Systems Engineering for the 21st Century

'Getting back on Track'

By

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A Brief History of …… Systems Engineering

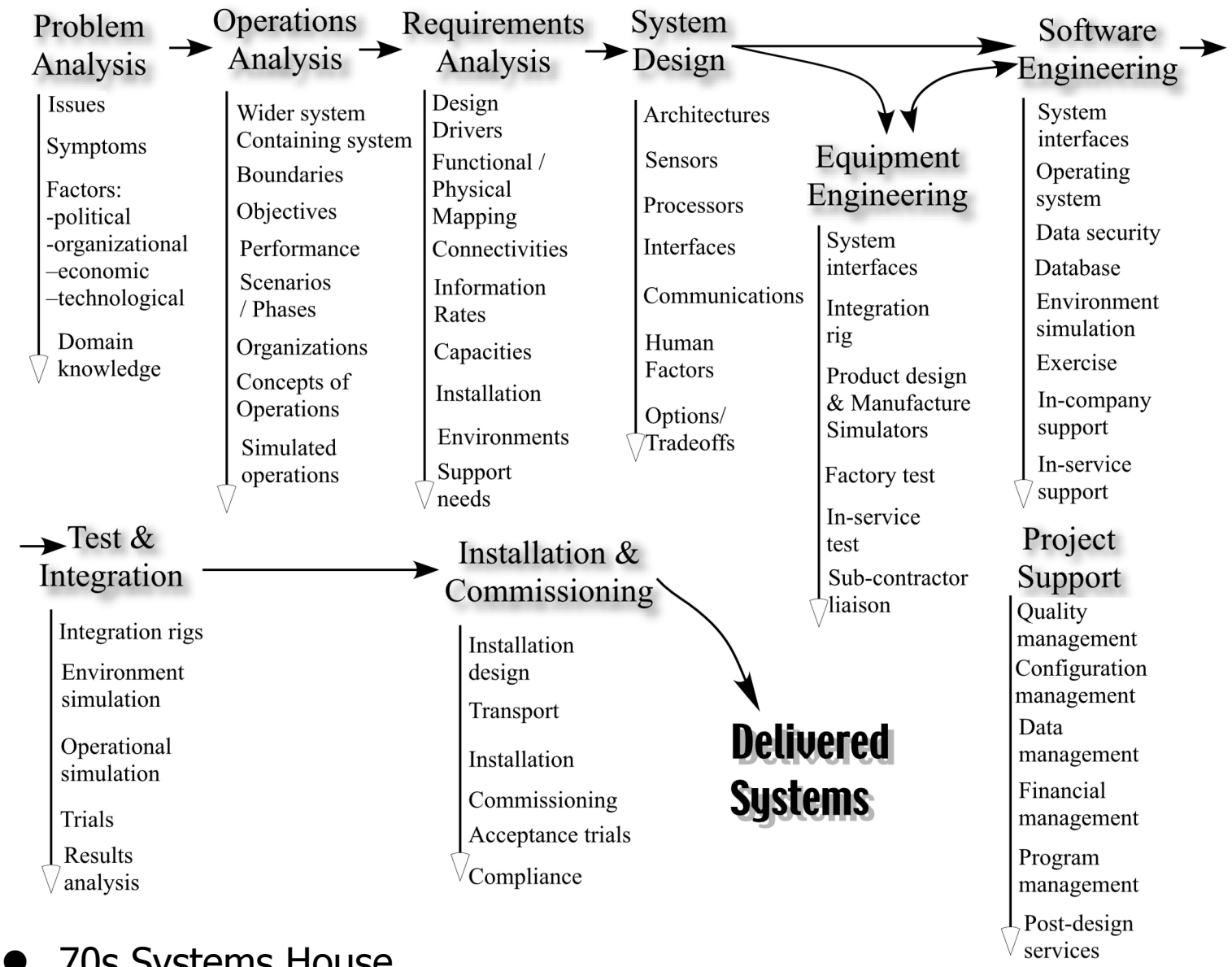
- Product of pre-WWII 'systems movement'
  - ➔understand whole, complex, dynamic, open systems
  - ➔address whole complex, dynamic problems:
    - How to organize WWII N. Atlantic convoys to minimize losses
    - How the RAF could defend the UK against air attack
    - How men could go to the Moon - and return safely
    - How to conceive, construct, operate and decommission atomic/nuclear power plants effectively and safely
    - How to solve the global energy problem
    - How to address complex social issues: national healthcare, creating new dams and reservoirs, large-scale agriculture, etc.
    - How to defend a naval fleet against air, surface and sub attack.
- Rapid development during WWII
- Further developed during East-West Cold War
- Development in West slowed post Cold War
- Separate strand developing since WWII in S.E. Asia

