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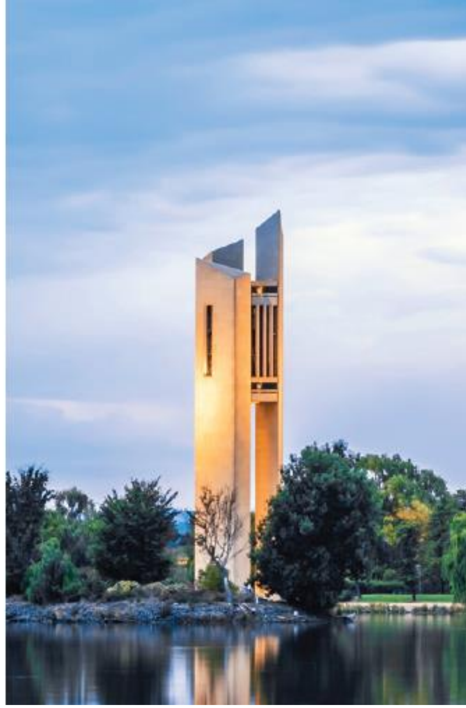


SYSTEMS SCIENCE & ENGINEERING FOR A BETTER AUSTRALIA SETE2019.COM.AU

Tutorial: Smarter, Faster and More Flexible Ways to Build Networks

John Risson

Tutorial Outline

- Introduction
- The Case for Systems Engineering of Networks
- The Systems View of a Network
- Applying Systems Engineering Practices to Networks
    - Models, Principles, Activities, Techniques, Questions, Heuristics, Competencies
- Related Work
- Conclusions

This tutorial relies on primary sources listed in Related Work and in the companion INCOSE Technical Publication, "Guide for the Application of Systems Engineering to Large Communication Networks", version 0.93, Oct 2018. Also see the tutorial worksheet.

Introduction

Introductions. Who are you and why do you need this tutorial?

Tutorial Purpose

To explore how providers of communication network solutions can be smarter, faster and more flexible in satisfying stakeholder needs:

- Smarter – How to satisfy telecommunications stakeholders by understanding and delivering on their needs. Effective. Competitive.
- Faster – How to deliver on telecommunications stakeholder needs quickly. Efficient. Cost-effective. Competitive.
- Flexible – How to respond to changing telecommunications stakeholder needs. Responsive. Agile. Competitive.

This tutorial is about how to successfully deliver network solutions.
It is not about the latest network technology.
Give a man a fish, and you feed him for a day. Teach a man to fish, and you feed him for a lifetime.

Tutorial Motivation – Why It Matters

- Purpose
  - Telecommunication services and solutions underpin communities, businesses and governments.
  - They support critical defence, education, energy, finance, health and transportation capabilities.
  - They help people enjoy life, participate in community, learn and work effectively.
- Mastery
  - Opportunity knocks. The systems engineering community has led and excelled in most advanced technology industries. It is under-represented in the telecommunications industry.
  - Systems engineering competence gives competitive advantage in the design, development, maintenance and operation of telecommunications solutions.
- Autonomy
  - Innovation happens at the seams. The most interesting opportunities occur at industry, business and technology boundaries. This is especially true in telecommunications today.
  - Systems engineering is transdisciplinary: it enables one to build solutions from a diverse set of engineering disciplines and technologies.
  - This tutorial surveys best practices for engineering of communications systems, so you and your enterprise can rove and seize these opportunities.

Where do you see the opportunities for better engineering of communications systems?

Tutorial Scope

This tutorial is to enable telecommunications systems stakeholders and providers to better support their users:

- Critical and emergency services personnel
- Federal and municipal governments, utilities and transportation agencies
- Enterprise and consumer users of commercial telecommunications services
- The broader public

Show of hands: with which networked industry are you most closely aligned?

Tutorial Approach

- Review topic, then
- Work on a problem in twos or threes, then
- Be ready to present and defend your opinions, accept constructive criticism and listen to others

We have a short session to cover a broad and deep engineering discipline, less than one third will provide exposure to systems engineering, the remainder will workshop its application to networks.

Tutorial Outcomes – Learn How To

- Apply systems engineering practices to the development of telecommunications solutions
- Plan the optimal systems engineering life cycle for various kinds of network upgrades
- Recognize and remediate network development weaknesses
- Engage with the International Council on Systems Engineering (INCOSE) and its emerging telecommunications working group
- Use the systems engineering body of knowledge to improve delivery network solutions

These are our five basic objectives.
I'm excited to see where the workshop discussion takes us.

The Case for Systems Engineering of Networks

Network Stakeholders

Network Stakeholders and Actors

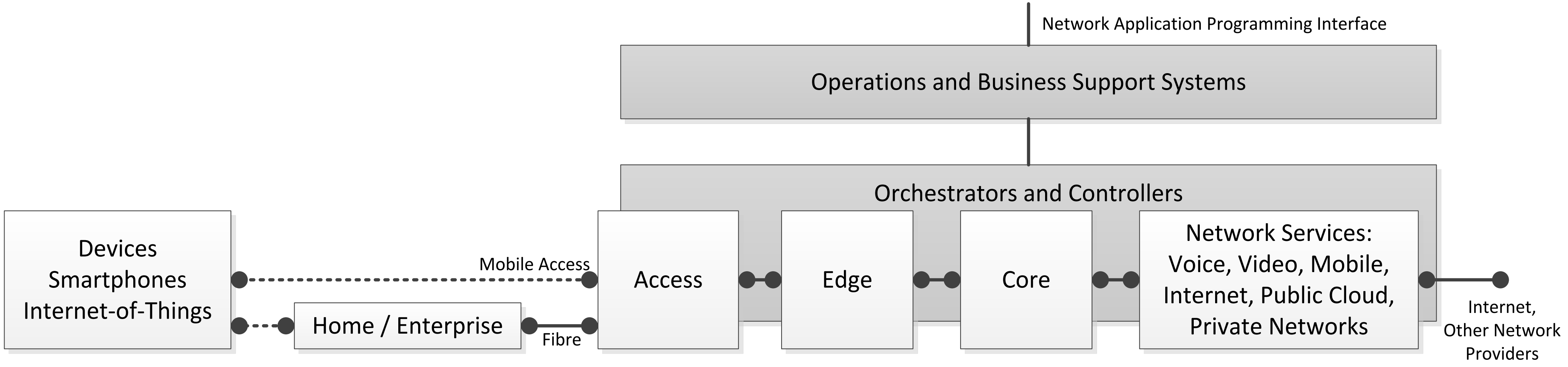
- Communications Service Provider
- Investor
- Customer
- User
- Infrastructure Provider
- Vendor
- Industry (Standards) Forum
- Network Attacker
- Regulator
- Government
- Law Enforcement Agency
- Competitor

