CSD&M Asia, INCOSE Beijing Summit – 12-13 April 2021

# Over the Horizon with Systems Engineering (SE)

# Imagine Tomorrow's Reality

MBE / situational awareness vital / intelligence augmentation reliance / knowledge-based expert libraries / voice-system interactions / qua... ...f-box-protocols / quick gene... ...s / big data techniques / resil... ...expected / AI / virtual-reality ...gement / sound architectures / pr... ...mart nations / machine-learn... ...elationships trade-offs betwee... ...singularity impact research / ...es / blockchain security / edge-c... ...simulators interoperability / ... ecodesigns / smart systems / a... ...e colonisation / MBE / situational... ...s / voice-system interactions / quantum-communications / out-... ...ration & adaptation of models / big data techniques / resilient-safe-secure-sustainable... ...platforms / stakeholder engagement / sound architectures / predictive models research of s... ...ning implementations / inter-relationships trade-offs between sustainability challenges / ... ...quantum-computing resources / blockchain security / edge-computing / smart-data-filters... ...augmented-reality platforms / ecodesigns / smart systems / a... ...e colonisation / MBE / situational... ...s / voice-system interactions / qua... ...f-box-protocols / quick gene... ...s / big data techniques / resil... ...expected / AI / virtual-reality ...gement / sound architectures / pr... ...mart nations / machine-learn... ...elationships trade-offs betwee... ...singularity impact research / ...es / blockchain security / edge-c... ...simulators interoperability / ... ecodesigns / smart systems / additive manufactured everything / IoT / renewable energy / societal acceptance / space colonisation /

