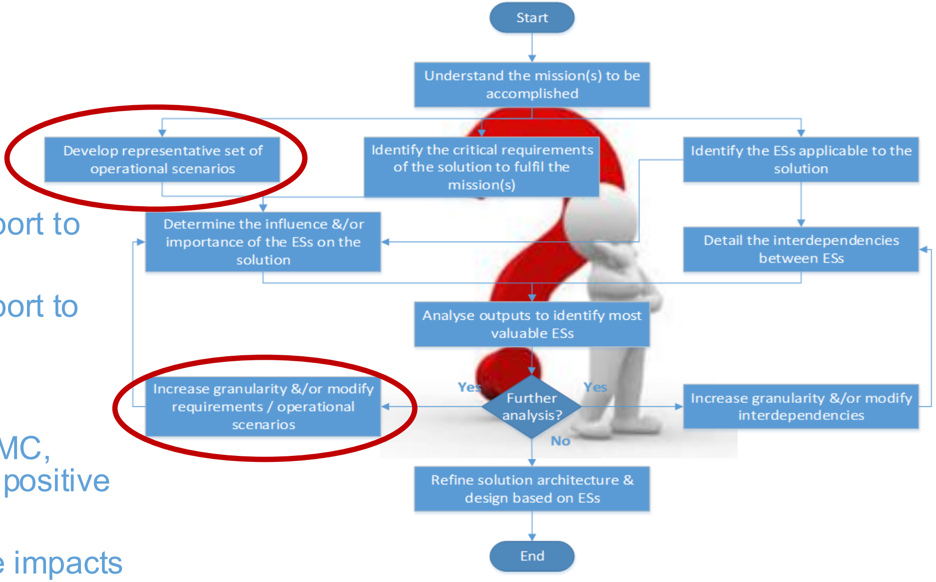
CS1 – DCM Results

- Based on critical requirements analysis –
  - Human Factors & Security have the greatest impact
  - EMI/EMC & Supportability have the least impact
- Based on ESs interdependency network –
  - Human Factors & Supportability provide the greatest support to other ESs
  - EMI/EMC, Security, & Performance provide negative support to other ESs
- Based on ESs interdependency impacts –
  - Need to focus on reducing the negative impacts of EMI/EMC, Security, & Performance, while maintaining/improving the positive impacts
  - Protect the integrity of Human Factors to reap the positive impacts on the other ESs



Get clarity through further analysis using operational scenarios

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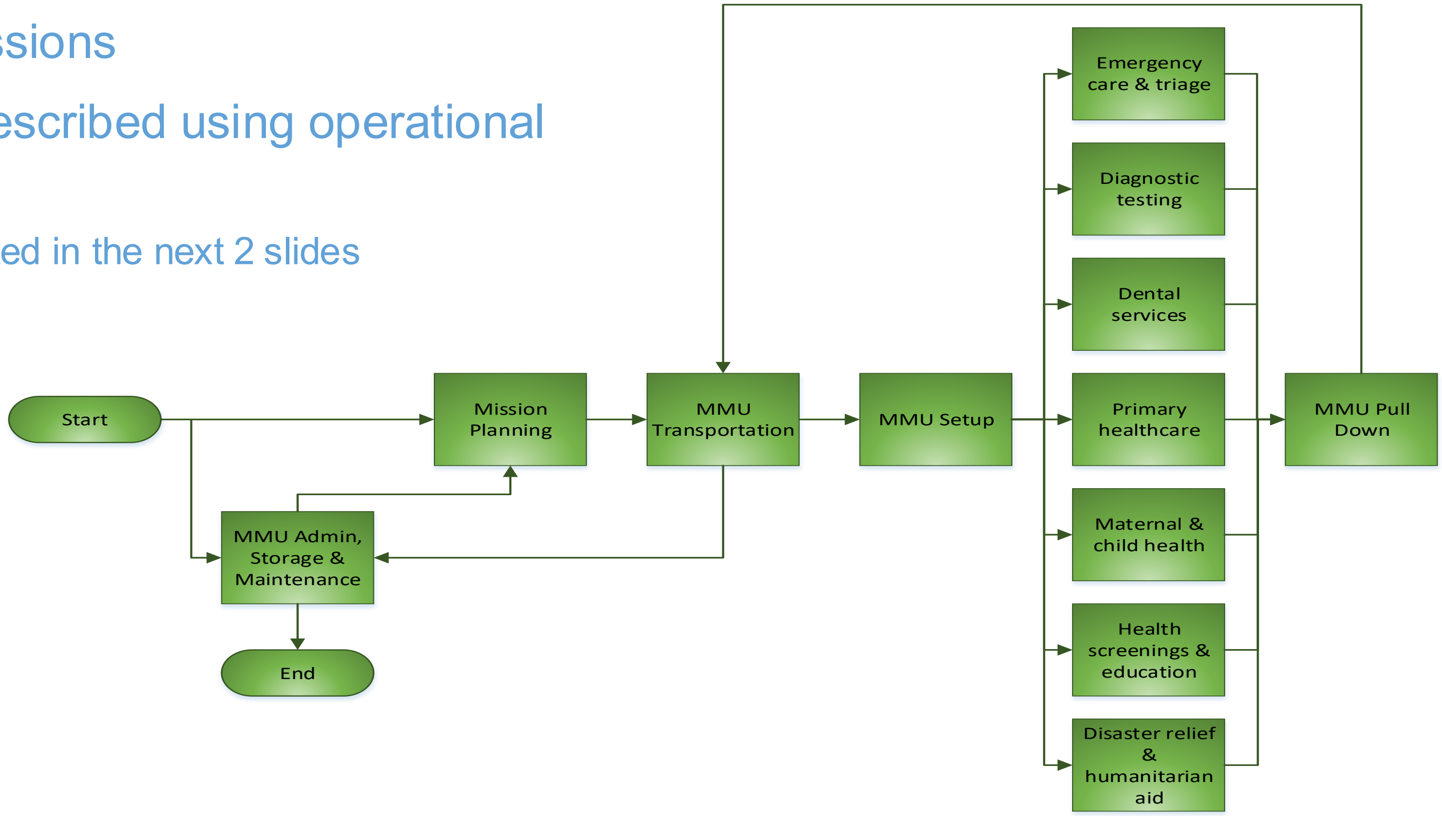
CS2 – MMU Missions

