Managing Complex and Increasingly Intelligent Systems

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NICER Research Group
The Emergence of Complex Intelligent Systems – The Future of Management
WAPS-HS

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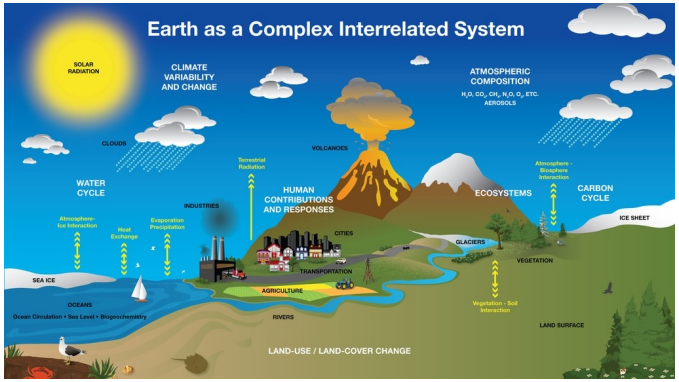
The Future of Management

AI as part of Complex Intelligent Systems



Our research's underlying premise is that the potential to reach societal benefits is a function of how well AI is understood in relation to its role in complex systems and context

Focus on complex intelligent systems (CoIS):

- high cost, engineering-intensive and emergent in character
- inherent and recursive growth in diversity, scale and embeddedness
- high demands on systems integration with digital, physical and AI-based solutions as well as contributions from humans making up the system

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(Yu, Lakemond, and Holmberg 2024; Lakemond and Holmberg 2022; Hobday 1998)

What do we know on Management in Complex Systems

Normal Accident Theory

Complex Products and Systems

1983 1984 1989 1998

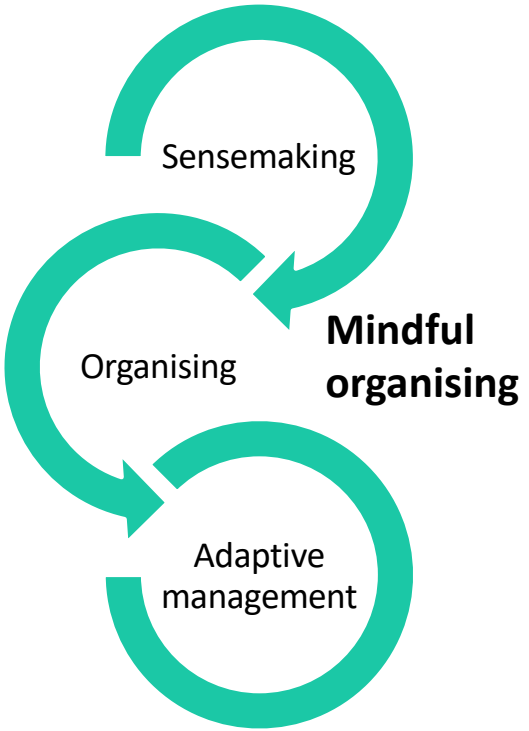
Present time

Large Technical Systems

High Reliability Organizations

HRO organizations

- **Preoccupation with failure** - anomalies as symptoms of a problem with the system
- **Reluctance to simplify interpretations** – looking for comprehensive understanding
- **Sensitivity to operations -** sensitive to unexpected changed conditions
- **Commitment to resilience** - develop the capability to detect, contain, and recover from errors
- **Deference to expertise** - follow hierarchy during routine operations, but defer to the person with the expertise to solve the problem during upset conditions



Weick et al. (1999)

Complex Products and Systems

- **Definition:**
  [A]ny high-cost, engineering-intensive product, subsystem, system, network, software system, high-technology service, capital good or construct supplied by a unit of production (i.e. a single firm, production unit, group of firms or temporary project-based organisation)

- Units of analysis for innovation purposes are (a) the project and (b) its output (or product) and (c) the links between them.