# What is Systems Engineering (SE)?
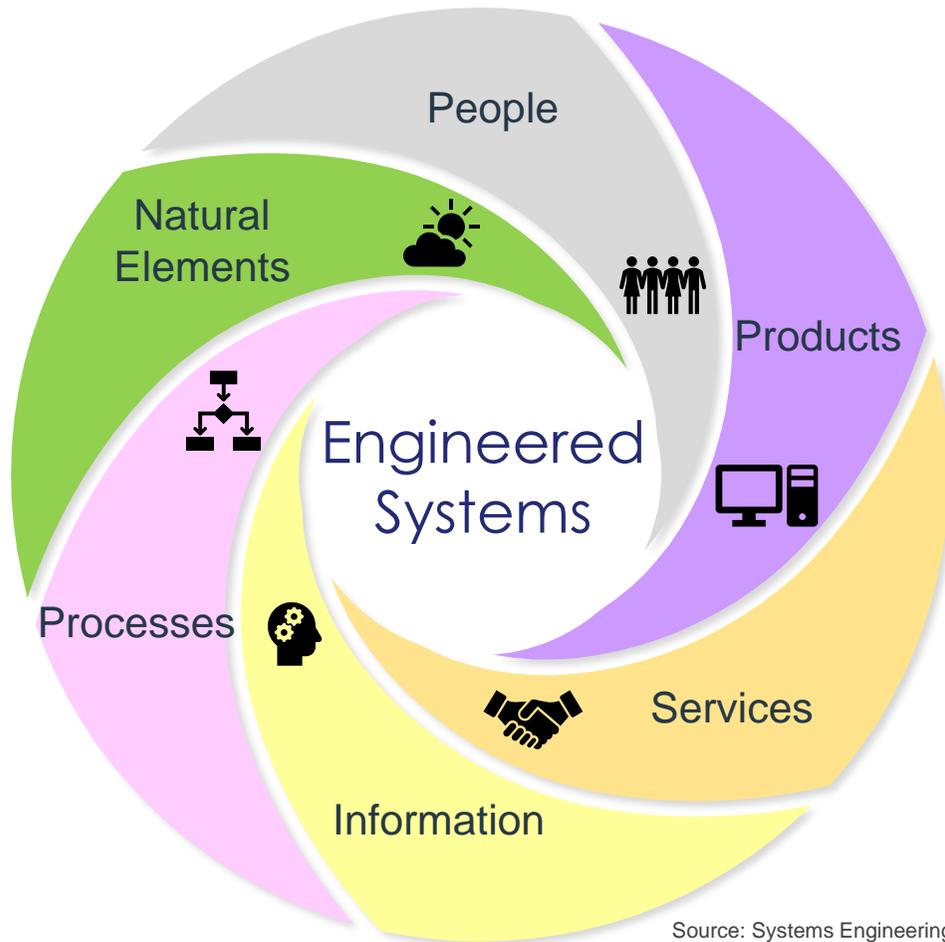


SE Definition

- Systems Engineering (SE) is a **transdisciplinary** & **integrative** approach to enable the successful realisation, use, & retirement of engineered systems, using systems principles & concepts, & scientific, technological, & management methods

Source: Systems Engineering & System Definitions V1.0, Jan 2019;
Author team - Sillitto, Martin, McKinney, Griego, Dori, Krob, Godfrey, Arnold, Jackson;
INCOSE Technical Product

# Looking Further - 2045 Horizon

- "**Purchase** high-quality **emotions** online" – Alex Ayad
- "**Cities** made from living, dynamic materials that **respond to the environment**" – Alex Ayad
- "Driverless cars will **just be**… cars" – Tamar Kasriel
- "**Hyperloop** will be another means of transport" – Ian Pearson
- "**No more smartphones** – replaced with augmented reality" – Ian Pearson
- "**3D printed houses** readily available" – Ian Pearson
- "Simply just **talk** or even press a button **to interact** with a **machine**" – Pam Melroy

Source: Image courtesy of Forward Thinking Farming

Source: Image courtesy of metamorworks

Source: Volvo Concept 26 – The Future of Not Driving

- "Robot intelligence could **match** human intelligence" – Murray Shanahan
- "The personal network will be a "**hyperlocal grid**"" – James Kendrick
- "**Transportation as a Service** (TaaS) will replace private car ownership" – Alfred Poor
- "The notion of "**big data**" will seem **quaint**" – Andrew Brust
- "**Brain prints** join fingerprints" - Sarah Lazlo & Zhanpeng Jin
- "I have set the date **2045** for the "**Singularity**"" – Ray Kurzweil
- "The **division between "haves" & "have nots"** to begin with will increase" – Greg Nicholas

## What will be the evolution of Systems Engineering?

# Consider Practicing SE in 2045

**New &/or Greater Importance**

- Situational awareness will be critical
- Reliant on intelligence augmentation (AI – General)
- Utilization of knowledge-based expert libraries – via subscriptions
- Primary interaction with models & tools will be voice
- Quick generation & adaptation of models & prototypes
- Resilience, safety, security, environmental sustainability expected, not asked
- Information & data paramount

**But Still Relevant**

- Lifecycle models – new & existing
- Stakeholder engagement
- Risk mitigation activities
- Sound architectures
- etc

Source: Image courtesy of Miguel Medina
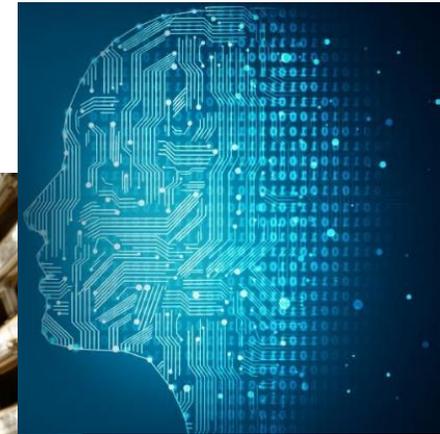
# Consider Systems Research in 2045

Coming out of the 4th Industrial Revolution, ie

*"… this period* ~~is~~ *was characterised by a range of new technologies that* ~~are fusing~~ *fused the physical, digital & biological worlds, impacting all disciplines, economies & industries, & even* ~~challenging~~ *challenged ideas about what it means to be human."*

- Klaus Schwab & his book "The 4th Industrial Revolution"