- Six primary missions
- Missions are described using operational scenarios
  - Examples illustrated in the next 2 slides



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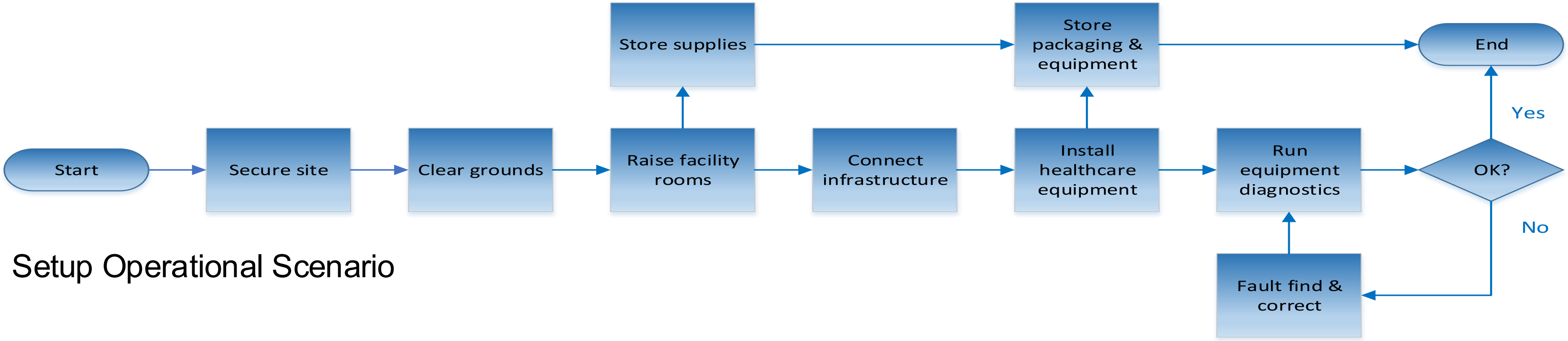
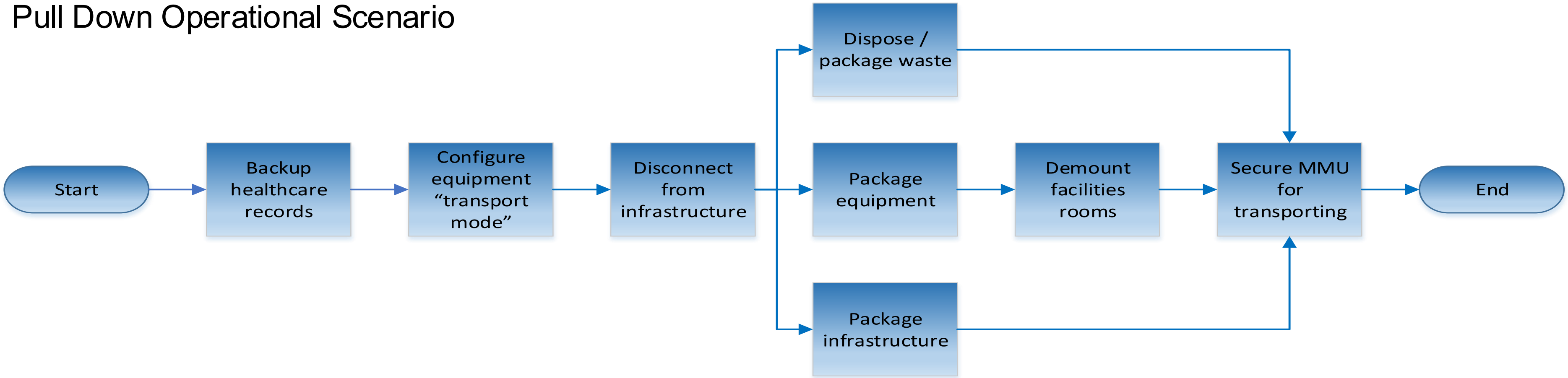
CS2 – MMU Mission Description Examples (1/2)