Classic SE in the 1950s

Classic SE in 60s

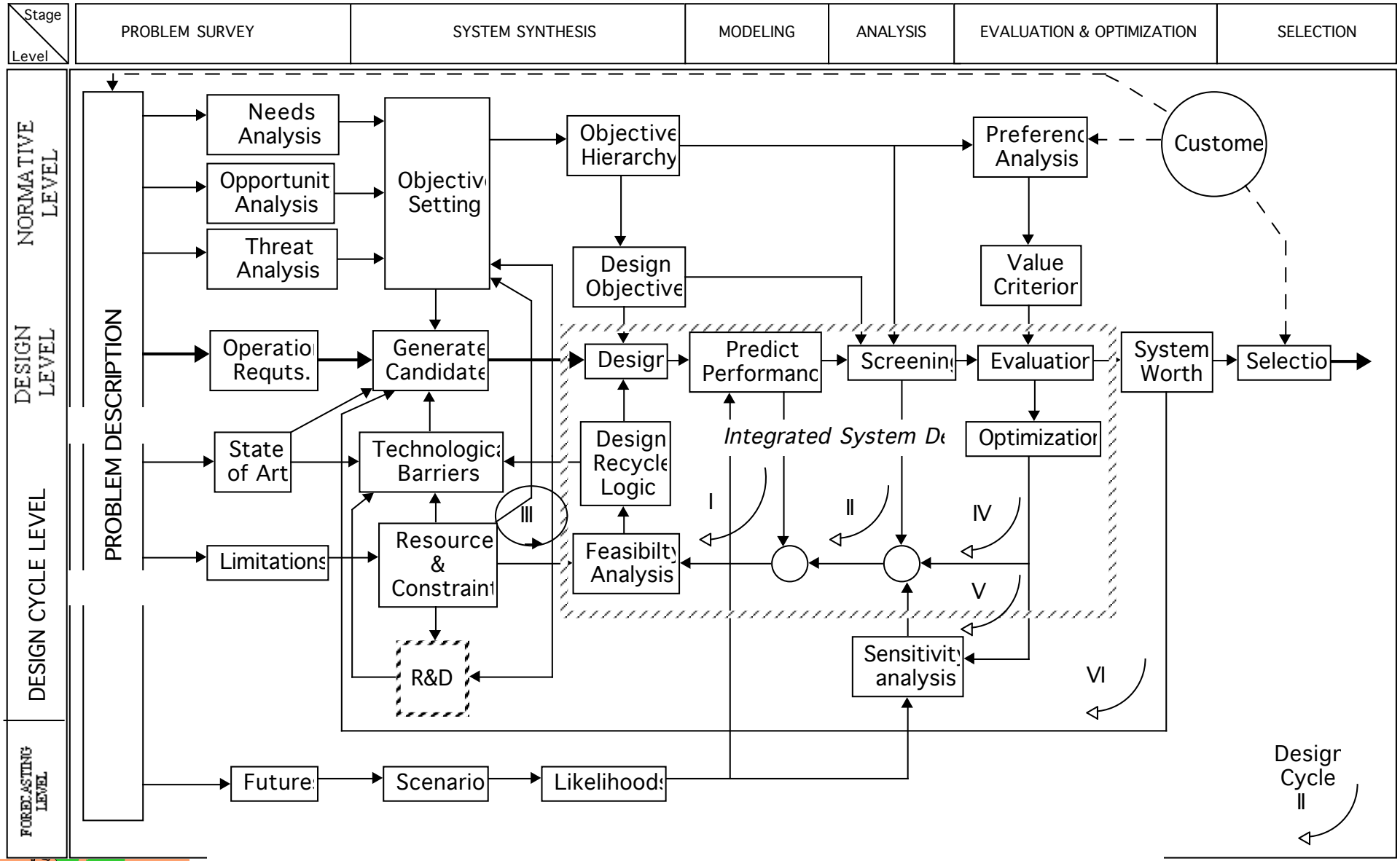
- Gemini and Apollo programs
- Central system design team, coupled with…
- peripheral system design teams:
  - ➔per major subsystem: lifter, lander, command module, rover, etc., etc.
  - ➔Communications • infrastructure • test and trials • command systems • etc.
- Central design team 'walked through' CONOPS:
  - ➔What the crew members needed to do to achieve mission
  - ∴What functions, process and capability were needed to meet crew members needs…
  - ➔So, less engineering - more, satisfying/enabling crew members purposes and intents…to achieve mission
  - ➔I.e. operational systems engineering