- Impact of Singularity
- Human adaptation research in closed, artificial environments
- Group think & AI
- Societal acceptance in cyber-genetics
- Human- Robot Interactions
- Predictive models of smart nations
- Continuing evolution of life cycle models
- Inter-relationships between sustainability challenges
- …
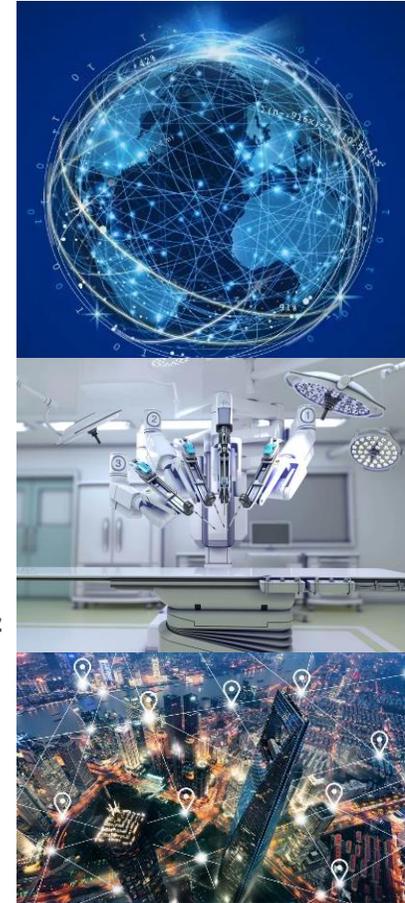
# Over the Horizon for SE



(Note – this is only a representative set)

Diversity Equity Inclusion

Continuous Integration

Digital Engineering Transformation

System Resilience

Synergies Through Systems Thinking
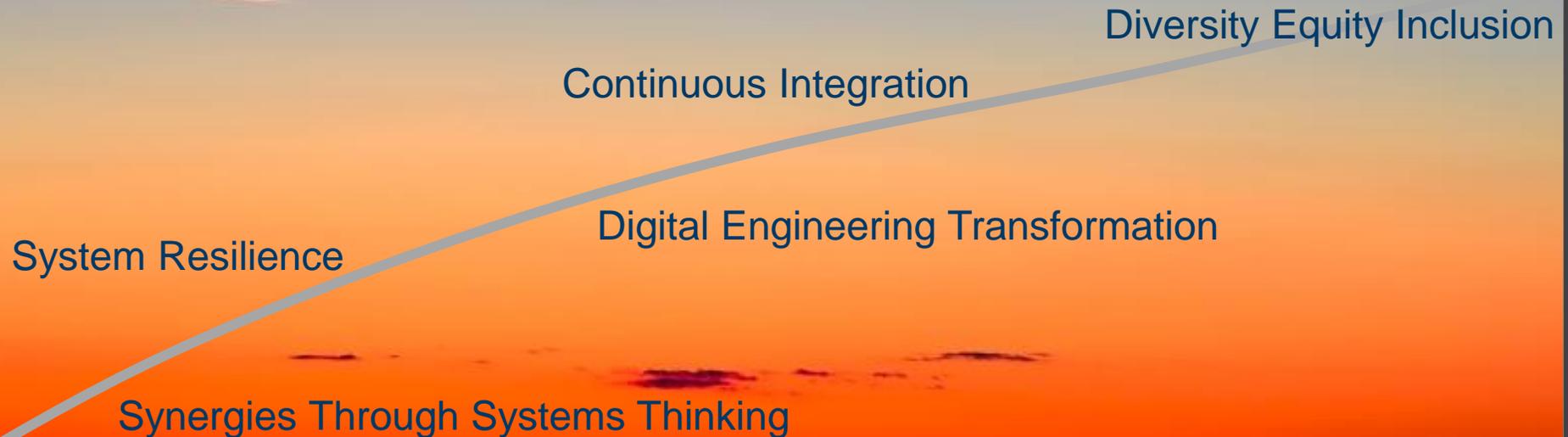
**Key Skills to Master to Engineer Systems of the Future**

