Unraveling Systems Engineers from Systems Engineering:

frameworks for describing the extent, variety and ambiguity of systems engineering and systems engineers

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Goal

Build on the existing literature to -

1. **Tackle long-running issues about**
   - scope and boundaries of systems engineering,
   - specialisation and differentiation of "systems engineers" within these boundaries.
2. **Set out an integrated framework for understanding the internal flavours and specialisations of systems engineering**
3. **Inform senior leaders in systems engineering organisations responsible for organisational and workforce development**

Issue

The “litmus test” of SE is “ successful systems”

- NOT necessarily synonymous with “successful project”

We need a clearer definition of the extent and limitations of

- what SE is and can deliver
- what systems engineers do

Drivers

Increased complexity of real world problems, coupling between systems

- People who can apply a “systems approach” to provide coherent and effective solutions to complex large-scale multi-domain problems

The need to improve organisational performance

- Lean thinking for end-to-end value
- Specialisation to improve efficiency,
- “T-shaped people” to align purpose and provide leadership across diverse stakeholder groups

The need to accommodate sustainability considerations

- Systems engineers need to expand system boundary to include “eco-systems”, “geo-systems”.

Systems and Software engineering “coming together”:

- Interdependence of SE/SW for a very important class of complex system solutions,
- A wide dissatisfaction with the effectiveness of the interface between the two disciplines,
- Need improved skills in software definition among a large subset of the SE community

Overlap between SE and programme/project/engineering management

- Lack of clarity on the unique technical content and added value of some key systems engineering roles, which are often performed poorly or not at all.

Structure of presentation

1. **Models that explain and structure the extent, variety and ambiguity (EVA) of SE**

2. **Models that explain the different flavours of SE practice and professional attainment**

3. **Discuss the difference between**

- “What systems engineers do” and
- “the cross-disciplinary landscape that needs systems thinking and a systems approach”

Prior knowledge and concepts

Jack Ring – "EVA" – extent, variety and ambiguity

Godfrey and Blockley – accept uncertainty (Italian Flag)

Numerous references – "tolerance of ambiguity"

Warfield – "spreadthink index", measures ambiguity

Busby and Oxenham, DSTL – "systems people"

Moti Frank – "Capacity for Engineering Systems Thinking"

Hitchins and Kasser – 5 levels of systems engineer

Hitchins – 5 levels of system

ISO/IEC 15288 implied lifecycle

Stupples – 3 types of SE

Blooms Taxonomy (Education - BKCASE)

Wider Engineering professional standards – e.g. Engineering Council UK-SPEC

etc etc etc

Extensions for sustainability (Sillitto & Godfrey, 2009)