Types of Stakeholders Concerns

- purpose
- suitability
- feasibility
- risk
- impact
- maintainability
- evolvability

Give one example of each of the stakeholder concerns in a network context.

Networks and Network Challenges



- Upgrading and interfacing legacy infrastructure
- Massive last-mile customer connectivity
- Customer expectations for capacity and speed keep growing, while time-to-market cycles are shrinking and revenue is flat
- Ever-increasing pace of technology evolution and obsolescence
- Deploying technology solutions with greater levels of complexity and integration
- Increasing complexity – there are many more interfaces and component types for software-intensive and virtualised network solutions. This complexity is hidden. We're largely utilizing the same tools and techniques.

Are there particular network challenges you would like addressed in this session?

Responding to Change

- The more uncertain changes in a Network's external environment usually relate to the human element:
  - Industry restructuring
  - Different network support organisations respond to failures in ways that may delay service recovery for end users
  - Industry stakeholders swarm to various technology trends
  - Networks are susceptible to threats from changing security actors
- Network systems engineering responses to change include:
  - Proactive scanning of stakeholder needs on short, medium and long term horizons
  - Maintaining network capability development and network capacity plans
  - Developing network architectures that can morph to meet a range of needs without becoming brittle
  - Automating rapid development and deployment of security capabilities

One key function for an agile engineering organisation or team: scanning.

Return on Investment in Systems Engineering

- Projects without systems engineering incur cost overruns of over 50%.
- Program costs are minimized when the systems engineering effort is between 8 and 19% of the total program cost.
- If a project has no systems engineering effort, every dollar of additional systems engineering effort reduces the total project costs by seven dollars.

Current systems engineering effort (% of program cost)	Average cost overruns (%)	Return on Investment for additional systems engineering effort (cost reduction $ per $ systems engineering added)
0	53	7.0
5	24	4.6
7.2 (median of all programs)	15	3.5
10	7	2.1
15	3	-0.3
20	10	-2.8

A very effective discipline. Most of the core systems engineering disciplines “show significant correlation” with at least two of three program outcomes: cost compliance, schedule compliance and overall success.
But “correlation against technical quality is nil”. Why?

The Systems View of a Network

System – Network Properties

System Properties. A System …	Network Properties. A Network …
Exists within a wider context.	Exists amongst enterprise and consumer networks and applications, aside competing Networks, with customer, investor and government expectations of its performance.
Is made of parts that interact with each other and the wider context.	Is made of network elements, network software, network configurations, support systems, orchestrators, network personnel, network facilities like buildings, racks, towers, power and ducts.
Has emergent properties that are not attributable to individual parts.	Enables communication, education, entertainment, enterprise efficiency and effectiveness, identification, social interaction, escapism.
Has a life cycle, function, structure, behaviour and performance characteristics.	Has a very long life cycle with continual integration of better technologies; Has fault, configuration, accounting, performance and security management functions; Has hierarchic, layered structure with increasing geographic centralisation and component disaggregation.
Changes and adapts to its environment when deployed	Adapts to changing customer usage patterns and devices, competitor architectures and pricing, infrastructure interfaces and pricing, and regulation.
Contains feedback loops that make cause and effect relationships hard to determine.	Contains race conditions between technology domains, network protocols and network layers.

The network garden.

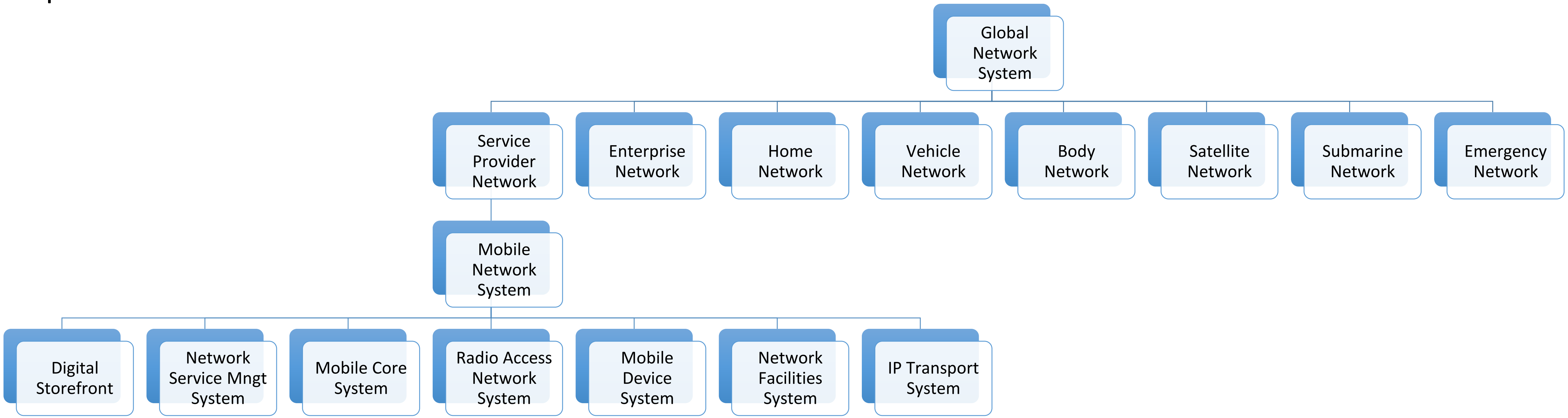
System – Network Engineering Anti-Patterns