Classic SE in 1970s



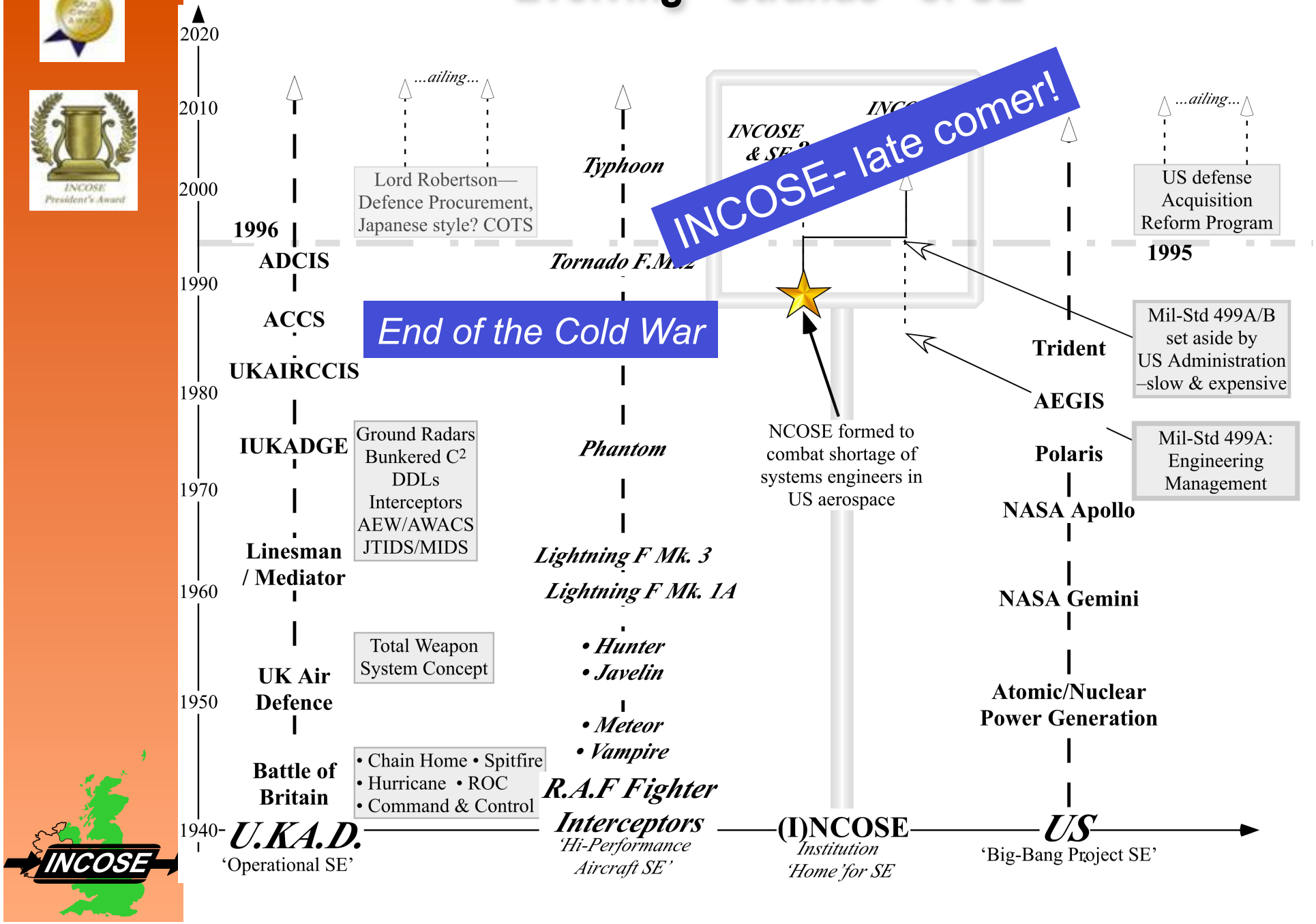
- 70s Systems House
  - ➔Worked along same lines as NASA's Apollo