Hitchins: levels of system

Level 1 – subsystems and technical artefacts

Level 2 – project systems

Level 3 – business systems

Level 4 – societal systems

Level 5 – Societal systems

Level 6 – Eco systems

Level 7 - Geo systems

Stupples: levels of SE

Level 1 – SE within a discipline

Level 2 – SE across disciplines

Level 3 – Socio technical integration

Level 4 – Environmental integration

ISO-IEC 15288: lifecycle processes

Holistic understanding of problem situation

Stakeholder requirements

Requirements analysis

Architectural design

Implementation

Integration

Verification

Transition

Validation

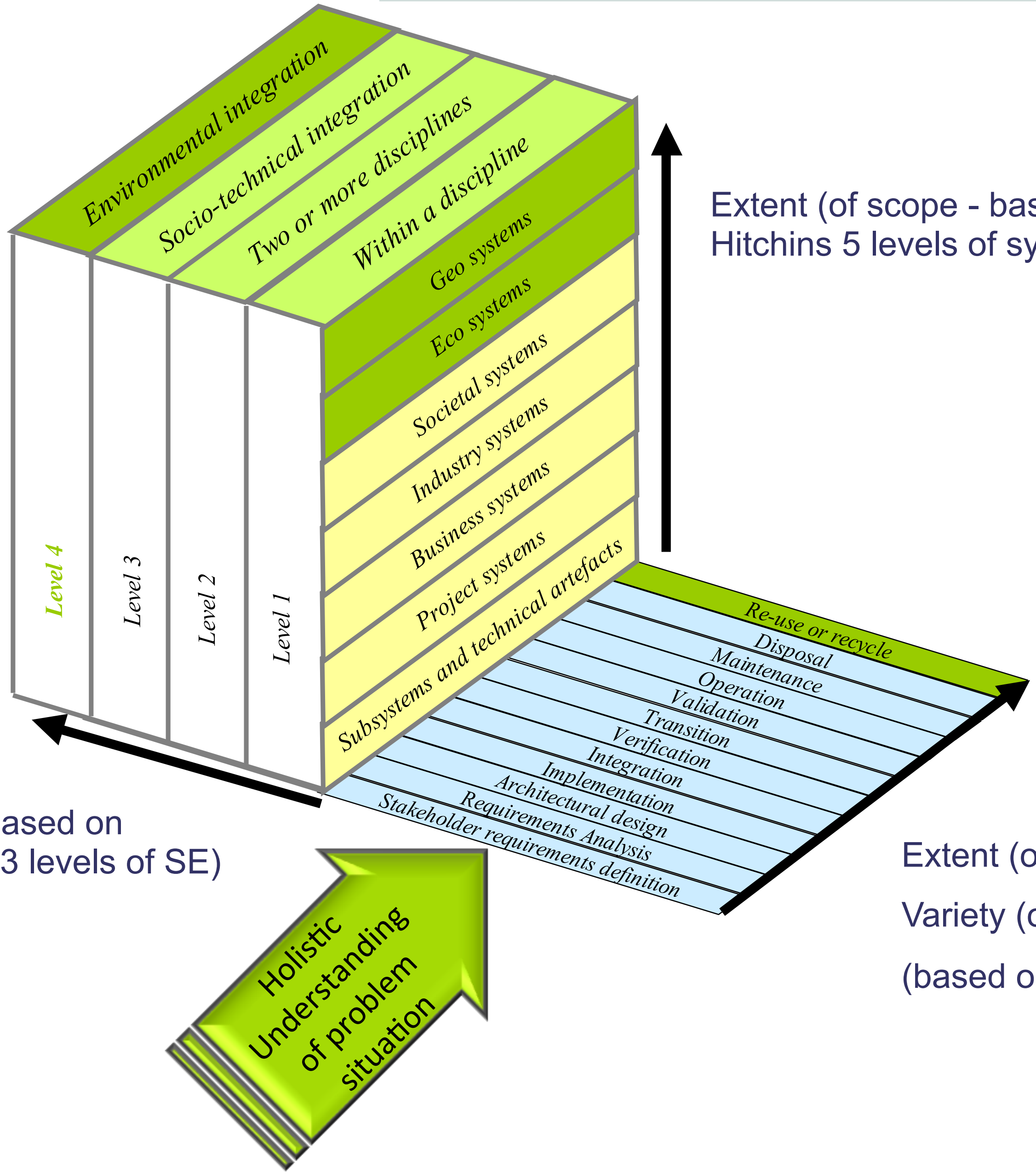
Operation

Maintenance

Disposal

Re-use / recycle

Integrating



Extent (of scope - based on Hitchins 5 levels of system)

Variety (based on Stupples 3 levels of SE)

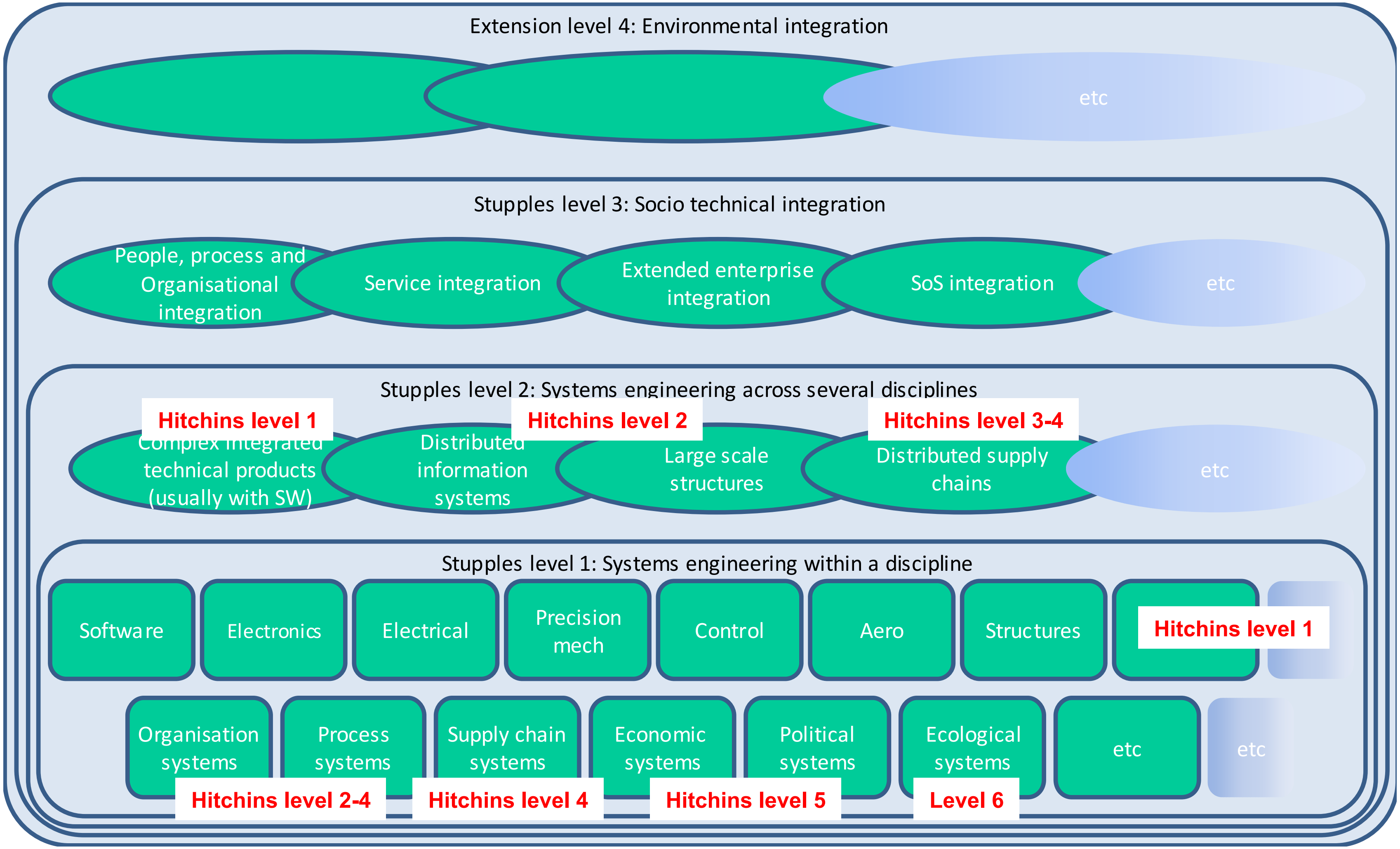
Extent (of time)