System Properties. A System …	Network Engineering Anti-Patterns. Network engineers ignore this system property when they …
Exists within a wider context.	Do not actively engage Network stakeholders to understand underlying needs; Implement a trendy technology with limited end-to-end design and verification of the primary function for stakeholders.
Is made of parts that interact with each other and the wider context.	Concentrate on familiar network and software technologies while skipping design of external user, application and network interfaces to customers and third-party providers.
Has emergent properties that are not attributable to individual parts.	Skip design and testing for potential interactions between network domains and layers, exposing critical national infrastructure to availability and security risks.
Has a life cycle, function, structure, behaviour and performance characteristics.	Do not adequately address through-life operational and capacity growth concerns; Emphasize physical architecture while omitting functional architecture; Choose a network architecture without considering its support system complexity; Ignore performance characteristics, especially those for customer.
Changes and adapts to its environment when deployed	Fail to scan for future enterprise needs, competitive threats or security risks; Lock in network architectures that are difficult to change.
Contains feedback loops that make cause and effect relationships hard to determine.	Ignore interactions between devices under their control and devices outside their control; Assume without evidence that network layering or geographic diversity provides adequate availability.

How to neglect the network garden.

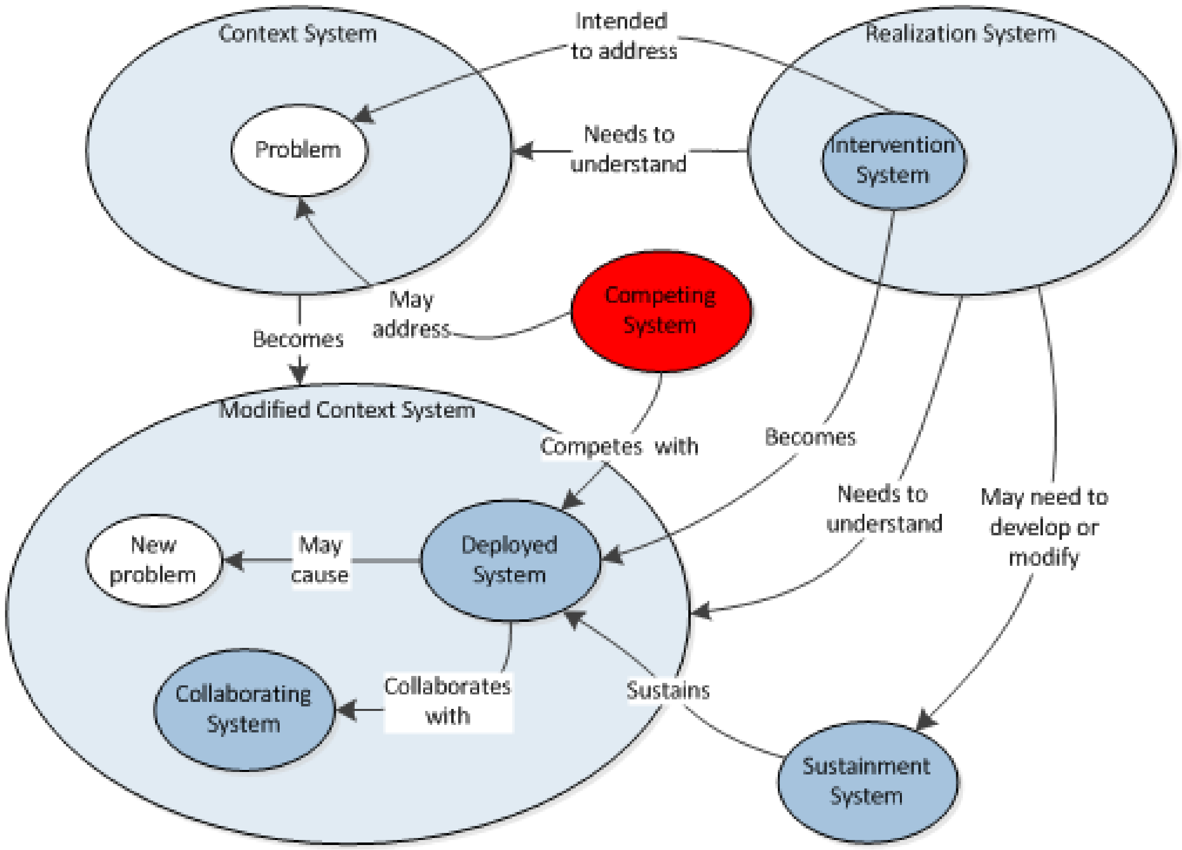
System of Systems

- A system of systems consists of managerially and/or operationally independent systems.
- They are characterised by geographic distribution, emergent behaviour and evolutionary development processes.



Networks are almost always systems of systems. Engineer them accordingly.