*Table 1.1: Examples of complex products and systems**

Air-traffic control systems	Nuclear decommissioning systems
Aircraft carriers	Nuclear fusion research facilities
Aircraft engines	Nuclear power plant
Armoured fighting vehicles	Nuclear waste storage facilities
Avionics equipment	Ocean-drilling vessels
Baggage-handling systems	Offshore oil production platforms
Banking automation systems	Oil-refining equipment
Base stations for mobile comms	Oil tankers
Battleships	Passenger aircraft
Bridges	Port loading/unloading systems
Bulk carriers (ships)	Process control systems for oil refining
Business information networks	Production systems (automated)
Chemical plant	Racing cars (e.g. Formula 1)
Clean rooms for semiconductors	Racing power boats
Combined-cycle gas turbines	Radio towers (large)
Cruise liners	Rail signalling/control systems
Dams	Rail transit systems
Docks and harbours	Refuelling aircraft and systems
Electricity network control systems	Remote nuclear decommissioning units
Electronic commerce systems (e.g. internet systems)	Road systems/flyovers
Electronic retail networks	Road traffic management systems
Flexible manufacturing systems	Robotics equipment
Flight simulators	Rollercoaster equipment
Frigates	Runways for aircraft
Ground to air missile control units	Satellite systems
Helicopters	Semiconductor fabrication equipment
High-speed trains	Sewage treatment plant
Hovercraft	Software packages
Integrated mail-processing systems	Space launch vehicles
Integrated tram systems	Space observatories
Intelligent buildings	Space stations
Intelligent warehouses	Strategic bombers
Jet fighters	Submarines
Mainframe computers	Supercomputers
Maritime communication systems	Superserver networks
Mine hunters (and other large military ships)	Synchrotron particle accelerators
Missile systems	Telecommunications repeater systems
Tank communication systems (battlefield and tactical)	Training jets
Tanks (e.g. main battle)	Water filtration/purification plant
Telecommunications exchanges	Water supply systems
Telecommunications network management systems	Wide area networks
	Yachts (e.g. 12-metre racing)

* These products include various kinds of capital goods, networks, systems, subsystems, and engineering constructs (e.g. intelligent buildings).
Source: Hobday (1998: 697).

Hobday, M. (1998). Product complexity, innovation and industrial organisation. *Research policy*, *26*(6), 689-710.
Davies, A., & Hobday, M. (2005). *The business of projects: managing innovation in complex products and systems*. Cambridge University Press.

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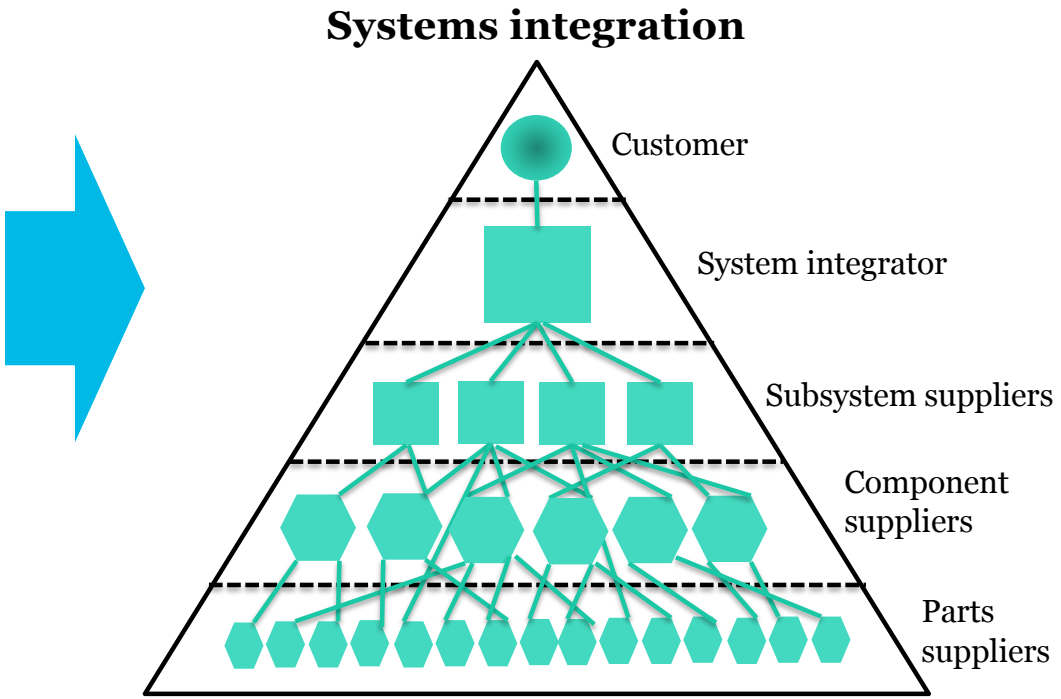
The project and the task of systems integration