Variety (of task)

(based on ISO/IEC 15288)

Elaborating and cross-correlating:

Stupples levels with Hitchins overlaid



Extension level 4: Environmental integration

etc

Stupples level 3: Socio technical integration

People, process and Organisational integration

Service integration

Extended enterprise integration

SoS integration

etc

Stupples level 2: Systems engineering across several disciplines

Hitchins level 1

Complex integrated technical products (usually with SW)

Hitchins level 2

Distributed information systems

Large scale structures

Hitchins level 3-4

Distributed supply chains

etc

Stupples level 1: Systems engineering within a discipline

Software

Electronics

Electrical

Precision mech

Control

Aero

Structures

Hitchins level 1

Organisation systems

Process systems

Supply chain systems

Economic systems

Political systems

Ecological systems

etc

etc

Hitchins level 2-4

Hitchins level 4

Hitchins level 5

Level 6

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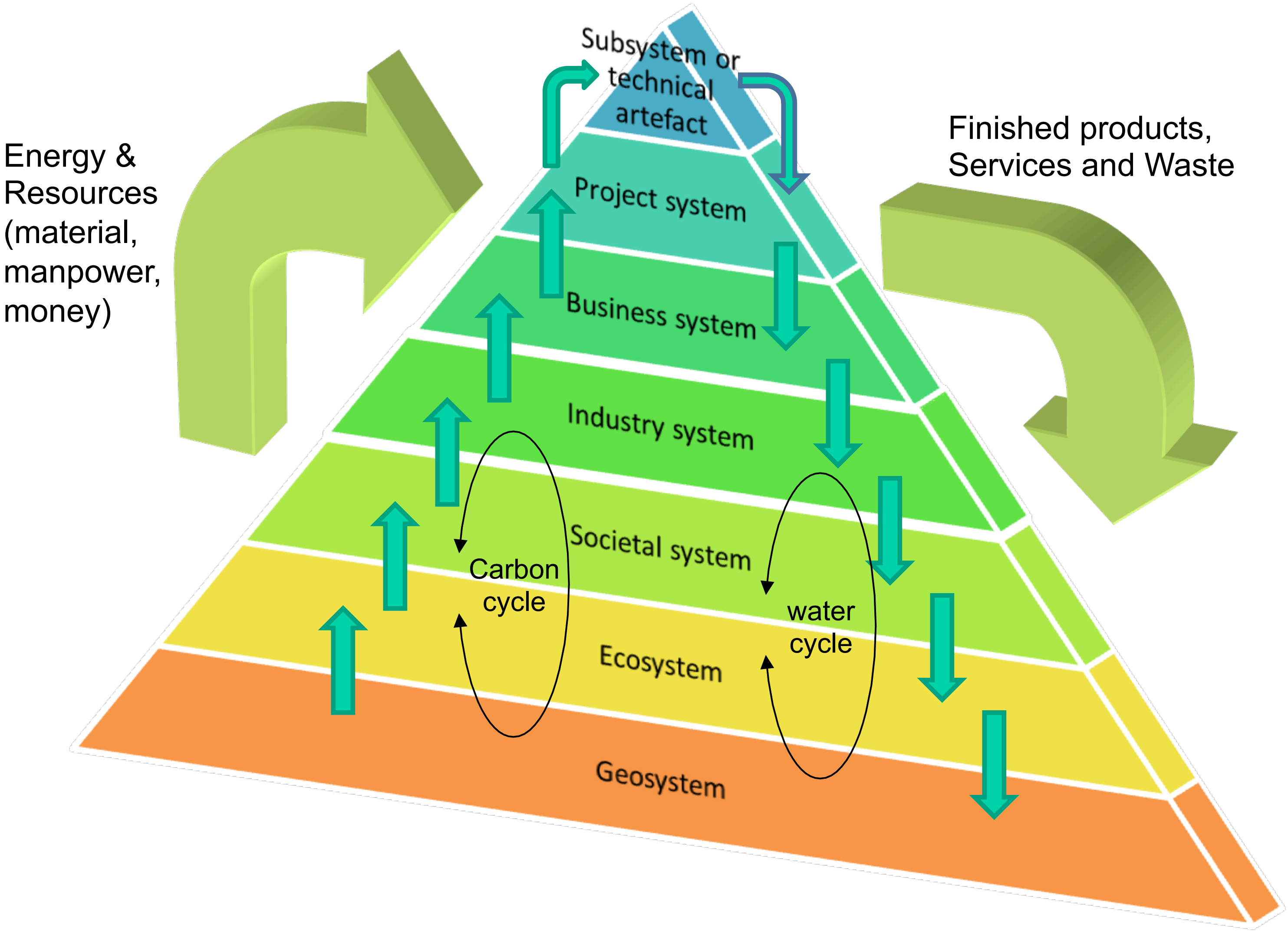
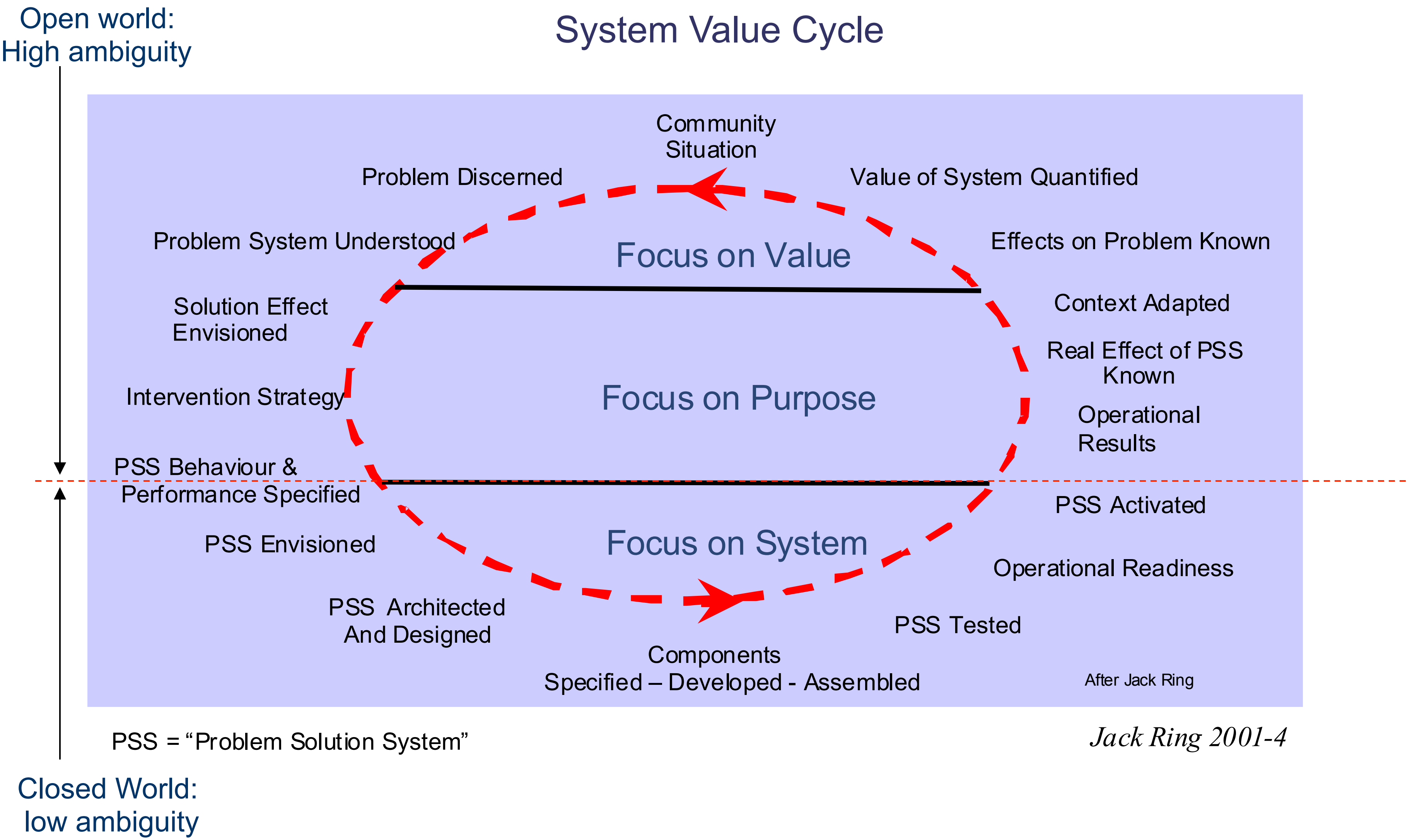
Now: we can trace flows and causal loops through the Hitchins levels