Setup Operational Scenario

Pull Down Operational Scenario



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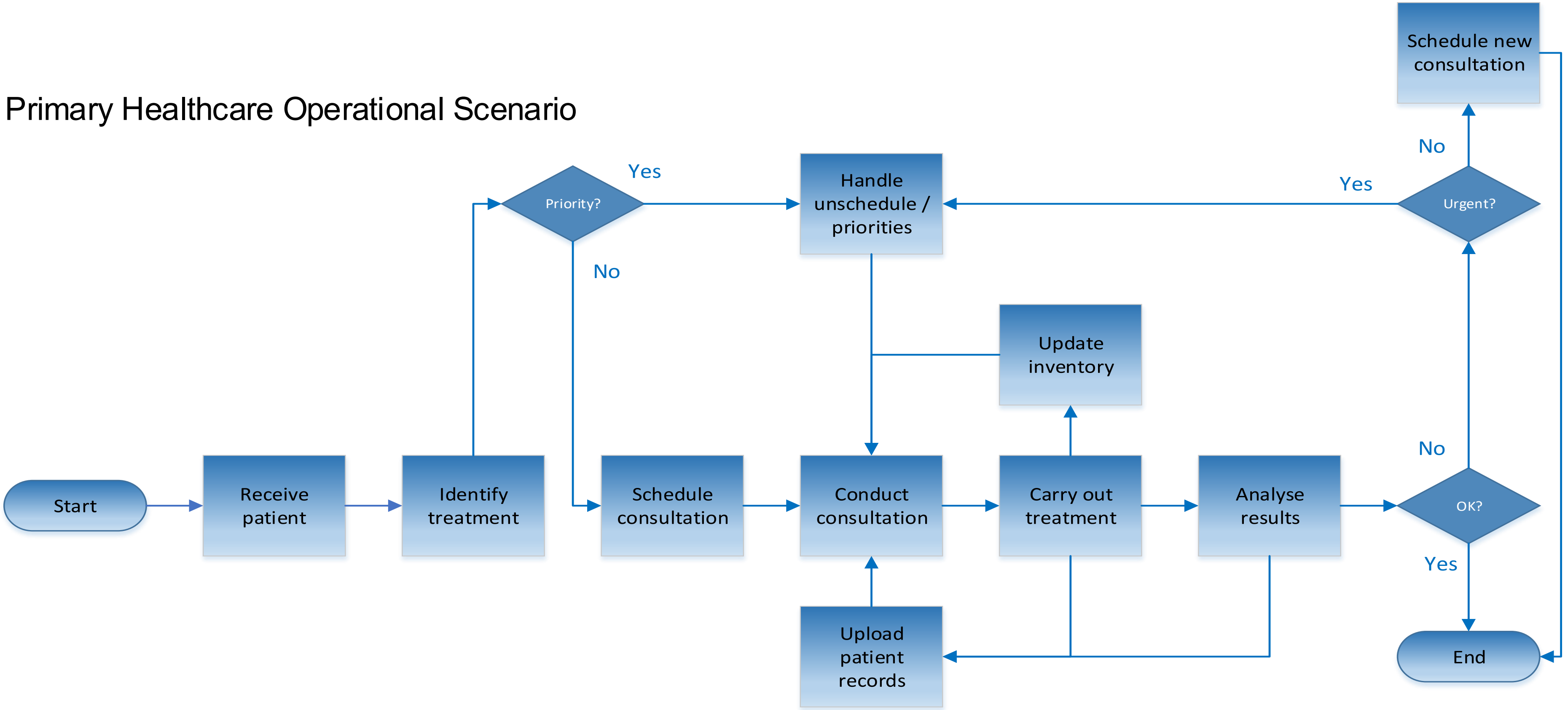
CS2 – MMU Mission Description Examples (2/2)