Project focus

- Represents a clearly defined supply task which is undertaken within a certain timescale with given resources and the specific needs of one or more customers in mind
- Temporary coalition of organizations which extends beyond the boundary of the single firm
- Key form of coordination, communicating design parameters, architectural knowledge and combining the resources, skills and know-how of involved suppliers



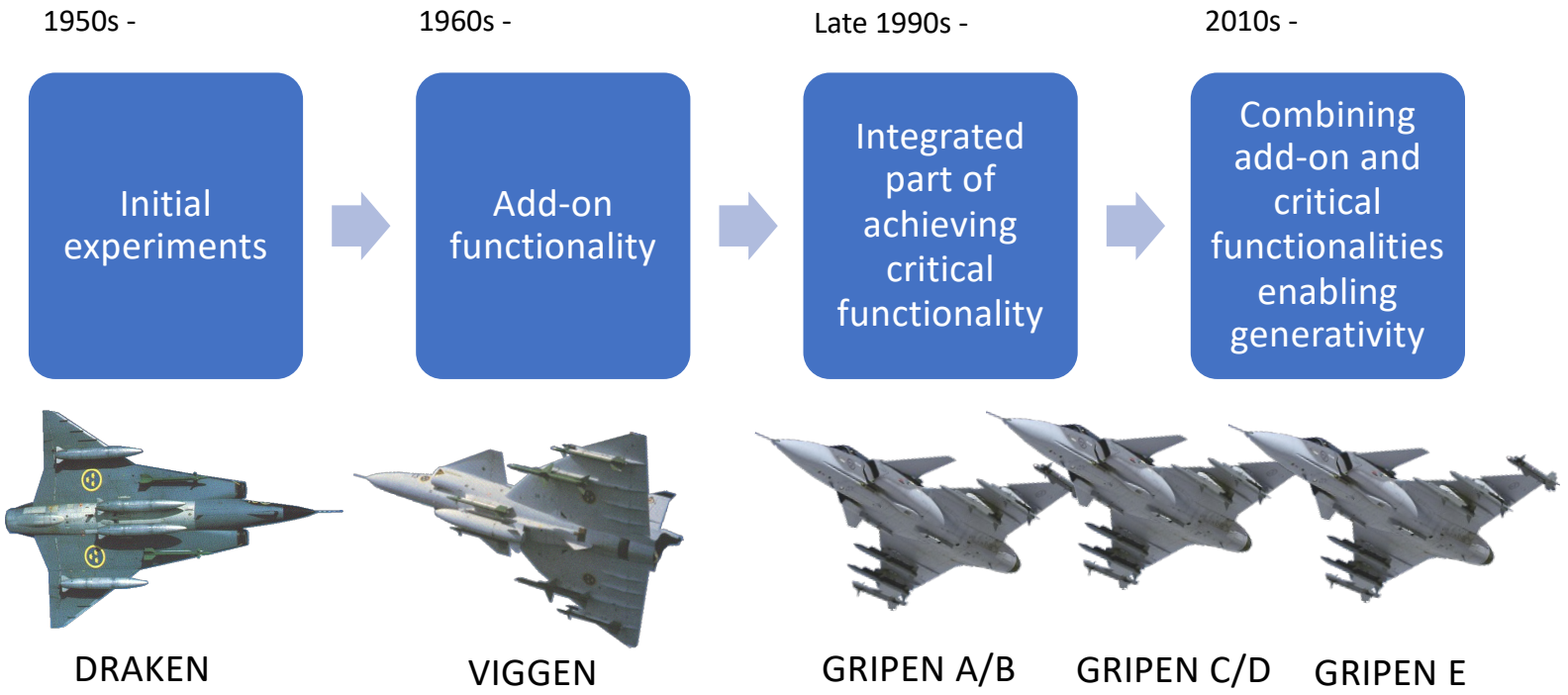
Davies, A., & Hobday, M. (2005). *The business of projects: managing innovation in complex products and systems*. Cambridge University Press.