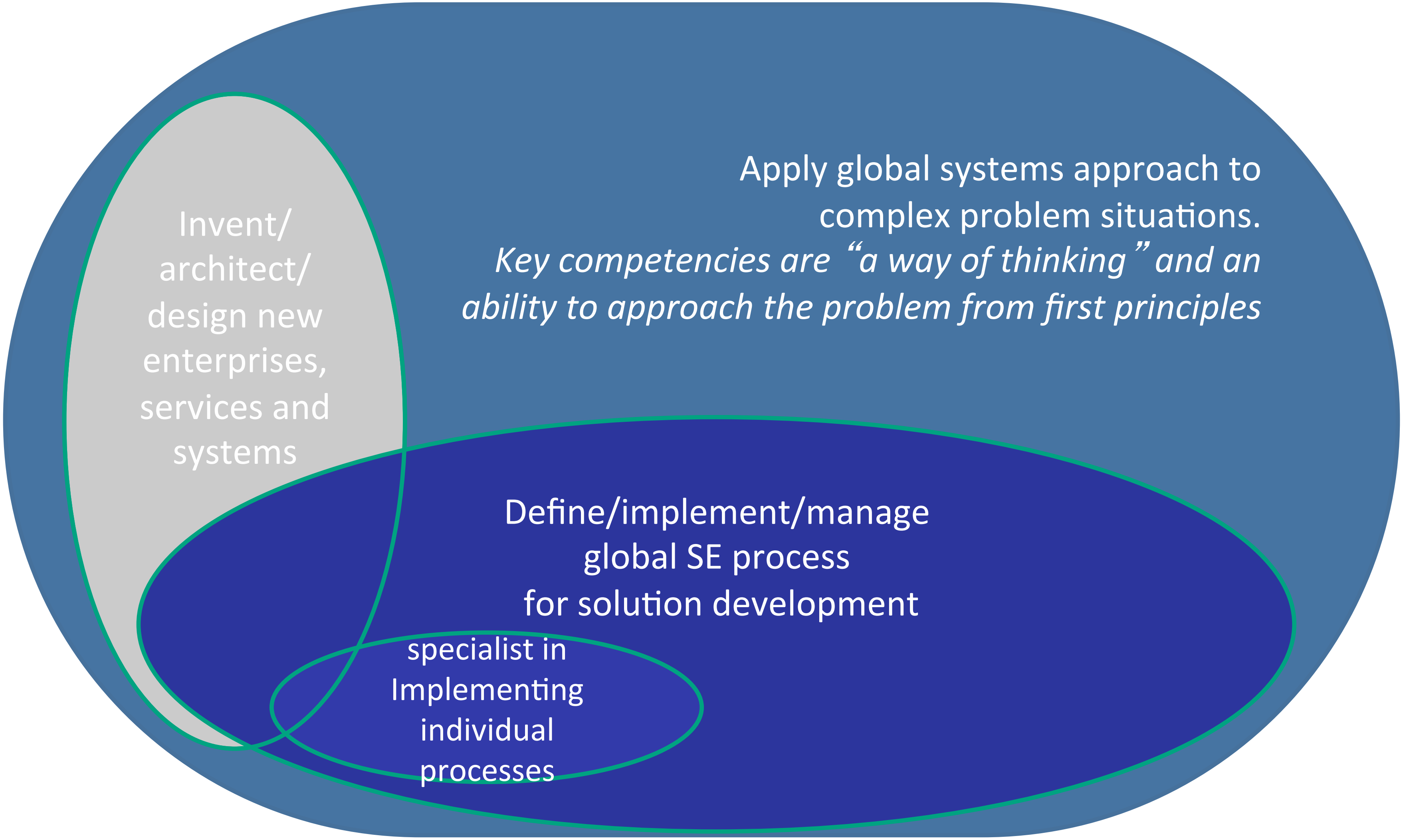
Levels of complexity and ambiguity



PSS = "Problem Solution System"

Jack Ring 2001-4

Different roles



Apply global systems approach to complex problem situations.

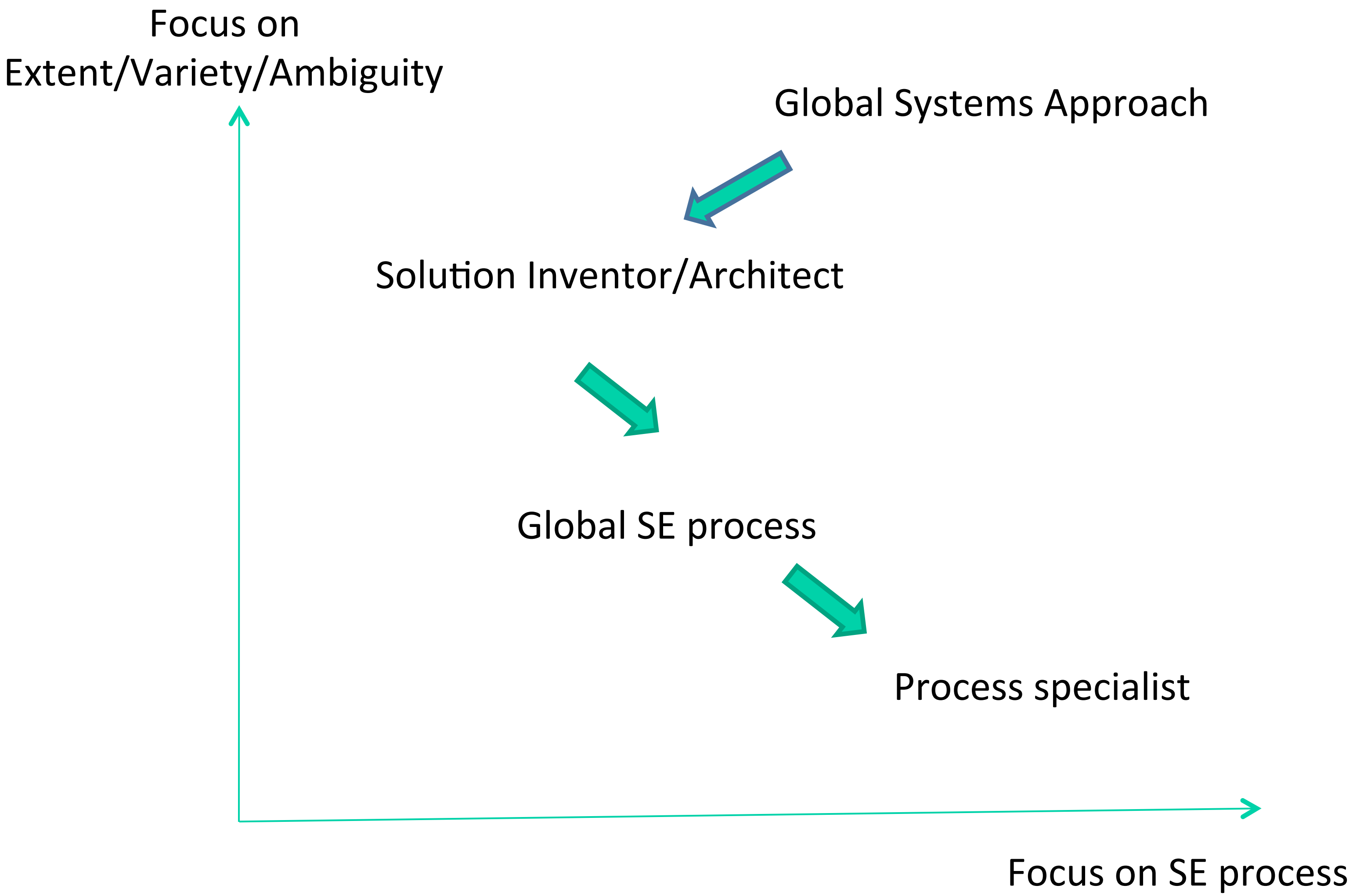
Key competencies are “a way of thinking” and an ability to approach the problem from first principles