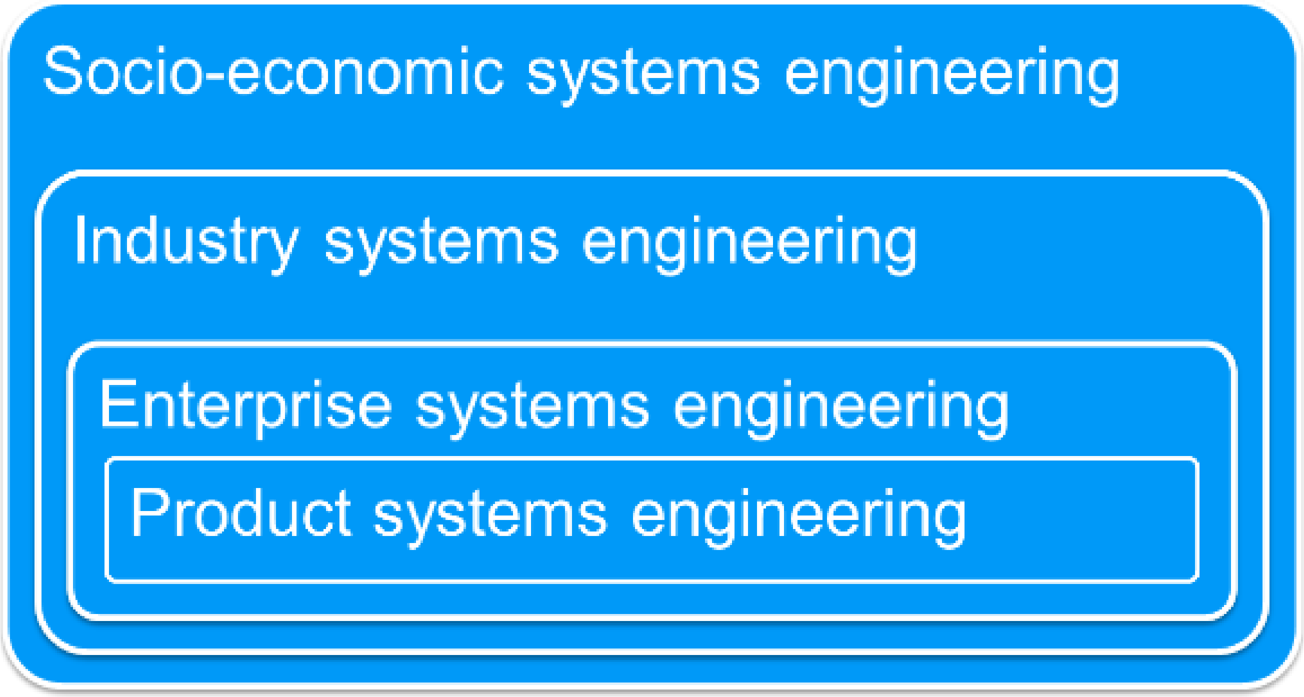
Interrelated Systems



Give examples of each system in a network context. What happens when one is neglected?

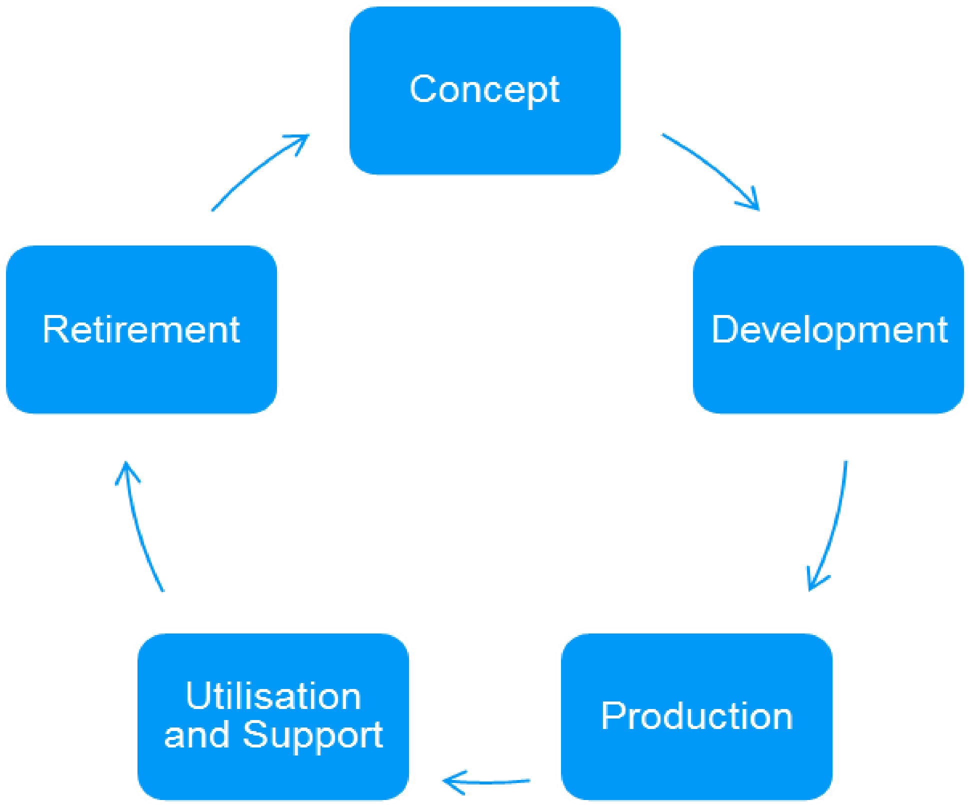
Applying Systems Engineering Practices to Networks