# Synergies Through Systems Thinking

| | | | |
|---|---|---|---|
| Advance personalised learning | Engineer better medicines | Secure cyberspace | Manage the nitrogen cycle |
| Make solar energy economical | | Provide access to clean water | |
| | Advance health informatics | | Develop carbon sequestration methods |
| Enhance virtual reality | | Provide energy from fusion | |
| Reverse-engineer the brain | Restore & improve urban infrastructure | Prevent nuclear terror | Engineer the tools of scientific discovery |
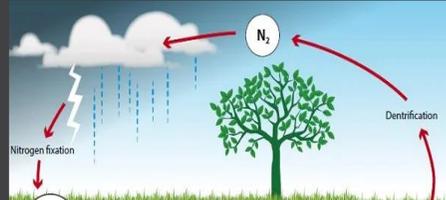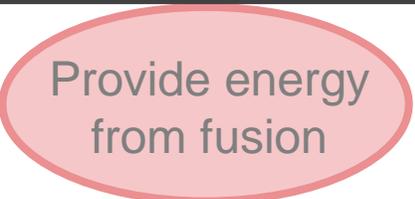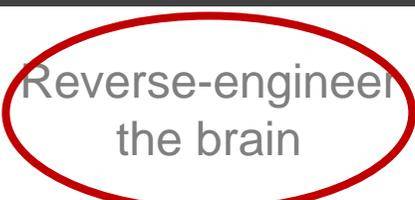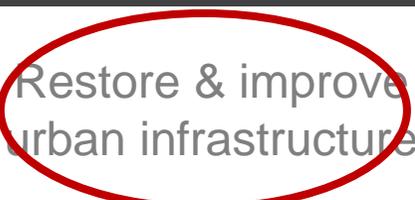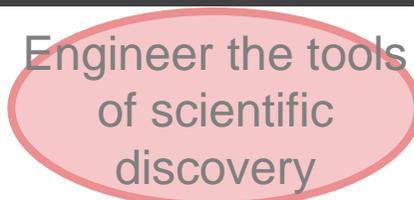
# Challenges of System Resilience



RMS Titanic, departing Southampton ,April 1912, 5 days prior to sinking

Source: Wikipedia

Skytree Tower,Toyko Height: 634m July 2008

Source: Wikipedia

Deepwater Horizon Offshore Drilling Rig Fire, April 2010

Source: Wikipedia

MARS Perserverance, Sol 20, 11 Mar 2021

Source: Image credit – NASA/JPL-Caltech

- To educate all stakeholders on what it means to be resilient wrt providing a system or a service
- To get resilience fully integrated into the "normal" SE flow
  - Not too early in the lifecycle but not as an afterthought
  - SE needs to take a more holistic view of resilience in the design effort
- Unify resilience with other loss-driven SE* specialty areas (security, safety, risk, availability, etc)
  - Work closely, exploit their commonalities & synergies
    - * Loss-driven SE addresses the potential for loss associated with the delivery of the capability, ie –
      - Meeting performance expectations → capability-driven
      - Meeting acceptable loss expectations → loss-driven

# Applying Techniques for System Resilience

Source: System Resilience, SEBoK

> Resilience is the ability to provide required capability in the face of adversity

• Jackson & Ferris

• MITRE



**Jackson & Ferris diagram:**

"Allows a system to withstand a threat in the normal operating state"

Achieved through –
• Absorption
• Physical redundancy
• Functional redundancy

Robustness / Adaptability — Attributes — Tolerance / Integrity

"Allows a system to restructure itself in the face of a threat."

Achieved through –
• Restructuring
• Human in the loop
• Complexity avoidance
• Drift correction

"Allows a system to degrade gracefully following an encounter with adversity."

Achieved through –
• Loose coupling
• Neutral state
• Reparability
• Defence in depth

"Allows a system to sustain a viable architecture in the face of adversity."