Invent/ architect/ design new enterprises, services and systems

Define/implement/manage global SE process for solution development

specialist in Implementing individual processes

The four roles have different EVA and process focus



Focus on Extent/Variety/Ambiguity

Global Systems Approach

Solution Inventor/Architect

Global SE process

Process specialist

Focus on SE process

Measuring ability (or whatever you want to call it)

academic

Bloom, 1956	Anderson & Krathowl, 2001
Evaluation	Creating
Synthesis	Evaluating
Analysis	Analysing
Application	Applying
Comprehension	Understanding
Knowledge	Remembering

As used in BKCASE/GRCSE

SE proposal

Kasser (next paper)

Type V

Type IV

Type III

Type II

Type I

SE community competence models

INCOSE UK SE Competency Framework

INCOSE CSEP certification (ASEP, CSEP, ESEP)

Several organisational models discussed in BKCASE (MITRE, Raytheon, NASA, - - -)

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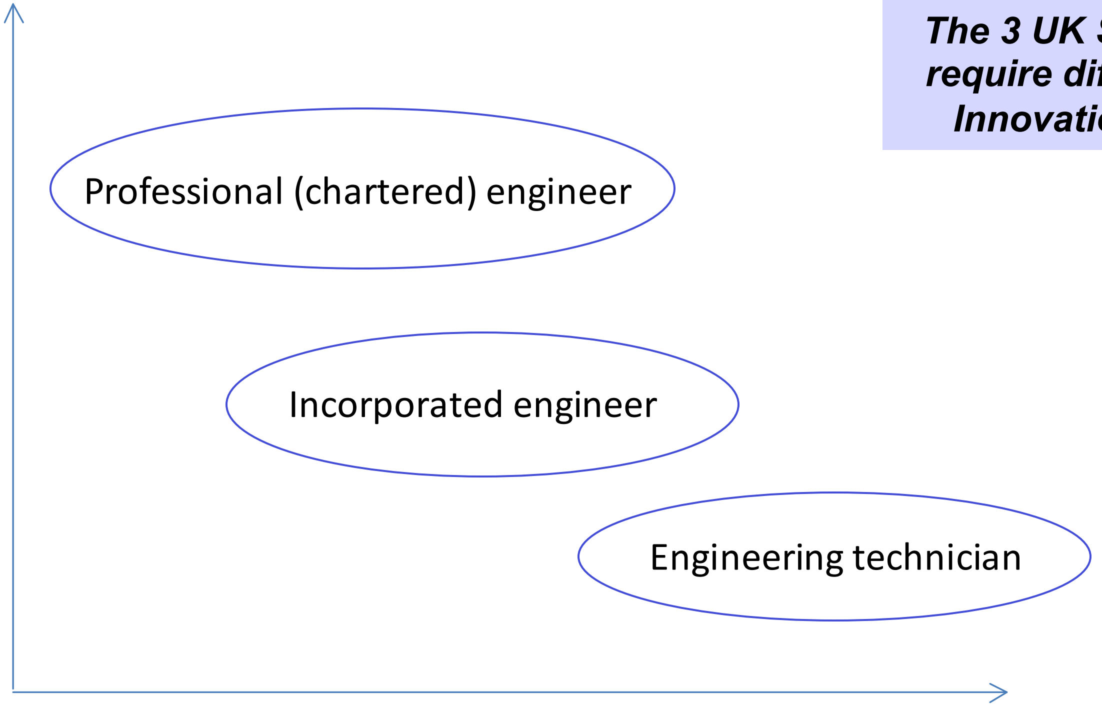
“Professional engineers”: UK SPEC