Classic SE in 1980s



- Philip M' Phersons System Design Framework, 1981

Evolving ‘Strands’ of SE



After the Cold War…

- New war: industrial and commercial warfare,
- S. East Vs. West
- Japanese industrialists follow *bushido* and Sun Tzu - (War and Management) - create vibrant approach to industrial SE
  - ➔Japanese LVSS take world markets by storm
    - Automobiles • white goods • brown goods • machine tools • electronic devices
    - Low cost, high quality, innovative…demand, volume, profit…
- 1995/6 Major threat to US DoD Defense Acquisition
  - ➔EM seen to be *slow*, and v. expensive
  - ➔Cf. COTS procurement, Japanese style
  - ➔US DoD Engineering threatened - extinction!
- SE faces new challenges: complex, dynamic commercial, industrial and social problems and issues.

Meanwhile SE Vs. EoS…

- INCOSE formed, 1990 - 91
- Classic SEs flock to join, worldwide
  - ➔there had never been an 'institution' dedicated to SE
- INCOSE 'influenced' by US DoD, Mil-Std-499A, etc.
  - ➔Esp. after it was 'withdrawn,' 1995
- 2005: INCOSE declares "systems engineering ≈ engineering of systems"
  - en·gi·neer·ing n: 'the application of science in the design, planning, construction, and maintenance of **buildings**, **machines**, and other **manufactured things**
- Engineering of systems ≈ engineering management
- So, INCOSE dedicates itself to engineered artefacts:
  - ➔hence, ***not*** dedicated to classic systems engineering
  - ➔worse, could INCOSE be openly opposed to classic SE?
  - ➔EoS is unable to address systems with people in them
    - HAS, enterprises, industries, sociotechnical systems, social systems…

Meanwhile SE Vs. EoS (2)…

- Reason? Perhaps DoD Engineering Department influence?
  - ➔ *"… systems engineering is* **not** *a discipline. It is a way of thinking, an approach for engineering systems, albeit a disciplined approach."*
  - ➔ *"…systems engineering is* engineering done better*."* (NCOSE 'founding father')
- *Some* founders considered changing name to INCOES in 1993: but did not, and have not…
- Meanwhile, systems engineers worldwide joined INCOSE:
  - ➔Many believed institution dedicated to the… discipline and practice of systems engineering
  - ➔Not unreasonable, given the institution title.

1990s - *Mil*-Std-499A - Engineering Management

(1 May 1974 *Mil*-Std-499A (USAF))

- Engineering Management
  - ➔Puzzle: why systems? whence systems engineering connection?
  - ➔In some aircraft companies, everything that is not *airframe* or *propulsion* is called *systems!* (Sic!)
  - ➔Defense Systems = ***everything*** *carried on USAF aircraft, excluding engines, airframe and crew*
  - ➔*Original meaning probably: "engineering management (of defense systems)"*
    - Often called 'systems *engineering management*…'
    - Essentially, nothing to do with classic systems engineering…
- EM: Management of 'the application of science in the design, planning, construction, and maintenance of **buildings**, **machines**, and other **manufactured things**:
  - EM concerned only with technological artefacts – not 'systems' in the classic sense of 'wholes' - not people systems - not teams, platoons, squadrons, enterprises, industries…

INCOSE Future?