What has happened with complex systems since the 1990s

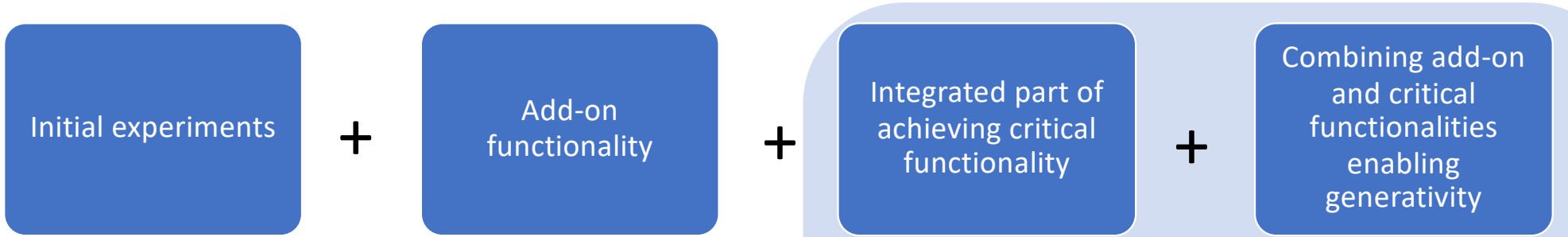
- Software increasingly important
- Inclusion of modern digital control systems
- Established system engineering practices – modelling (e.g. MBSE)

- Complexity beyond human cognition
- Increasing number of organizations – knowledge integration, ecosystems
- And…

Use of Digital Technologies



Use of digital technologies - what happens with AI?



Experimentation, actors look for stand-alone application of AI solving single isolated tasks or experimenting for future application.

Add-on functionality, where the application is provided together with a system. The add-on functionality may be very complex but could be taken away and the system is still working.

Critical functionality in a system that is dependent on AI applications to function.

Combined critical and add-on functionality, where resources are shared between applications with different levels of integration

Central for benefits of AI in society

N. Lakemond, G. Holmberg and A. Pettersson, "Digital Transformation in Complex Systems," in *IEEE Transactions on Engineering Management*, vol. 71, pp. 192-204, 2024, doi: 10.1109/TEM.2021.3118203.

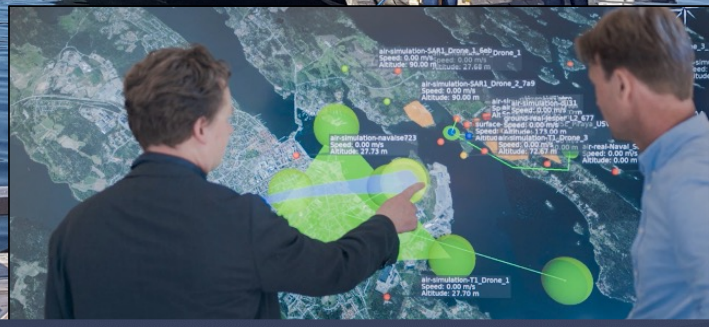
Research Arena for Public Safety - WARA-PS

Autonomy – a multi-domain topic

Challenging environment with unforeseen events in Space-Air-Land-Sea-Underwater-Cyber

Research Focus:

"**Collaborative systems for public safety** that supports teams of **humans** and systems acting and interacting in a distributed context supporting human authority and benefitting from functions with various degree of **autonomy**."