Primary Healthcare Operational Scenario



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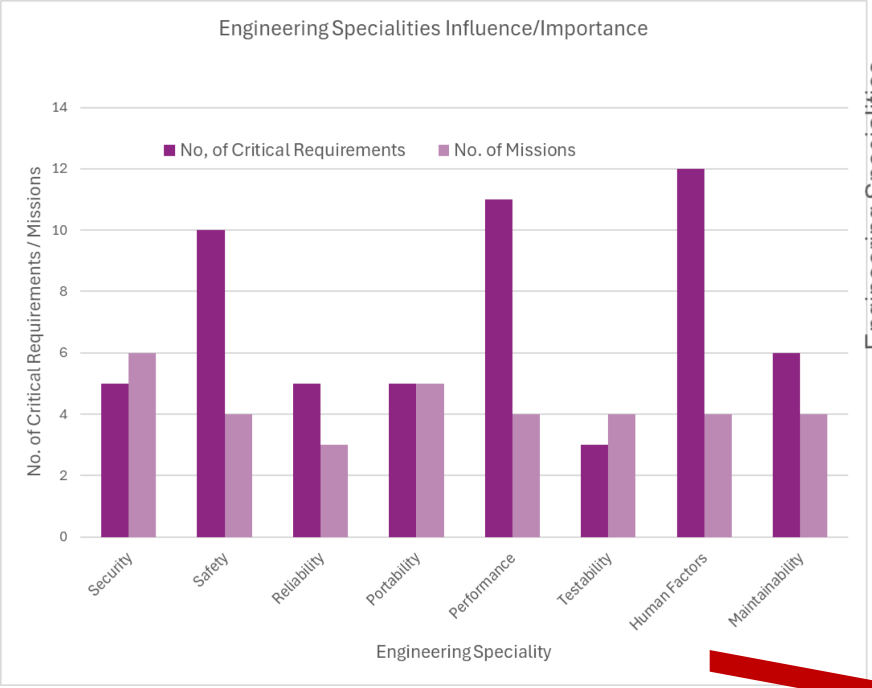
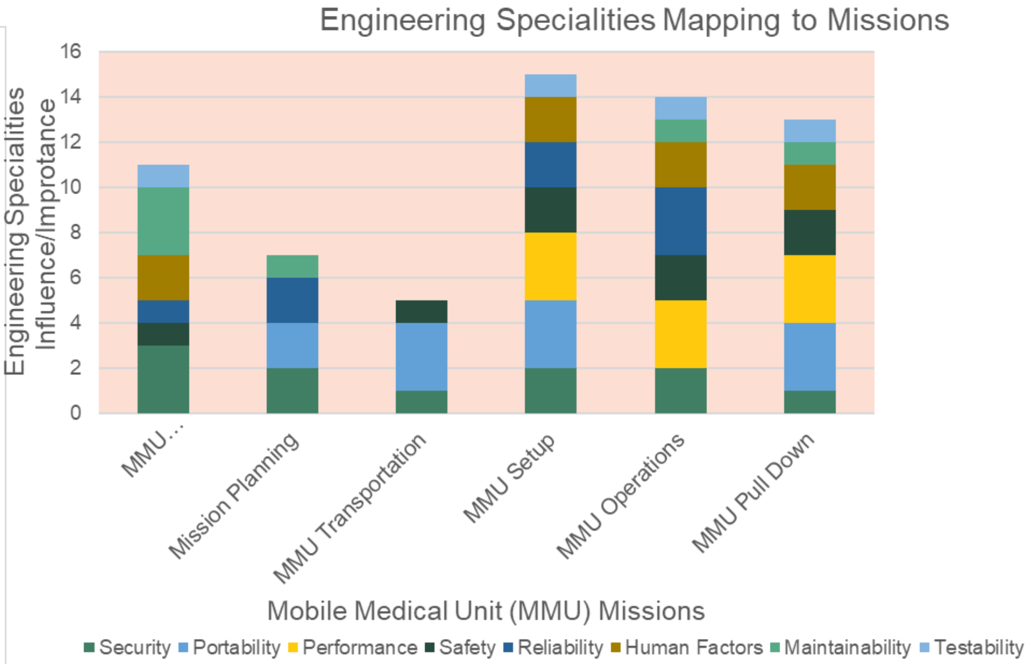
CS2 – MMU ES & Critical Requirements & Missions