- Little future pursuing DoD's engineering of systems:
  - ➔Defence engineering no longer a major economic worldwide differentiator
  - ➔Commercial engineering matches/exceeds defence standards
    - Japan, Asian Tiger Economies, India, China, Europe
  - ➔With end of Cold War, fewer major defense engineering projects…diminishing market?
- Commercial/industrial 'Engineering of systems' is addressed by the engineering institutions
  - ➔It always has been, along with engineering management
  - ➔So, who needs INCOSE for EoS when there are:
    - IEEE, IEE, IET, RAeS, IMechE, etc.,etc.?

INCOSE in Disarray

- INCOSE is fragmented:
  - ➔Leadership pursues Engineering of Systems (EM)
    - US Government Defense Engineering customer?
    - Follow the money?
    - Nothing wrong with EoS/EM - *it just isn't systems engineering!!!*
      - *actually, Japanese show EM to be v. expensive and slow!*
- Burgeoning interest in System of Systems
  - ➔Systems formed by bringing operating systems together:
    - i.e., largely human activity systems (HASs), + sociotechnical
    - ***Nothing to do with engineering of systems***
- Great Interest in Intelligent Enterprises (IEWG)
  - ➔HASs that 'behave intelligently'
  - ➔***Nothing to do with engineering of systems***
- Meanwhile classic SE subjects *evading* INCOSE:
  - ➔Architecture design • C^2, C^3I, C^4ISTAR • systems-design • complex problem-solving • Network enabled capability • IDA systems • stock market systems • security systems • enterprise systems • LVSS, etc.
  - ➔***Nothing to do with engineering of systems***
- ***INCOSE leadership, & EoS, out of step with members!***

So, where does that leave INCOSE and SE?

- Meanwhile, the organization grinds on relentlessly:
  - ➔Developing SEBOK - about EoS?
  - ➔SysML - for engineering of systems, not systems engineering…
  - ➔We need a *real* **systems** modelling language for *real* SE:
    - Exploring problem spaces • problem solving • situation assessment • developing conceptual remedial solutions • exploring solution spaces • trading options • developing CONOPS • threat assessment and neutralization • decision making • functional design • functional architecture • design optimization • functional-physical mapping • etc., etc.
    - Following the Systems Approach: dynamic simulation of open systems, interacting with other systems, adapting to them and their environment. Dynamic optimization. Developing active emergent properties, capabilities and behaviours
  - ➔***Nothing to do with engineering of systems!!***
- Feel the Force!! INCOSE future *bleak* unless…
- *…we draw back from the Dark Side*

Way Ahead…

5	Socio-economic	Many industries make a socioeconomic system: the stuff of government and legislation
4	Industry	Many enterprises make an industry Japan operates at this level
3	Enterprise	Many projects make a business West operates at this level
2	Project	Many artefacts can make a system project
1	Artefact	Some engineers believe this is the only systems engineering…

- Not rocket science! Get back to genuine systems engineering.
- Address *all* levels of 5-Level SE Model: not just Level 1
  - EoS does not even address Level 1!
- Stop contemplating navels and establish the discipline of SE
- …which necessitates identifying our ***systems methodology*** - the ***'how'*** of systems engineering
- How can we be members of an institution for systems engineering that does……

…**not *know how* to do 'systems engineering**?"

SE Vs. EoS - Could they be more different?

- 'Systems' is about 'wholes:' fundamentally, systems ***are*** wholes.
  - ➔whole problems…… whole solutions
  - ➔whole aircraft = man+artefacts • whole team = full complement of skills • whole radar = operators +artefacts • whole enterprise = people + artefacts.
- tenets: holism, synthesis and organicism
- Systems engineering is about exploring, understanding, designing and creating whole solutions to whole problems
- …looks like a discipline to me…

Systems Engineering	Feature	Engineering of Systems
Synthesis	***Paradigm***	Reduction
Whole >∑ (Parts)	**Emergence**	Whole =∑ (Parts)
Organismic, non-linear	**Metaphor**	Mechanistic, linear
Open System, adaptive	**Conceptual Model**	Closed System, fixed
Homeostatic	**Control**	Cybernetic
Dynamic, high energy	**Stability**	Static, low energy
Systems Approach	**Methodology**	Analytic
In	**People**	Out
Manages and conceals complexity	**Complexity**	Generates complexity, complication and detail

So, what is classic systems engineering?

