

# Safely managing the emergent properties of complex systems

Complex systems are composed of multiple elements that interact with each other. These interactions can produce emergent properties that cannot be attributed to any single element and may not have been expected by the system's designers.

This complexity is not determined by the size of the system or the number of system elements and interactions, but is instead determined by the nature of these interactions and their relationships with other systems and the environment.<sup>1</sup> These factors make complex systems difficult to understand and their behaviour difficult to predict.

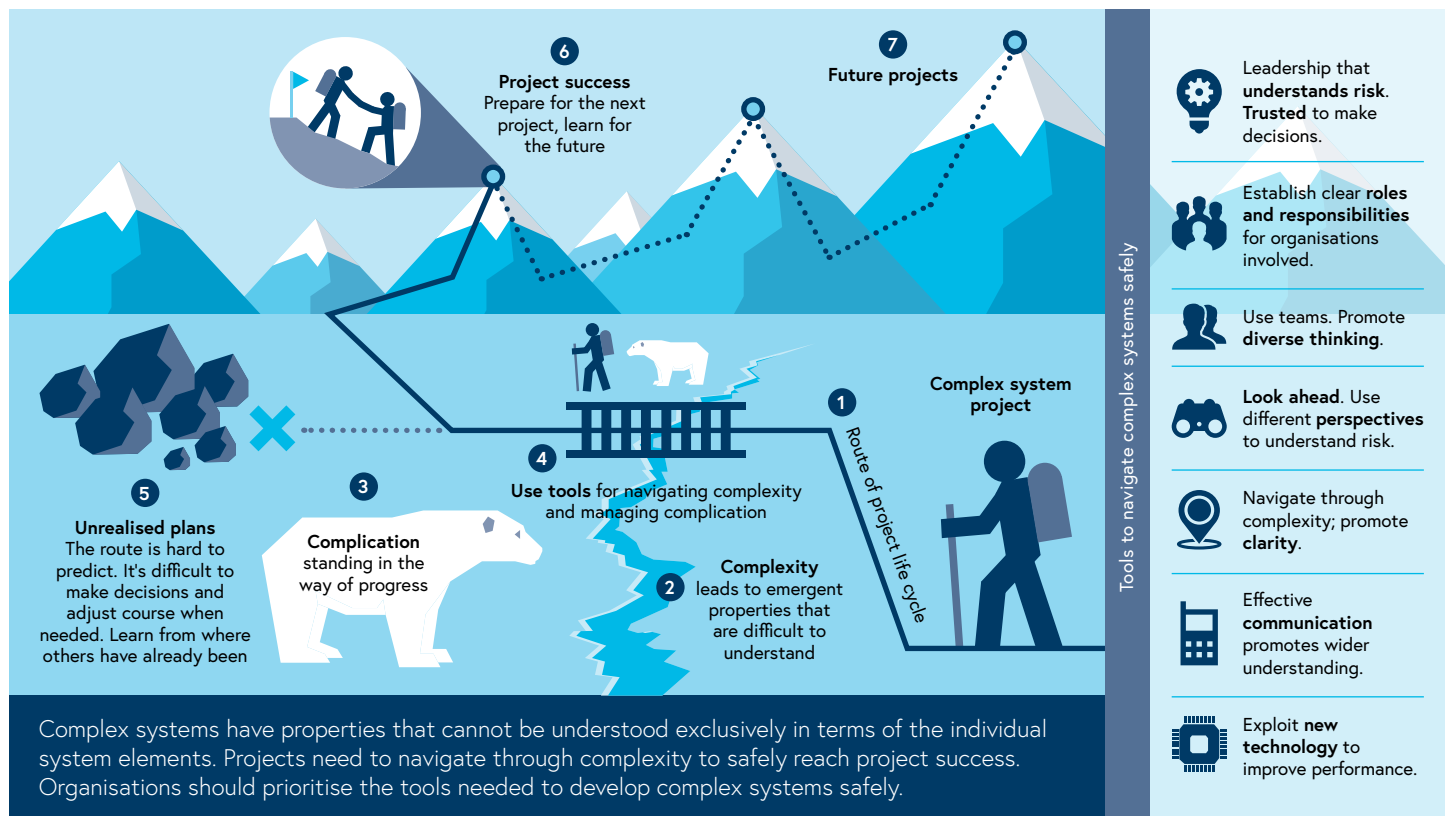
A high proportion of the total life cycle costs for a system is committed by decisions made during early development.<sup>2</sup> If these decisions are not based on a good understanding of a system's complexity, the effects of emergent properties may be discovered late, leading to costly changes. Making good decisions relies on good analysis that uses good data.

To develop a system that is safe, a sufficient understanding of its properties is needed. For a complex system, this must include emergent properties, without which understanding is not complete and confidence in its safety cannot be claimed.