Models – Layers within Layers



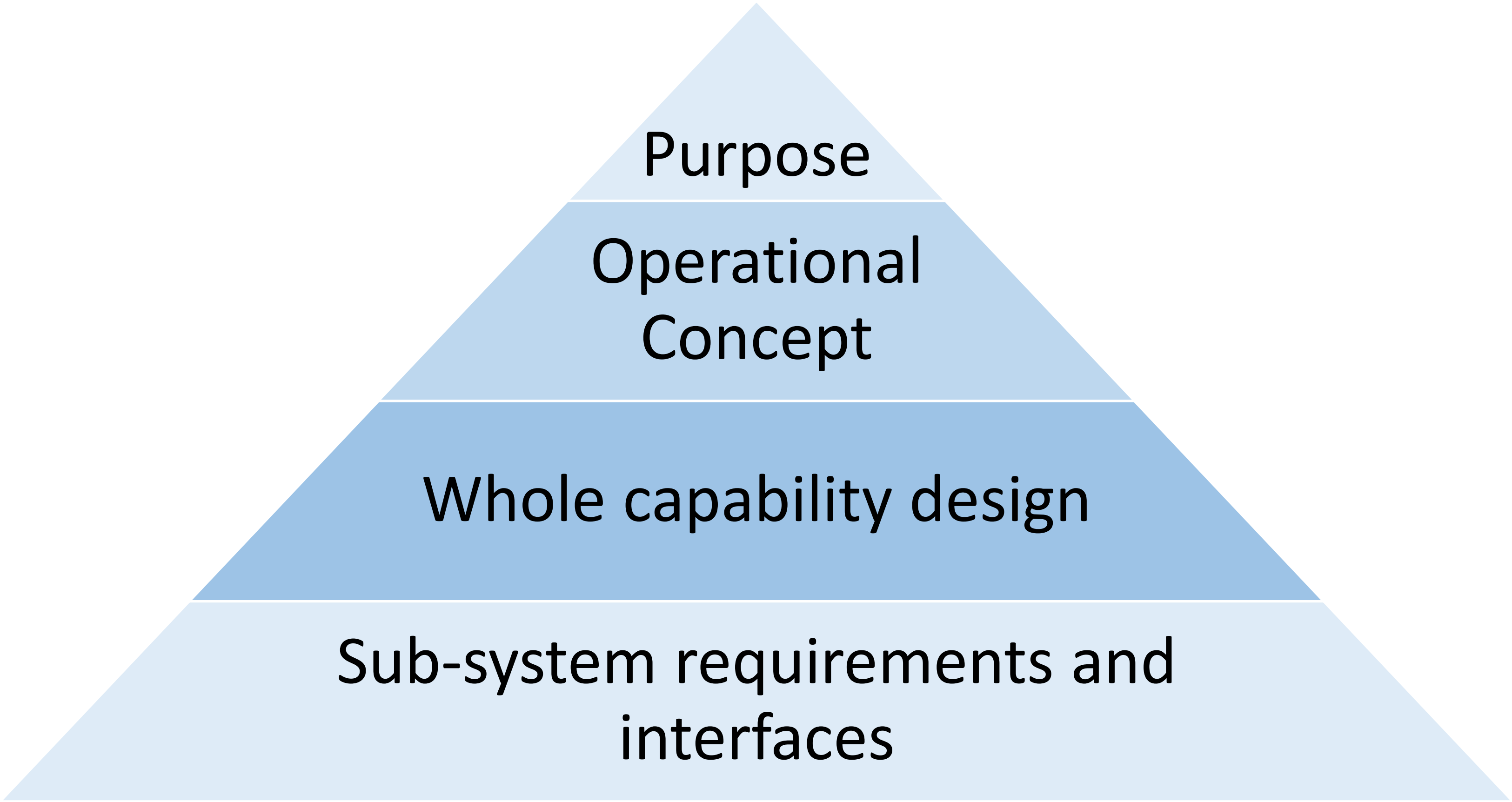
How might we have higher impact on the broader engineering layers in a network context?

Models – Life Cycles



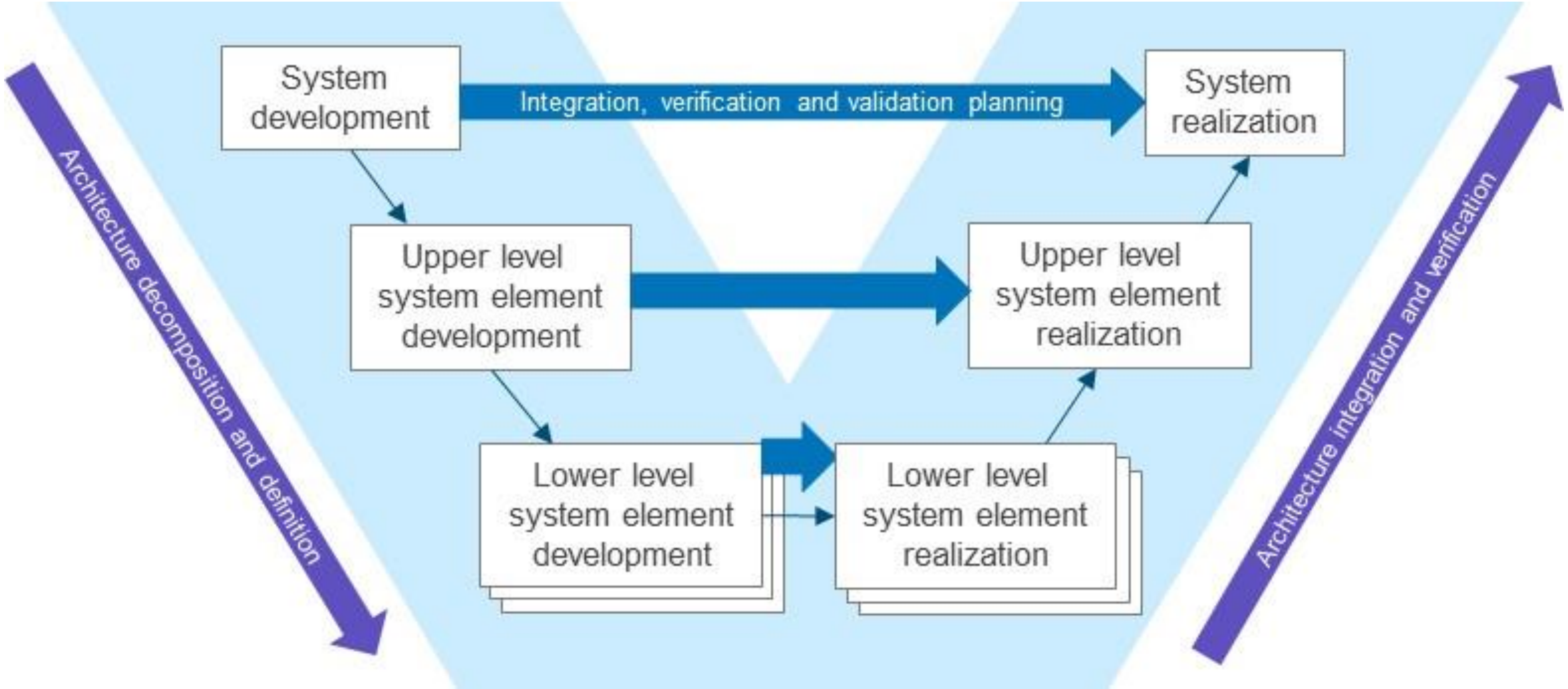
Birth to death. How do you ensure your systems engineering is effective through the whole network life cycle?