Achieved through -
• Coherence
• Holism
• Interaction between nodes

**MITRE diagram:**

**Fundamental Objectives**
• Avoid adversity
• Withstand adversity
• Recover from adversity

**Means Objectives**
• Adapt
• Anticipate
• Understand
• Disaggregate
• Prepare
• Prevent
• Continue
• Constrain
• Redeploy
• Transform
• Re-architect

Engineering Techniques / Means Objectives / Fundamental Objectives

**Engineering Techniques**
• Adaptive response
• Analytic monitoring
• Coordinated defence
• Deception
• Distribution
• Detection avoidance
• Diversification
• Dynamic positioning
• Dynamic representation
• Effect tolerance
• Non-persistence
• Privilege restriction
• Proliferation
• Protection
• Realignment
• Reconfiguring
• Redundancy
• Replacement
• Segmentation
• Substantiated integrity
• Substitution
• Threat suppression
• Unpredictability

> Similar concepts, different terminology, many techniques to master

# Digital Engineering (DE) vs SE

DE Definition
- Digital Engineering (DE) is the practice in which new applications are conceived & delivered, through leveraging data & technology (Source: Cognizant),

OR
- DE is an umbrella term that covers technologies, data collection devices, analytics, predictive modelling & data management software that brings it all together in a powerful & user-friendly way (Source: Redeye),

OR
- DE is the creation of computer readable models to represent all aspects of the system & to support all the activities for the design, development, manufacture, & operation of the system throughout its lifecycle (Source: SEBoK),

OR
- …
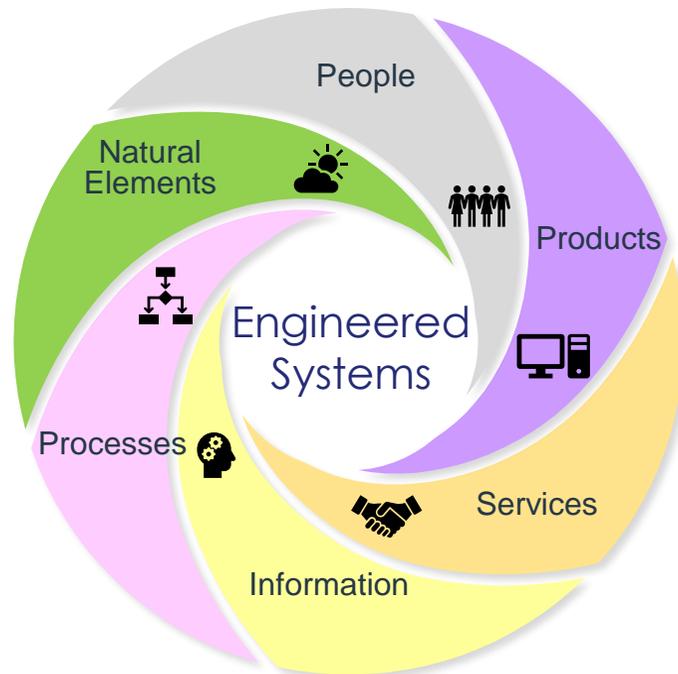
**Recall -**

SE Definition
- Systems Engineering (SE) is a transdisciplinary & integrative approach to enable the successful realisation, use, & retirement of engineered systems, using systems principles & concepts, & scientific, technological, & management methods



People

Natural Elements

Products

Engineered Systems

Processes

Services

Information

Source: Systems Engineering & System Definitions V1.0, Jan 2019;
Author team - Sillitto, Martin, McKinney, Griego, Dori, Krob, Godfrey, Arnold, Jackson;
INCOSE Technical Product

# Systems Transformation through DE



Source: Penn State News, Sep 2020
Image: Pixabay

**DE**

**DE mirroring SE (similarities)**

Holistic approach / Strong stakeholder engagement / CONOPS / Multi-disciplinary field / Architect before design / Linkages through mission & operational threads / Models & simulation usage / Continuous integration