ES Heat Map

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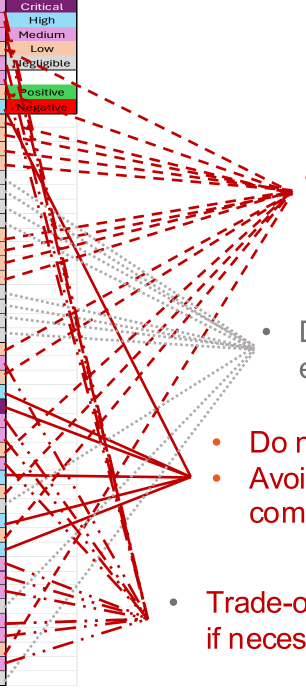
CS2 – MMU ES Impacts Based on Operational Scenarios

- Requirements are mapped to a mission determined through the applicable operational scenario
- ES mapped based on the requirement in a specific operational scenario / mission

Mission	Critical Requirements														Engineering Specialty	Engineering Specialty Ranking		
	Protection of patient records	Protection of networked equipment	Simple patient/ equipment interface	High reliability - equipment level	High reliability - MMU level	Fabrication of rooms <=4 people	Equipment <= 2 people lift	Setup <=4 hrs	Pull down <= 4 hrs	Triaging (receipt, identify, schedule) <= 20mins	Automated self tests	Clear equipment operation procedures	Equipment self diagnostics	HUMS		Positive Potential Impacts	Negative Potential Impacts	Total Potential Impacts
MMU Admin, Storage, & Maintenance															Security	6	0	6
															Safety	4	0	4
															Reliability	6	0	6
															Portability	1	0	1
															Performance	2	3	5
															Testability	4	0	4
															Human Factors	3	0	3
															Maintainability	7	0	7
Mission Planning															Security	2	0	2
															Safety	2	0	2
															Reliability	2	0	2
															Portability	2	0	2
															Performance	0	0	0
															Testability	0	0	0
															Human Factors	0	0	0
															Maintainability	0	0	0
MMU Transportation															Security	1	0	1
															Safety	1	0	1
															Reliability	1	0	1
															Portability	1	0	1
															Performance	0	0	0
															Testability	0	0	0
															Human Factors	0	0	0
															Maintainability	0	0	0
MMU Setup															Security	3	0	3
															Safety	4	0	4
															Reliability	2	0	2
															Portability	7	0	7
															Performance	7	3	10
															Testability	4	0	4
															Human Factors	5	0	5
															Maintainability	1	0	1
MMU Operations															Security	4	1	5
															Safety	6	1	7
															Reliability	2	0	2
															Portability	0	0	0
															Performance	4	5	9
															Testability	3	0	3
															Human Factors	7	0	7
															Maintainability	6	0	6
MMU Pull Down															Security	2	2	4
															Safety	3	1	4
															Reliability	0	0	0
															Portability	6	0	6
															Performance	4	1	5
															Testability	1	0	1
															Human Factors	4	0	4
															Maintainability	0	0	0