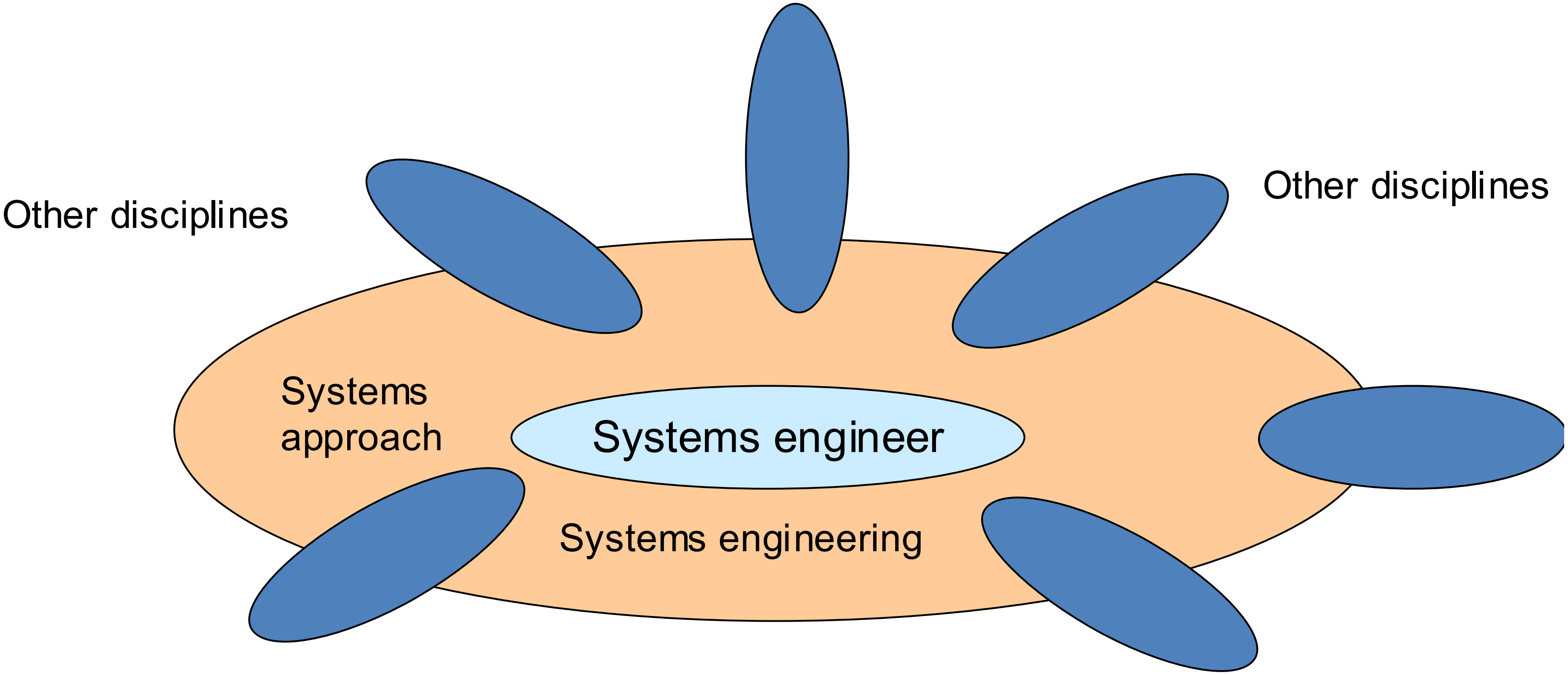
Capacity to innovate, working from first principles to solve unprecedented problems and create new knowledge



Skillfully apply existing knowledge to solve defined problems within defined areas of competence

The 3 UK SPEC levels require different Skill/ Innovation balance

The systems engineer is one actor in a much larger community



Fixing the PM/SE interface

You can't fix all of cost, time and performance in a situation with high levels of uncertainty (Rechtin).

Common programme management practice:

- seek certainty
- divide the job into ever smaller parts,
- increase planning time (and cost) to increase precision of estimates.

But:

- interactions proportional to (number of chunks)^2

So

- more precise (but not necessarily more accurate) estimate of cost of the chunks,
- increased risk through more complex interactions and interdependencies

An effective approach for system success:

Focus on increasing shared knowledge,

- building consensus and discharging risks -
- “learning by DOING” rather than faith-based PLANNING.

Not to say that planning doesn’t matter: but

the flexibility of the plan and architecture must match the level of uncertainty and change in the problem/solution space.

Decisions must be evidence based not faith-based,

- and made at the “last responsible moment”
- not just because the schedule/milestone plan says so.

There is also evidence that

- competitive and transactional behaviours destroy synergy and increase risk
- alignment of purpose and incentives leads to collaborative behaviours that reduce risk and increase prospects of success – even with constrained time and budget!

Key Deductions

There is a clear place for systems engineering and systems engineers within large projects developing complex technology-intensive product systems.

- There is an increasing demand for systems engineers skilled at handling the system/software interface within such projects.

There is a much wider scope of activity that needs a "systems approach" – including many roles in organisations developing high-tech complex systems and products.

- This needs to focus on soft issues and sustainability considerations that are now the limiting factor in most complex system developments, and would ideally be based on an underpinning "systems science" foundation.