Models – Doing the Right Things



Capability engineering: caring about outcomes.

Models – Doing Things Right



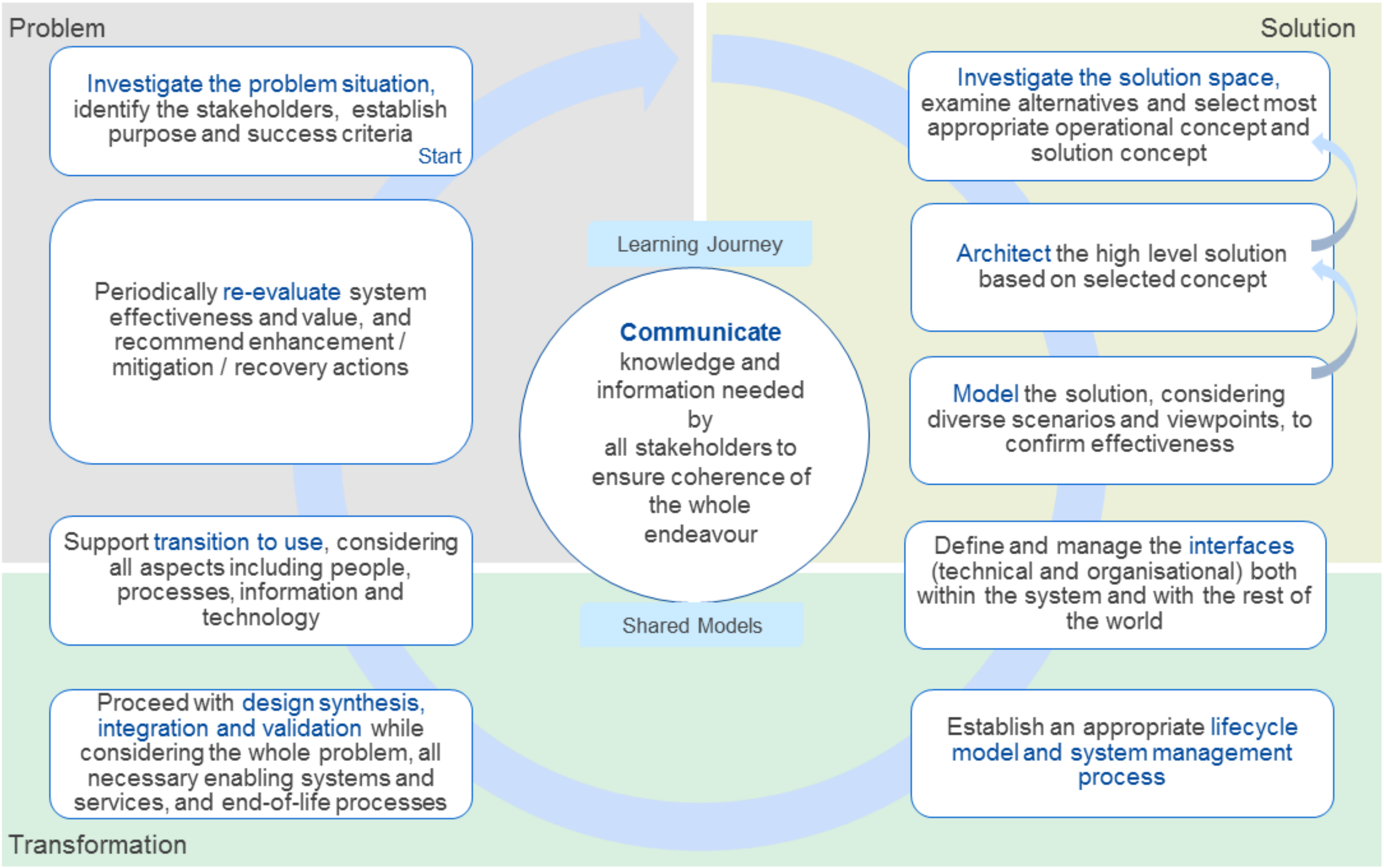
A structured approach to ensure the parts work together to address the whole problem.
How would you respond to the assertion, “traceability is obsolete”?

Models – Principles

Stakeholder value-based guidance	• Systems are successful if and only if they meet the needs of all success-critical stakeholders.
Incremental commitment and accountability	• Systems are successful when there is incremental and iterative delivery, with development accountabilities and stakeholder commitment aligned at each step.
Concurrent multi-discipline engineering	• Systems are successful when a multi-disciplined, integrated team collaborates from the outset, progressing work concurrently.
Evidence-based and risk-based decisions	• Systems are successful when there is objective quality evidence for development decisions and when delivery risks are actively mitigated.

What is missing?

Models – Activities



Critique the typical health of each of these activities in a network engineering context.

Techniques - Business Analysis

- Soft systems methodology
- Benefits mapping
- Operational analysis
- Use cases
- Enterprise architecture
- Modelling and simulation
- Human-in-the-loop experimentation
- Performance thread analysis
- Monte-Carlo performance simulation

What are the opportunities to better apply these for networks?