Key
Critical
High
Medium
Low
Negligible
Positive
Negative



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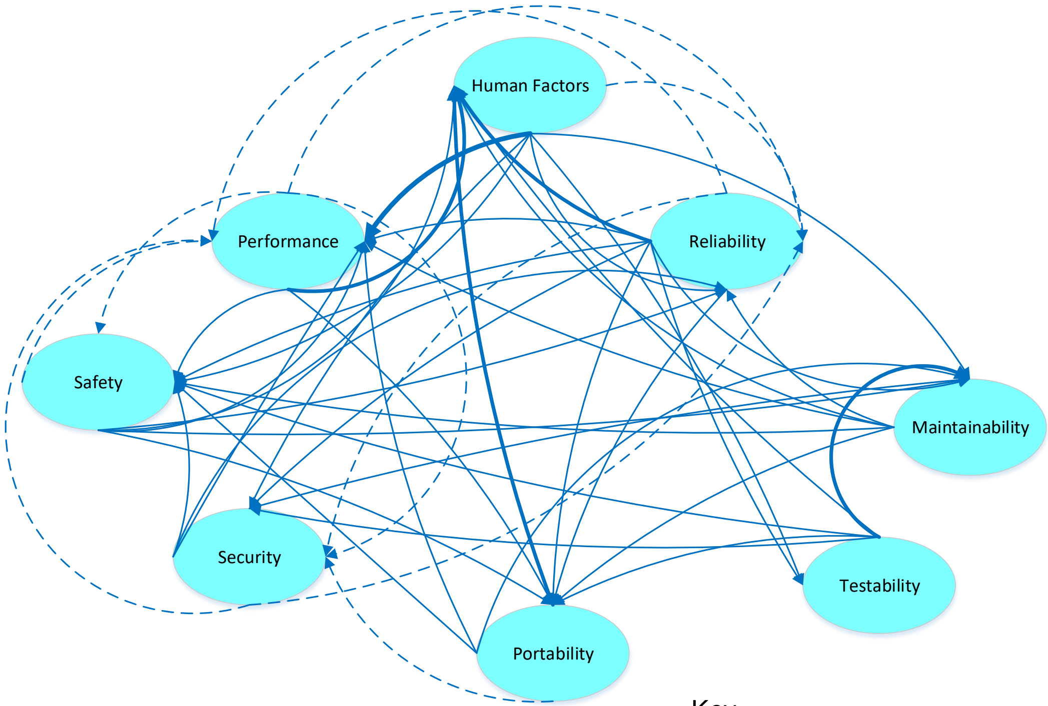
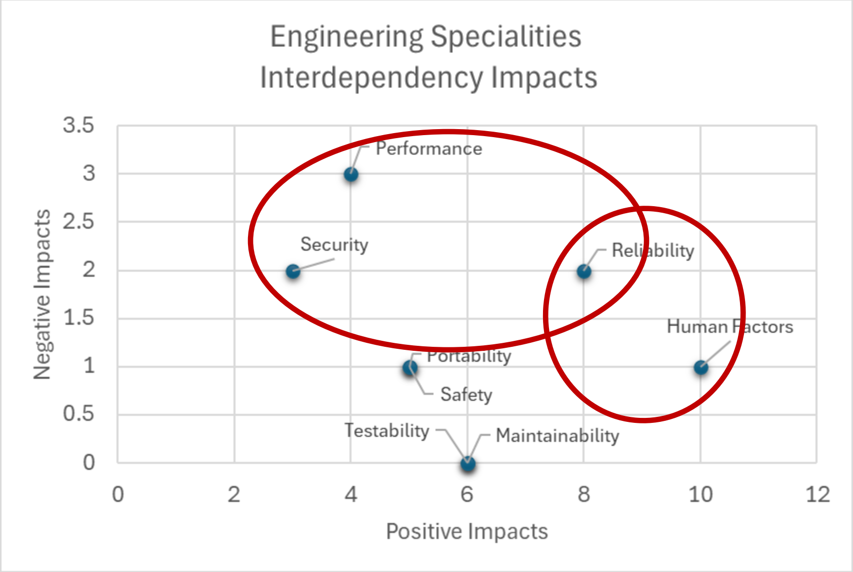
CS2 – MMU ES Interdependencies





Key –

positive impact dependency

negative impact dependency

Engineering Specialities Interdependency Network

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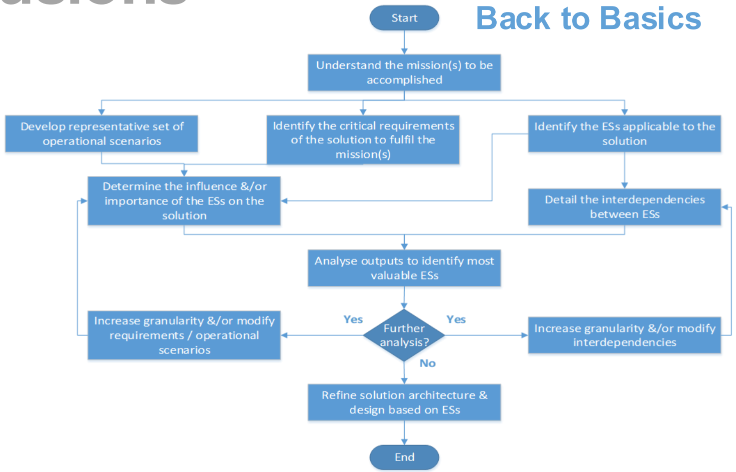
CS2 – MMU Results & Conclusions

- Based on operational analysis –
  - Safety, Performance & Human Factors rate high/critical for the Setup mission & MMU Healthcare mission
  - Maintainability & Portability also rated high but only for 1 specific mission each
  - Most combinations of security, safety, reliability & performance can potentially have a high negative impact on each other
- Based on ESs interdependencies
  - Human Factors & Reliability provide the greatest support to other Ess with the greatest positive impacts
  - Performance, Security & Reliability can negatively impact other ESs