**What is needed to engineer a system**

Source: www.incose.org



**SE**

**Digitising SE**
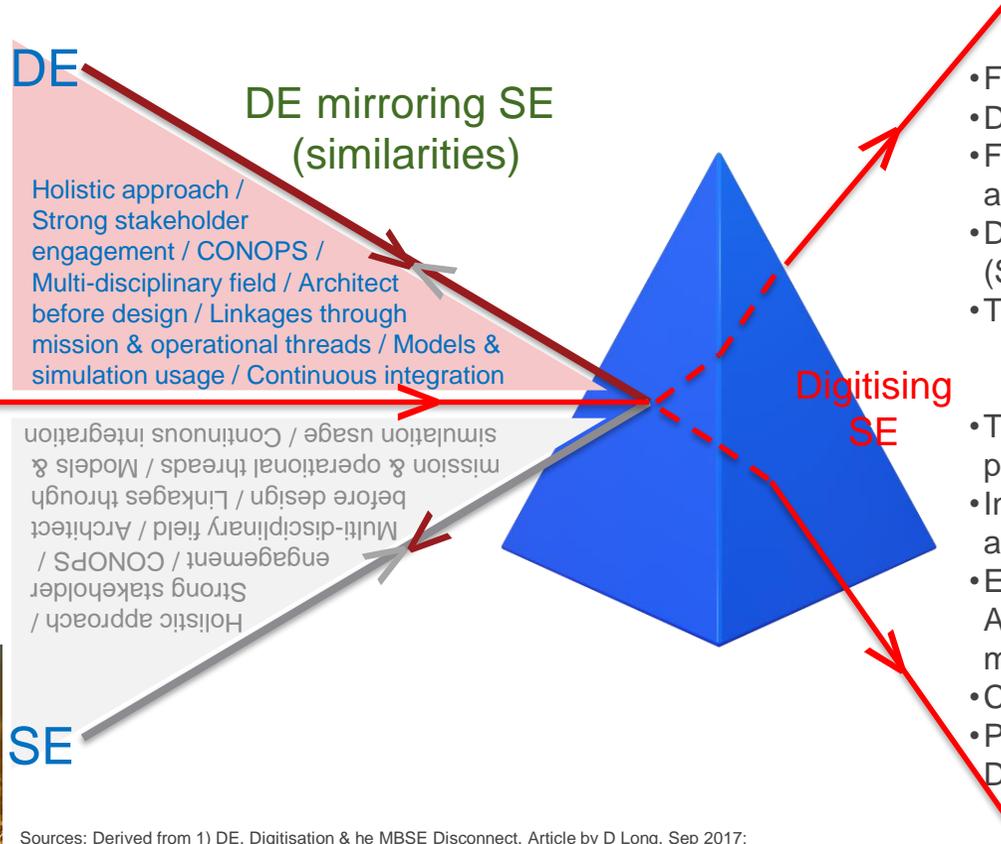
- Focus on the data
- Develop a core ontology for the practice
- Follow the digital thread, a data-driven architecture
- Develop & use the single source of truth (SST) for the data, ie authorised data
- Trust the authoritative data –
  - Eliminate large scale design reviews
  - Minimise project documentation set
- Trade off requirements to enhance key performance parameters
- Increase usage of data analytics, visual analytics, models, & patterns
- Embrace digital technologies eg IoT, AI, AUS, virtual / augmented reality, additive manufacturing
- Conduct event-driven reviews
- Perform system verification & validation via DE environment – early & often

Sources: Derived from 1) DE, Digitisation & he MBSE Disconnect, Article by D Long, Sep 2017;
2) Transforming SE through DE, Paper by Bone, Blackburn, Rhodes, Cohen & Guerrero, The Journal of Defence Modelling and Simulation, 2018

# Continuous Integration – 3 Facets to Balance



**Technical & Engineering Changes**

- Advanced Technologies
- Complexity Challenges
- New/Mixed Lifecycles
- Product Maturity
- Data Lakes
- Resource Diversity