- "The essence of systems engineering is in: selecting the right parts, bringing them together, orchestrating them to interact in the right way and so creating requisite emergent properties, capabilities and behaviours of the whole"
  - ➔Works for all kinds of systems: linear, nonlinear, HAS, technological, procurement, enterprise, pipeline…
- Get it right, and the whole really is greater than the sum of the parts, giving synergy, capability, economy, quality…
- The real problem with systems engineering over the last 60 years has been: ***knowing how to do it!***
  - ➔Anyone who knew kept it a trade secret!
  - ➔And that has been the problem
- Without an established method/methodology, folks have simply been making it up as they went along!

Systems Methodology (SM)

- The '**how**' of systems engineering
  - ➔How to solve, resolve or dissolve any complex problem
- SM: context independent, scale independent, system-type independent = 'generic'
  - ➔…*comprises:* paradigm, process, methods, techniques, tools, skilled people, domain experts, organization
  - ➔*…takes:* 'the systems approach' to open, adaptive, interactive systems…
  - ➔…*employs:* systems theory; systems science; systems thinking; scientific method;
- Used by individuals: teams: teams of teams
- Think about it! How have we been 'doing SE' all these years ***without*** a systems methodology? **SM *defines* SE!**

Systems Methodology (SM)

- With a 'universal' SM, we - INCOSE - we - individuals, teams, industries nations could…
- Address major problems:
  - ➔Conception/design of new systems using new technology to solve old and new problems • commercial viability and durability • famine relief; fresh water; species diversity; global warming; climate change; rising sea levels; global energy supplies; alternative energy; defence weapon systems; network-enabled capability…
  - ➔social disorder; de-civilization; global terrorism; defence acquisition, pollution, international transport, traffic congestion, expeditions to Mars & beyond…etc., etc.
  - ➔Club of Rome World Problematique:
    - environment • demography • development • values • governance • work in the future • information society • new technologies • education • the new global society • world economic and financial order
- …and everyday problems:
  - ➔Food supplies • dams & reservoirs • health care, surgeries, hospitals • social engineering • policing • traffic • pollution and recycling • conservation… • terrorism • schooling • housing • political correctness • health & safety • crime prevention • energy supplies • overcrowding • commuting • etc., etc
- The SM provides a methodological framework for people to work individually, or together coherently in teams and teams of teams to create solutions to complex problems that are provably correct.
  - ➔***Nothing to do with engineering of systems!!***

Foundations for Systems Methodology Evolution

1. A scientifically rigorous systems methodology for use by individuals, teams and teams of teams to address, and find solutions to, problems of all kinds, sizes and complexities
2. Continually-updated, context-independent tools, methods and techniques to revitalize the systems methodology
3. Continuing research program to develop first two bullets
4. Continuing education and training system to develop and equip future practitioners
5. A developing library of SM Case Studies
6. Continuing demand for complex problem solving

INCOSE to lead all the above -

surely, that is what INCOSE is for!