Techniques - Systems Architecture

- Functional decomposition and allocation
- Trade studies
- Decision trees
- Failure Mode Effects and Criticality Analysis (FMECA)
- Interface design
- Requirements traceability

How healthy is your network solution architecture discipline?

Techniques - Systems Analysis

- Linear programming
- Queueing theory
- Combinatorial optimisation problems like the shortest-path and spanning tree problems
- Availability analysis
- Performance analysis
- Data mining, machine learning, game theory …

Where do you use each of these in network engineering?

Techniques - Technology Management

- Parametric lifecycle cost model
- Technology readiness levels
- Cost benefit analysis
- Fault tree analysis
- Ishikawa fishbone method

Which are used for networks? Which could be better used?

Questions - Understand Capability Context

- Is the reason for upgrading the capability clear?
- Does the current capability do what is needed?
- Are there opportunities to exploit elements and the capability in new ways?
- Are elements becoming obsolete?
- Are there new legal or statutory changes that need to be incorporated?
- Are the purpose and outcomes of the capability change defined clearly enough?
- Will the proposed purpose and outcomes deal with the reason for the capability upgrade?
- Have alternative purposes and outcomes been considered and evaluated?

Capability engineering: failure to distinguish between capability and product will "generally result in sub-optimization and lost opportunities"

Questions - Design Capability

- Is the whole system operational concept agreed?
- Does it define who, what, why, where, when and how?
- Are the key elements of the concept needed to deliver an effective capability clearly defined?
- Is the whole system design of the capability agreed?
- Does the design describe how the capability will meet its measures of effectiveness?
- Is the organisational / supply network design understood and are organisations incentivised to deliver the capability? …

A very useful set of questions from the INCOSE UK Capability Systems Engineering Guide

Questions - Plan and Govern Capability Delivery

- Are the build, installation, test and transition arrangements suitable?
- Does the overall performance of the capability grow incrementally?
- Can the capability ‘roll back’ if the elements don’t work?
- Has the transition to the new capability been designed as a cultural change as well as an engineering change?
- Are the arrangements sustainable for the expected life of the capability?
- Is it clear who will maintain what elements?
- Are the key organisations incentivised to deliver an affordable, safe and available capability?
- Are senior stakeholders committed to success? What plans are there to ensure stakeholders remain committed through capability development?...

Heuristics - Stakeholder Needs

- Success is defined by the beholder, not by the architect.
- Don’t assume that the original statement of the problem is necessarily the best, or the right, one.

Actively engaging stakeholders. Always learning.
How can this be thwarted when engineering network solutions?

Heuristics – Architecture - 1

- Occam's Razor: 'The simplest solution is usually the correct one.'
- The greatest leverage in systems architecting is at the interfaces.
- In partitioning a system into subsystems, choose a configuration with minimal communication between the subsystems.
- Work forwards and backwards.
- Except for good and sufficient reasons, functional and physical structuring should match.
- Pause and reflect!
- Concept formulation is complete when the builder thinks the system can be built to the client's satisfaction.

How might these inform the conduct of architecture reviews for network solutions?

Heuristics – Architecture - 2

- A system architecture cannot be considered complete lacking a suitable match with the process architecture.
- Predicting the future may be impossible, but ignoring it is irresponsible.
- You cannot avoid redesign; it's a natural part of design.
- The stakeholders that are included in the early stages of product definition will have an outsized impact on the architecture.
- '2 down, 1 up'. The goodness of a decomposition at Level 1 cannot be evaluated until the next level down has been populated and the relationships identified.

Which comes first, the systems architecture or the process architecture?
What are the implications for the key network functions? For network automation?

Heuristics – Performance and Reliability - 1

- The ulcer heuristic: system performance is understood well enough when the implementers of the system feel only moderately ill about accepting the performance estimates as acceptance requirements for the system they will be constructing.
- An element 'good enough' in a small system is unlikely to be good enough in a more complex one.
- Next to interfaces, the greatest leverage in architecting is in aiding the recovery from, or exploitation of, deviations in systems performance, cost or schedule.

What are some common network performance pitfalls? How do you mitigate them?

Heuristics – Performance and Reliability - 2

- The least expensive and most effective place to find and fix a supply problem is at its source.
- Recovery from failure is not complete until a specific failure mechanism, and no other, has been shown to be the cause.
- Knowing a failure has occurred is more important than the actual failure.
- Reducing the failure rate by each factor of two takes as much effort as the original development.
- Tally the defects, analyse them, trace them to the source, make corrections, keep a record of what happens afterwards, and keep repeating it.
- The last 10 percent of performance generates one-third of the cost and two-thirds of the problems.

How might these inform your network technology planning?