**Mindset Change**

**Digital Culture Manifesto**

Source: Thales

| Empowerment | Data | Test & Learn | Collaboration | Users | Failure |
|---|---|---|---|---|---|
| Over Control | Over Opinions | Over Plans | Over Protection | Over Customers | Over Not Trying |
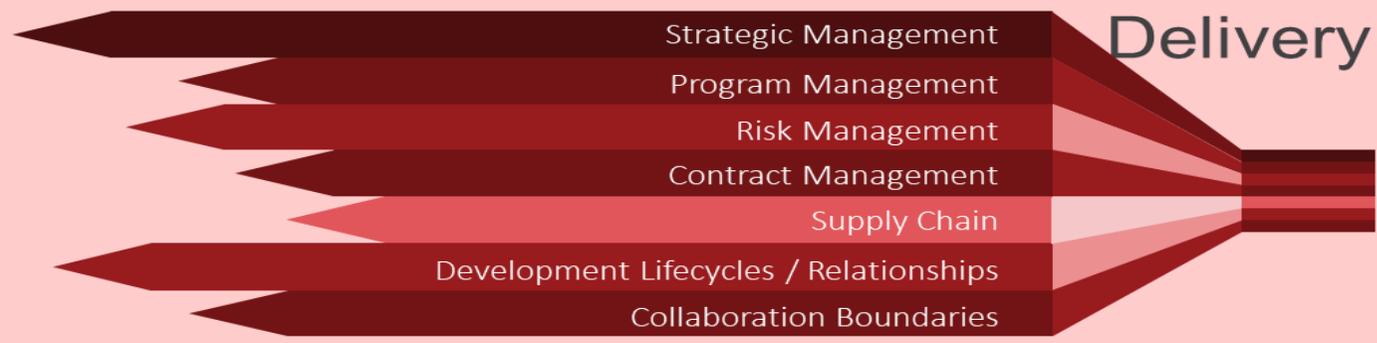
**Delivery & Support Changes**

- Strategic Management
- Program Management
- Risk Management
- Contract Management
- Supply Chain
- Development Lifecycles / Relationships
- Collaboration Boundaries
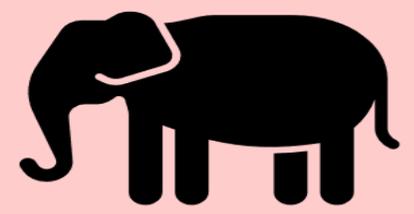
# Continuous Integration Guidance



- Adoption of digital mindset
- Collaboration strengthening
- Team integration

- Problem solving focus team structure
- Co-engineering
- Holistic governance

- People & technology harmonisation

- Stakeholder engagement frequent
- Flexible solution definition – incremental & evolving

- Shared development environment
- Supply chain lean but not too lean
- Parallel work activities

- Utilisation of knowledge-based expert libraries – via subscriptions
- Data enrichment at each stage

- Intelligence augmentation
- Situational awareness core
- Simulation & virtual reality support

- Patterns & anti-patterns focus
- Intentional obsolescence adoption
- Composable design

- Utilisation of models, digital twin, MBSE
- Quick generation & adaptation of models & prototypes

- Risk sharing profile
- Reward not penalise constructs
- Continuous integration cycles, including pilot programs

# Diversity Equity Inclusion (DEI)

- Enables us to bring different perspectives, skills, talents & experience
- Ask "Whose voice is missing? How do we include those voices?"