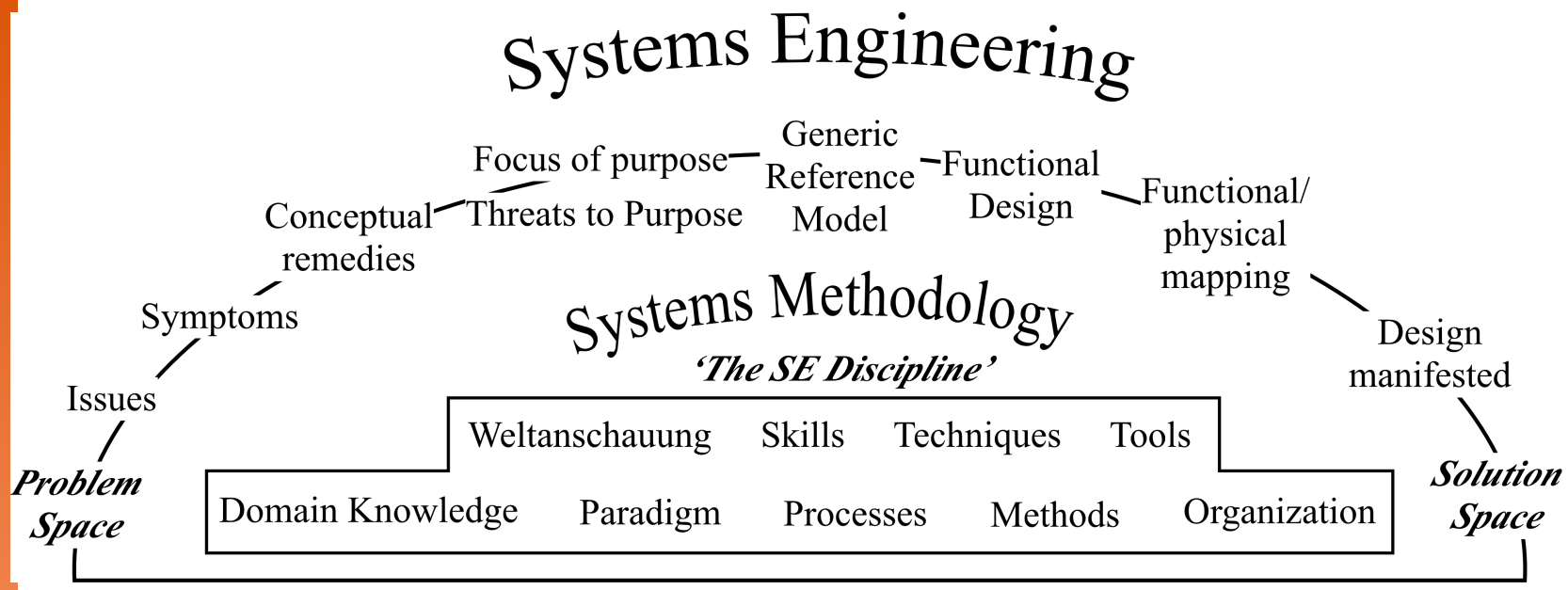
Developing the Systems Methodology

- Something INCOSE should have been doing since inception - Why no: ***'how to do it?'***
  - ➔Context-independent paradigm, process, skills, tools, techniques, methods, structure, organization
  - ➔Different tools for different jobs, like a surgeon selects the right scalpel…
- Once developed, to be taught in schools, colleges, universities:
  - ➔emerging scientists, technicians, physicists, mathematicians, engineers, etc., understand…
  - ➔ what systems engineering is, how to do it…
  - ➔ in the general case, and…
  - ➔ how to go from the general to the particular, and back

So, what does this SM look like?