Organisations that employ "systems engineers" are in a good position to apply systems engineering to their whole organisation

- because they have a continuous stream of systems engineers coming through the ranks,
- some of whom will show aptitude for applying the systems approach in the wider organisation
- and will know the organisation well enough to be able to do this effectively.

Systems engineering has an image problem outside its traditional domains of application

- the word "engineering" leads non-engineers to assume that systems engineering is not for them.
- experience, ability & professional level of systems engineers widely variable, like any other profession,
- not all systems engineers can do all aspects of systems engineering.

Possible remedies

Mature disciplines and mature professions segment and specialise to deal with such issues.

- Physicists specialise in different areas of physics.
- Doctors specialise in different areas of medicine.

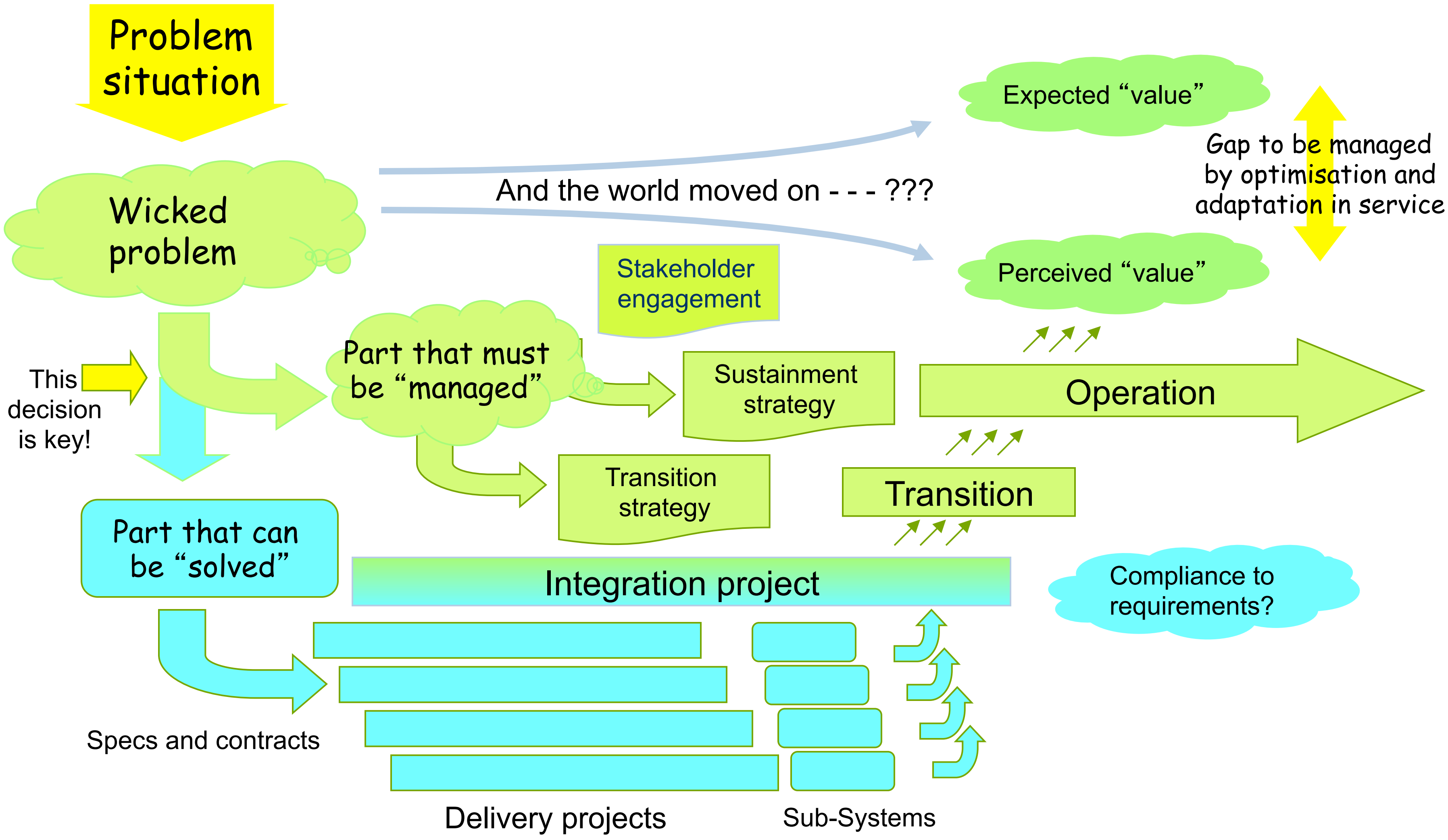
To move forward the systems engineering community now needs to

- deliver excellence within the areas that are well defined,
- engage synergistically with other communities to foster the systems approach in areas where a systems approach appears to be needed but is not currently used.

Thank you for your attention

Any questions?

Levels of complexity and ambiguity (2)


Problem situation
Wicked problem
And the world moved on - - - ???
Expected "value"
Gap to be managed by optimisation and adaptation in service
Perceived "value"
Stakeholder engagement
This decision is key!
Part that must be "managed"
Sustainment strategy
Operation
Transition strategy
Transition
Part that can be "solved"
Integration project
Compliance to requirements?
Specs and contracts
Delivery projects
Sub-Systems