Back to Basics



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[**Other techniques for assessing ES importance e.g. leverage points, HoQs, multi-criteria decision analysis**]

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Further clarity through knowing your Engineering Specialities

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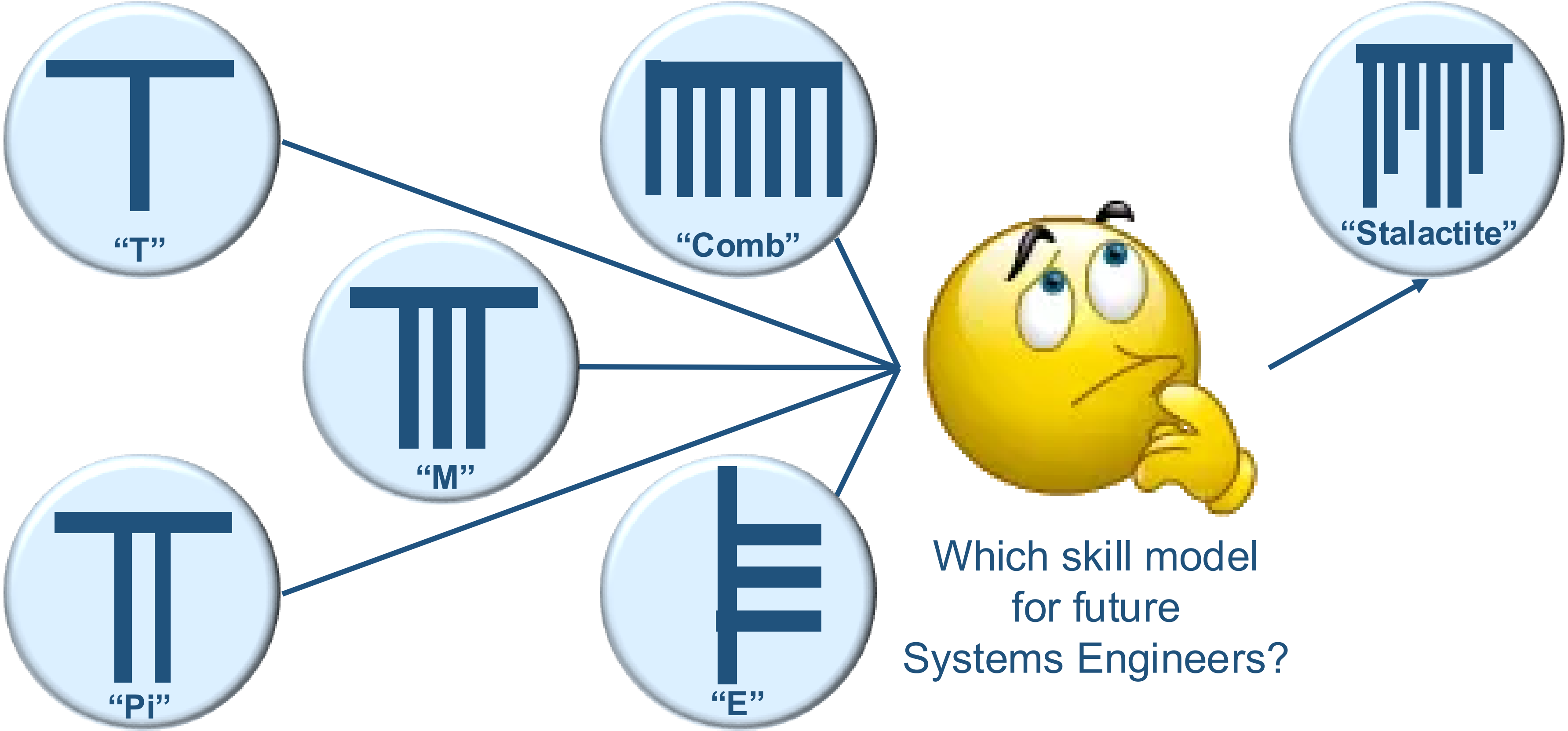
What Skills Model Best Serves Our Future?



Which skill model
for future
Systems Engineers?