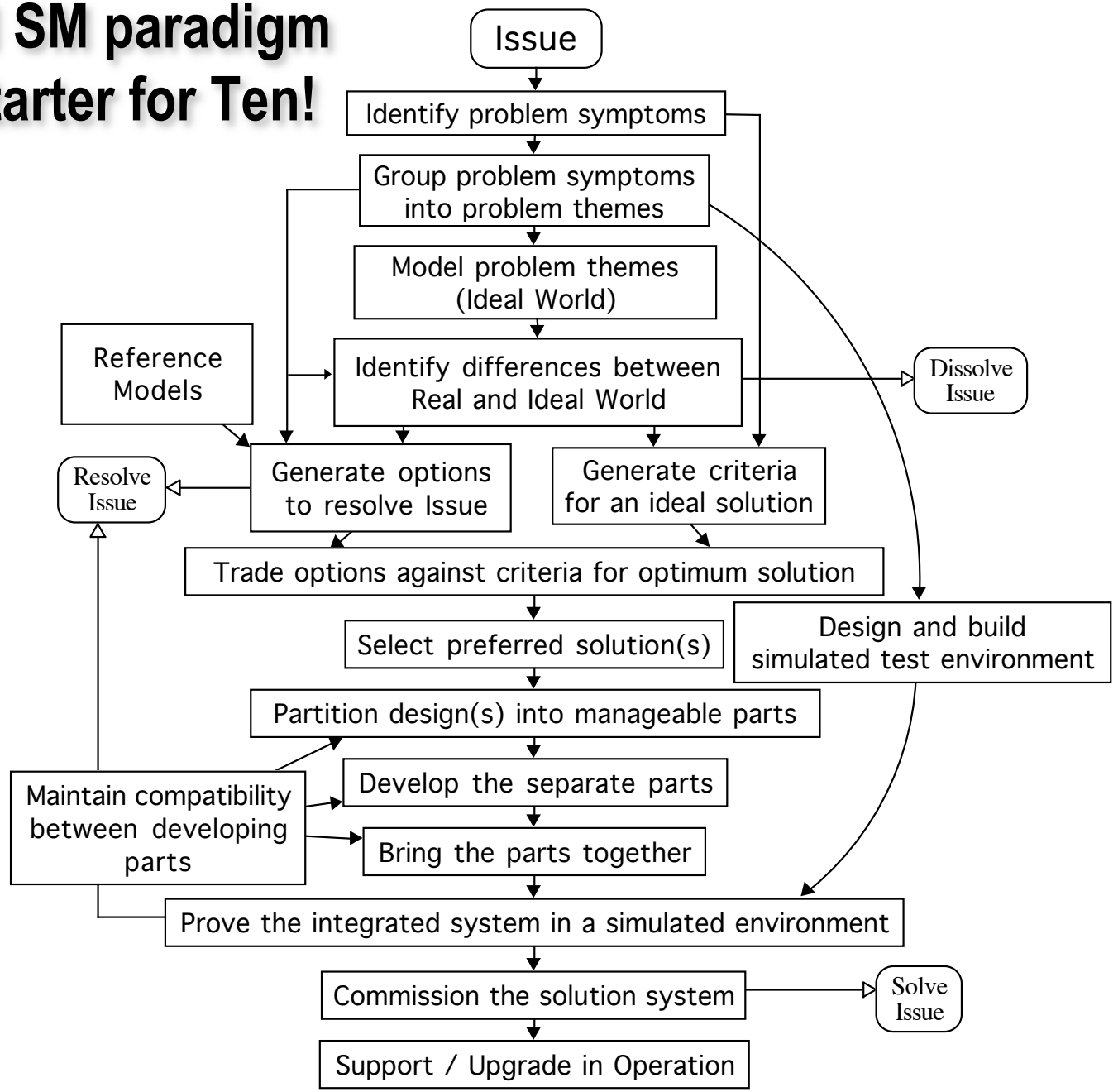
- Ah! but that's for us to find out. SM = INCOSE 'product!'
- We need to get our best brain's together and work out
  - ➔What the real systems engineering has always been about
  - ➔How its objectives can be realized…
  - ➔… in a rigorous, provable way
- We did it before…
  - Pyramids, Battle of Britain, IUKADGE, Lightning, Apollo, AEGIS, Trident, nuclear energy, Tornado, Typhoon, UKAIR, ACCS, etc.
- …without being sidetracked by:
  - ➔***Current business and management-speak***: stakeholders, Customer's 1 and 2 = engineering / business management
  - ➔**Engineering –** many solution systems involve little or no engineering, and real SE will specify what is needed anyway
  - ➔**Standards** which purport to be about ***systems engineering*** - they are about ***engineering management:*** useful in that context, irrelevant to real ***systems engineering***
- Methinks we need to do some research…

SE&SM - Bridging from Problem to Solution



- SE goes from Problem Space to Solution Space
- SM defines the discipline that is SYSTEMS ENGINEERING
  - ➔SM is a system in its own right
- INCOSE is (should be) the custodian of that discipline…
- If INCOSE is not, what is it really for?

Notional SM paradigm - Your starter for Ten!



Conclusion

- INCOSE needs SE *but* … • does SE need INCOSE?
- Systems engineering has been hijacked in INCOSE by EoS - against the wishes of many members
  - ➔Not right for INCOSE to be 'nobbled' by a minority Defense interest
- Put SE back in the driving seat - it is, and has always been, about systems - of all kinds, but always *systems.*
- INCOSE missing 'how you do systems engineering'
- INCOSE needs a generic/universal *teachable* Systems Methodology, to enable practitioners to go from problem space to solution space
- Without an SM? Slow slide into oblivion…
- With an SM? Challenges, opportunities and a vibrant future for both SE *and* INCOSE. It's up to us!