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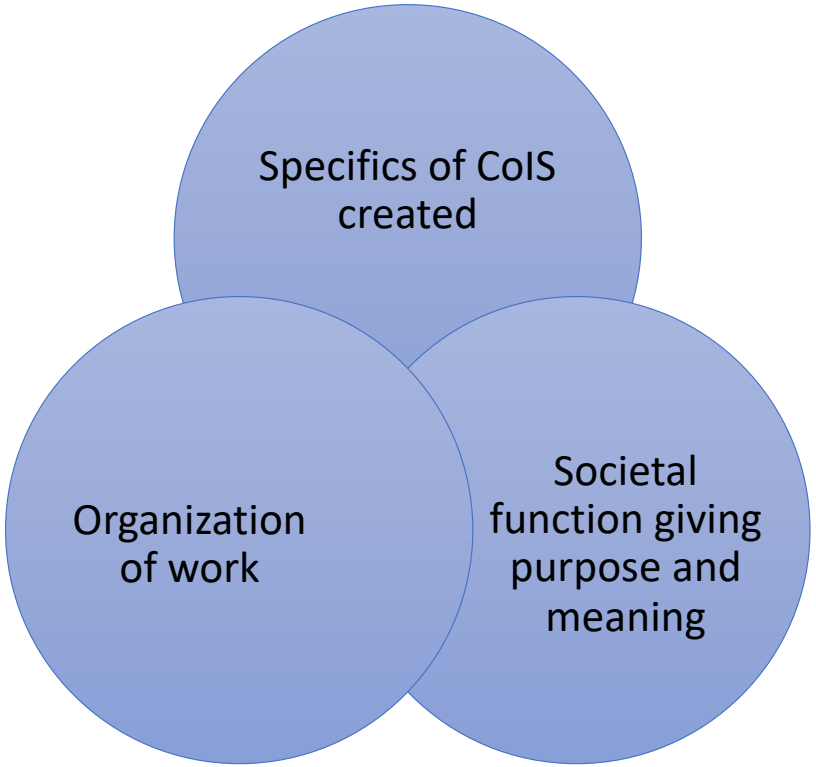
Evolving conjectures in WARA-PS (extract)

Conjecture	Combined human authority and systems autonomy	Combining safety criticality and generativity
Initial insights on the phenomenon in its context	Collaboration between humans and intelligent systems Humans and systems designing together during operation	Combination of safety critical operations with generative ecosystem of actors Safety and security are being complemented by purposeful aspects
Emerging insights leading to updated conjectures and implications	Combination of data- driven and model-based methods are promising route forward Fundamentals of future human-system interaction is evolving and vague	Combination of safety criticality and generativity enforces combination of strict methods and open generative methods Generative data and methods as important contributors to safety criticality Innovation-driven data generation

Lakemond, N., Holmberg, H. (2024), Creating Knowledge in the Partly Unknown – A Prescient Management Research Approach for Understanding a Future with AI in Complex Intelligent Systems, IEEE ICE Conference, 24-28 June, Madeira, Portugal.

Intertwinement of the three aspects – reciprocal considerations



More than just AI

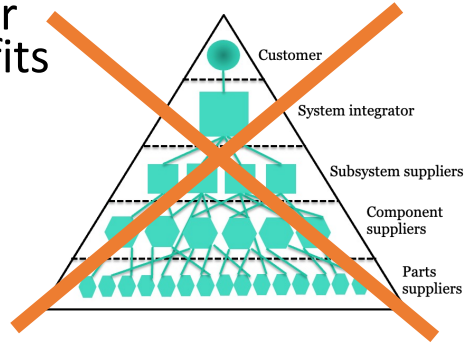
- AI solution advances with additional organizational and system architectural approaches to master the system, achieve societal benefits (or avoid negative outcomes)

New organization and coordination forms

- Fluid boundaries, SoS character, intelligent boundary objects

Additional logic

- Generative properties and critical functionality for society -> bounded generativity



Lakemond, N., Holmberg, G. (2024), Advanced Technologies For Societal Good – The Emergence of AI in Complex Systems and Contexts, R&D Management Conference, 16-19 June, Stockholm, Sweden.

AI in CoIS - Challenges for Management

Effects on CoIS and societal levels are not easily made salient and may as well be misleading or hallucinatory if not carefully reviewed

Continuous focus on awareness of the situation and relying on looser control such as allowing initiatives from contributing actors and a variety of logics in management of CoIS in a more fluid ecosystem

THANKS FOR LISTENING!