Heuristics – Risk - 1

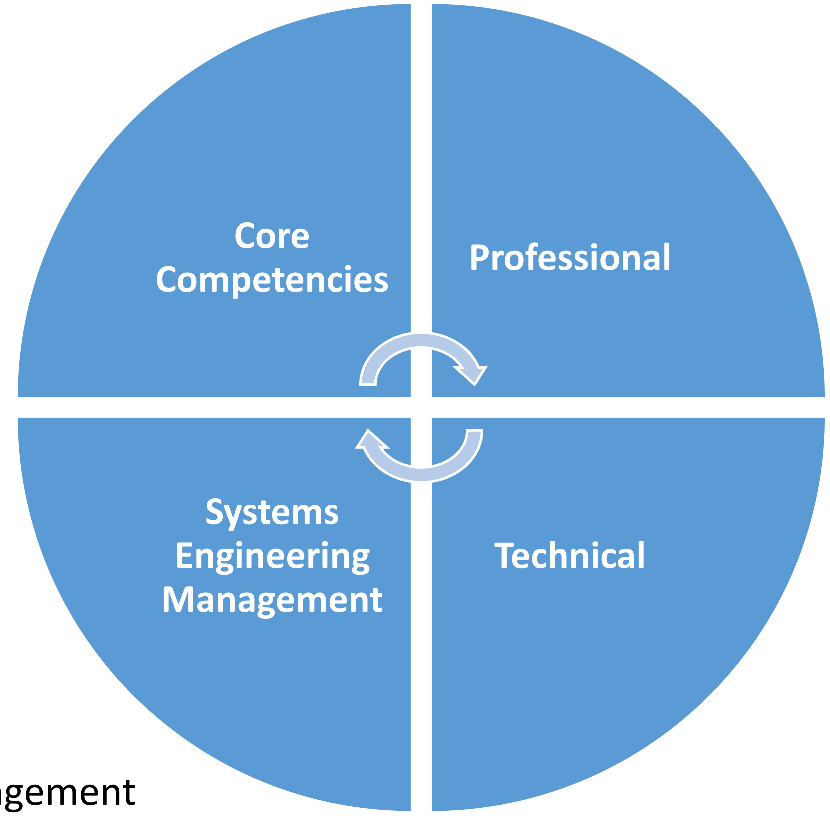
- Murphy's Law: If anything can go wrong, it will.
- In architecting a new system, all the serious mistakes are made in the first day.
- The greatest dangers are at the interfaces.
- Be prepared for reality to add a few interfaces of its own.
- Expect the unexpected.
- Build in and maintain options as long as possible in the design and implementation of complex systems; you will need them.
- Personal risk is proportional to the difference between responsibility and authority.

Give examples of where good interface design has lead to competitive advantage.

Competence

- Systems thinking
- Life Cycle
- Capability Engineering
- General Engineering
- Critical Thinking
- Systems modelling and analysis

- Planning, Monitor and Control
- Risk and Opportunity Management
- Decision Management
- Concurrent Engineering
- Business and Enterprise Integration
- Acquisition and Supply
- Information and Configuration Management
- Project Management
- Quality, Finance, Logistics



- Communication
- Ethics and Professionalism
- Technical Leadership
- Negotiation
- Team dynamics
- Facilitation
- Emotional Intelligence
- Coaching and mentoring

- Requirements definition
- System architecting
- Design for
- Integration
- Interfaces
- Verification
- Validation
- Transition
- Operation and Support

How might you use the INCOSE Systems Engineering Competency Framework to deliver better network solutions?

Incompetence

Systems Thinking vs Component Thinking

Lifecycles vs Death Spirals

Capability Engineering vs Encouraging Corporate Memory Loss

General Engineering vs Knowing Everything about Nothing

Critical Thinking vs Fuzzy Thinking

Modelling and Analysis vs Dissimulation about Modelling

Requirements Definition vs Jumping to Solution

Systems Architecting vs Spaghetti Architectures

Design for … vs Ignoring Stakeholders

Integration vs Disintegration

Interfaces vs Ignoring Interfaces

Verification vs Performing Inappropriate Tests

Validation vs Ignoring User Feedback

Transition vs Transition to Project Cancellation

Operation and Support vs Ignoring the Aftermarket

Engineering incompetence. Give examples common in network solutions.

Related Work

INCOSE Telecommunications Working Group

Problem statement

- Telecommunications underpins communities, businesses and governments.
- Its stakeholders need ease of use, performance, security and reliability.
- Its systems are complex, yet pressures exist for more responsive capability and capacity enhancements within challenging cost constraints.
- Its stakeholders could be much better served by systems engineering, which has a major part to play in the design, development, maintenance and operation of telecommunications systems.

Stakeholders

- Critical and emergency services personnel
- Federal and municipal governments, utilities and transportation agencies
- Enterprise and consumer users of commercial telecommunications services
- The public

Purpose

- Improve delivery of telecommunications solutions by enhancing the systems engineering body of knowledge for telecommunications applications.

See the online survey. How might it help you and your enterprise?

INCOSE Working Groups – Transformational Enablers

- Agile Systems and Systems Engineering
- Knowledge Management
- Lean Systems Engineering
- Model Based Systems Engineering Patterns
- Model Based Conceptual Design
- Object-Oriented Systems Engineering Method
- Process Improvement
- Systems Engineering for Very Small Enterprises
- System and Software Interface
- Systems Science
- Tools Integration & Model Lifecycle Management

How might these apply to network solutions?

INCOSE Working Groups – Analytic Enablers

- Affordability
- Competency
- Complex Systems
- Decision Analysis
- Digital Engineering Information Exchange
- Human Systems Integration
- Natural Systems
- Product Lines
- Reliability Engineering
- Resilient Systems
- System of Systems
- System Safety
- Systems Engineering Case Study
- Systems Security Engineering
- Training

What is the relevance for network solutions?

INCOSE Working Groups – Process Enablers

- Architecture
- Enterprise Systems
- Configuration Management
- Integration, Verification & Validation
- Life Cycle Management
- Measurement
- Project Management - Systems Engineering Integration
- Requirements
- Risk Management
- Systems Engineering Quality Management

How well are each of these practiced for network solutions?

INCOSE Working Groups – Application Domains

- Anti-terrorism
- Automotive
- Critical Infrastructure
- Defence Systems
- Global Earth Observation System of Systems
- Healthcare
- Infrastructure
- Oil and Gas
- Power & Energy Systems
- Space Systems
- Transportation

What are the local opportunities for network systems engineering in these industries?

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Which of the INCOSE guides have you found most useful for network solutions?

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How well is the systems engineering community engaged with the network industry ecosystem?

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Networks are software-intensive systems. Emerging networks are classic cyber-physical systems.
How might the systems and software engineering communities collaborate better?

Conclusion

Conclusion – We Have Learnt How to

- Apply systems engineering practices to the development of telecommunications solutions
- Plan the optimal systems engineering life cycle for various kinds of network upgrades
- Recognize and remediate network development weaknesses
- Engage with the International Council on Systems Engineering (INCOSE) and its emerging telecommunications working group
- Use the systems engineering body of knowledge to improve delivery of network solutions

Thank you