Clear governance and ownership for managing complexity is important, particularly when systems are developed by multi-organisational teams, using complex contracting structures. The reputational, financial, and operational implications of misunderstanding emergent properties are significant. For systems supplying critical services to society, the safety impacts cannot be understated. As complexity continues to increase, greater policy guidance will be needed to support safe system development.

Organisations with less experience in managing complex systems should begin building the right culture, skills, and processes to prepare for an increasingly complex future. Engineering managers and engineers should be supported in justifying the effort to understand and successfully execute the safe management of complex systems.

Figure 1: Navigating complex systems safely.



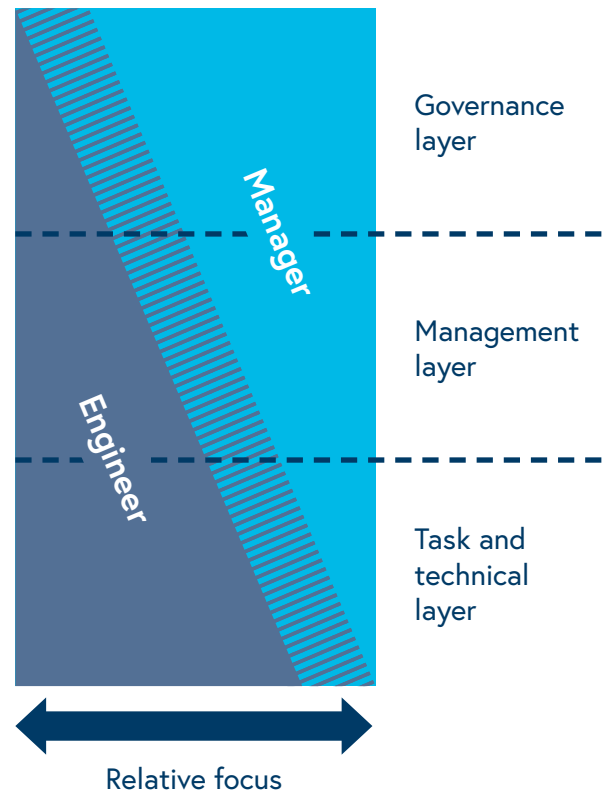
<sup>1</sup> Royal Academy of Engineering, Engineering X – Safer Complex Systems: An Initial Framework.  
<sup>2</sup> INCOSE Systems Engineering Handbook. Version 4, 2015.

Managers and engineers that understand complexity and emergent properties will be able to guide systems more clearly and safely through their life cycles. In doing so, there is greater potential to develop safe products that are fit for purpose, produced efficiently, and supported effectively.

## Objectives for engineering managers

- 1 **Complex systems can have very long life cycles.** The operating conditions and governance will change over a system's lifetime. Managers are temporary stewards of projects.
- 2 **Pervasive long term sustainable thinking.** Managers will need to justify investment in long projects. The ability to understand risks, insurance and support requirements will be critical. Prepare for low probability catastrophic risks. Learn to work with uncertainty. Early course correction may be the best action.
- 3 **Managers have a responsibility to present reality.** Nurture a culture of communication. Create opportunity for structured and open dialogue where all team members present reality and have time to explore emergence. Diverse thinking is needed on corporate responsibilities, risk based judgements, regulatory compliance, and accountability. Over optimism comes with high risk.
- 4 **Exploit technology for deeper management insights.** Business, financial, and organisational tools should support the complex systems that they manage. Technology options for enhancing governance should be exploited whilst retaining the accountability of human decision-making.

Figure 2: Managing complex systems.



Managing complex systems can be understood through three connected layers: task and technical, management, and governance.<sup>1</sup> Different roles will appropriately focus on each layer, but should appreciate the nature and connectedness between all three.

## Objectives for engineers

- 1 **Strive to understand complexity and emergent properties.** Early understanding of system-of-systems context, boundaries, interfaces, and interactions is critical across the full life cycle.
- 2 **Judge when understanding can turn into action.** More analysis could always be done before making decisions, but resources are rarely available. Effort should be devoted to deciding when understanding is sufficient to act.
- 3 **Integrate management and engineering.**<sup>3</sup> Management and engineering should fully support each other's endeavours to build a coherent approach to developing and supporting complex systems throughout their life cycles.

All feedback on this paper is welcome. Please contact [sep@theiet.org](mailto:sep@theiet.org)  
This paper has been produced by the Engineering Safety Policy Panel.  
For more details on the Panel's work please go to [theiet.org/engineering-safety](http://theiet.org/engineering-safety)

<sup>3</sup> UCL Principles of Systems Engineering Management: Reflections from 45 years of spacecraft technology research and development at the Mullard Space Science Laboratory.