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Typical SE Related Skills Model

	T-Model	Pi-Model	M-Model	Comb-Model	E-Model
Breadth	Broad general knowledge	Broad general knowledge	Moderate to wide breadth	Very broad general knowledge	Knowledge + soft / entrepreneurial skills
Depth	Deep expertise in 1 area	Deep expertise in 2 areas	Deep expertise in 3 core areas	Moderate expertise in several areas	Expertise + experience + empathy + execution
Traits	Interdisciplinary teams	Interdisciplinary teams	Multidisciplinary development	Highly adaptive roles	People-centric
Apt	Collaborative, interdisciplinary teams	Hybrid roles or dual-domain specialists	Innovation teams or multi-domain leadership	Consulting, freelancing or dynamic environments	Entrepreneurial or customer-centric leadership
Role examples	Systems engineers / product designers / researchers	UX designers / engineers	Product managers / transformation leads	Startups / systems engineers in complex integration roles	Startup founders / service designers

Stalactite Skills Model – Future System Engineers

Source: Derived by K Lunney from T-skills model concept

- Deep expertise at various levels
  - Reflects very broad general knowledge
  - 3 to 7 areas requiring various levels of moderate to deep knowledge
    - May or may not be considered an expert
    - Engineering specialities are likely to be the 3 to 7 areas requiring proficiency
  - Suitable for large &/or complex systems or systems of systems (SoS)
  - In comparison with the other skills models –

T-model	**Deep expertise in 1 area may be limiting**
Pi – model	Deep expertise in 2 areas may be limiting
M-model	Deep expertise in 3 core areas needs to be augmented with moderate to deep knowledge in at least 2-4 other areas
Comb-model	A broad range of moderate expertise in several areas may not address complexity
E-model	Complementary to the stalactite skills model

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Summary – Achieving Harmony in System Design

1. ESs are rarely realised in isolation
2. No one method or single answer to “balancing”
3. ESs influence & are influenced by the system architecture
4. Multiple ESs balancing options = multiple system architectures
5. ESs can be sources of technical debt
6. Applied to all projects & industries
7. Follow the ‘Back to Basics” process
8. Reuse ESs as important criteria input to other techniques
9. System Engineers strive to meet the “Stalactite” skills model
10. System Engineers work closely with ES experts to achieve harmony

Balancing ESs = working with a subset of “valuable” ES criteria & their interdependencies

↓

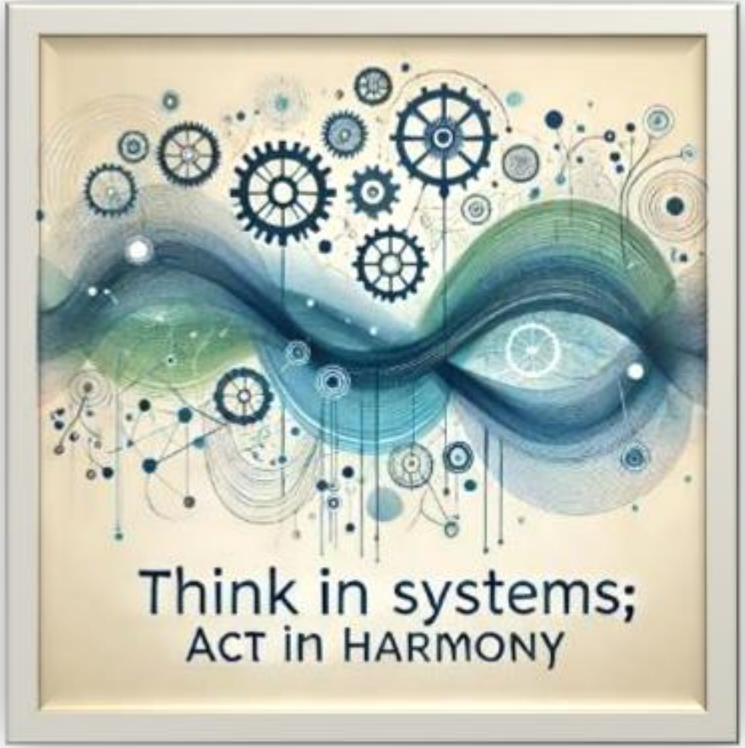
Harmony in System Design

Q&A Time

- References

  - INCOSE SEH (2023), Systems Engineering Handbook: A guide for System Life Cycle Process & Activities (5th edition), Published by John Wiley & Sons Inc
  - ISO/IEC/IEEE 15288: 2023, Systems & Software Engineering – System Life Cycle Processes
  - ISO/IEC/IEEE 24748-1: 2024, Systems & Software Engineering – Life Cycle Management
  - Investigating Relationships & Semantic Sets amongst System Lifecycle Properties (Ilities) De Weck, Rhodes & Ross MIT ESD-WP 2012:2012
  - Leverage Points: Places to Intervene in a System, Author Donella Meadows, http://donellameadows.org/wp-content/userfiles/Leverage_Points.pdf
  - Thales Advanced Architecting Training Material, 2025

Thank You



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