AI

Robotics

Autonomy

Sensor Networks

IoT

Data Analytics

Virtual Reality

And many more…

Health Informatics

Renewable Energy
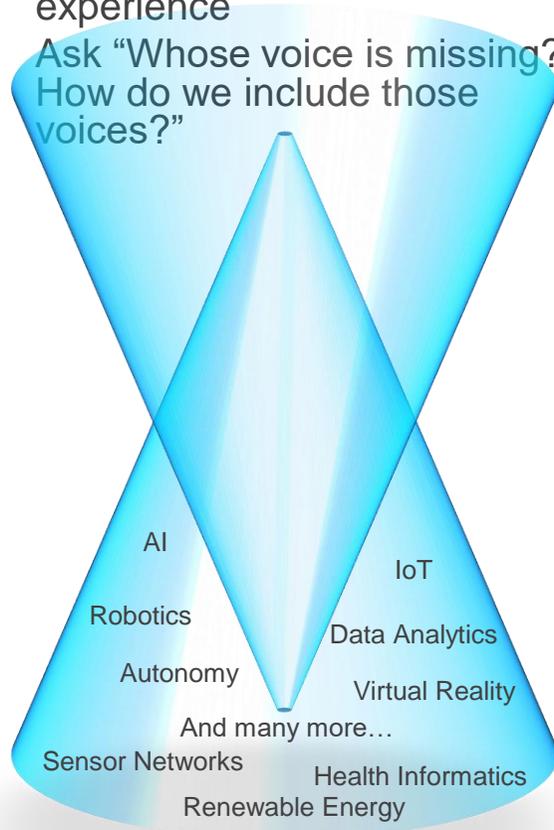


**Inclusive solutions require a diverse & inclusive team to create it**

# And 2045 is a Stepping Stone…



Government + Commercial Space Industry

Naval Fleet – Colonisation, Transport, Exploration, …

Source; Space Station Podcast, "A Star Trek-inspired space station"

Source: Lunar base made with 3D printing, ESA Engineer T Ghidini, Mar 2018

Source: Moon Base, pinterest.com

www.incose.org

# But For Now – Join Us at IS2021

*"Accelerating Through Adversity"*



Save the date

31st Annual **INCOSE**
international symposium

**Virtual Event**
July 17 to 22, 2021

"The International
SE Premier Event"
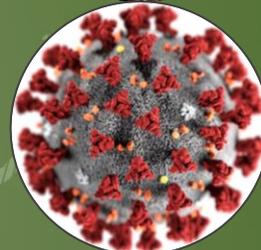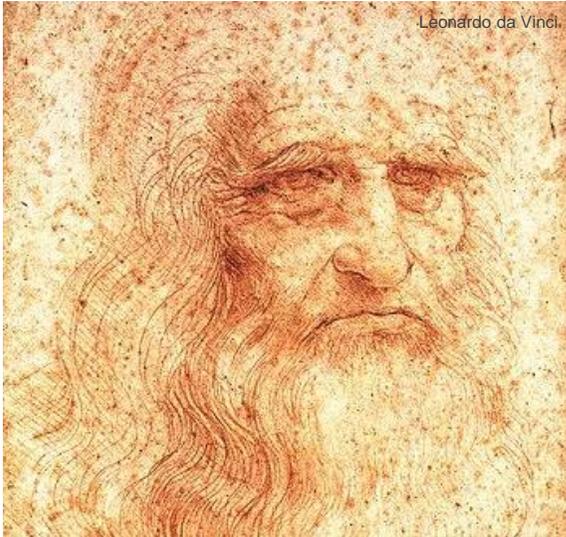
*"I have been impressed with the urgency of doing. Knowing is not enough; we must apply. Being is not enough; We must do."*

Leonardo da Vinci
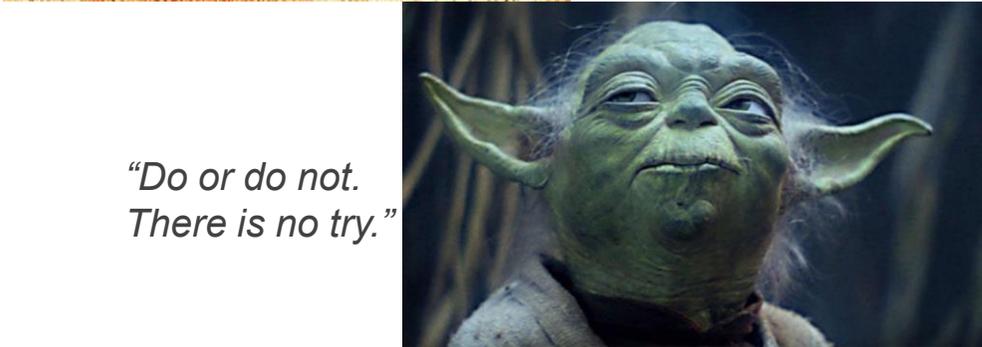
*"Do or do not. There is no try."*

For more information or to share ideas, contact:

Kerry Lunney CPEng EngExe ESEP
Thales Australia
Country Engineering Director / Chief Engineer
INCOSE President
kerry.lunney@thalesgroup.com.au

www.incose.org

www.thalesgroup.com