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Command and Control in the Future

Concept Paper 1: Grappling with Complexity

James Black, Rebecca Lucas, John Kennedy,
Megan Hughes, Harper Fine

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Research Report

Command and Control in the Future

Concept Paper 1: Grappling with Complexity

James Black, Rebecca Lucas, John Kennedy, Megan Hughes & Harper Fine

RAND Europe

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Prepared for the Development Concepts and Doctrine Centre (DCDC)

RAND EUROPE

Preface

This is the first in a series of four papers examining how Command and Control (C2) will manifest in the future. The other three papers in the series are as follows:

- Concept Paper 2: Rebecca Lucas, Conlan Ellis, James Black, Paul Kendall, John Kendall, Stephen Coulson, Peter Carlyon, & Louis Jeffries. 2024. *Command and Control in the Future: Concept Paper 4 – The Defence C2 Enterprise*. Santa Monica, Calif.: RAND Corporation. RR-A2476-1.
- Concept Paper 3: Conlan Ellis, Rebecca Lucas, Stella Harrison, James Black, Ben Fawkes, Martin Robson, Alan Brown, & Edward Keedwell. 2024. *Command and Control in the Future: Concept Paper 3 – Command and Control as a Capability*. Santa Monica, Calif.: RAND Corporation. RR-A2476-3.
- Concept Paper 4: Rebecca Lucas, Stella Harrison, Conlan Ellis, James Black, Ben Fawkes, Martin Robson, Alan Brown, & Edward Keedwell. 2024. *Command and Control in the Future: Concept Paper 4 – Enablers*. Santa Monica, Calif.: RAND Corporation. RR-A2476-4.

The overarching study is being delivered by the Development, Concepts and Doctrine Centre (DCDC) Strategic Analysis Support Contract (SASC) with the Global Strategic Partnership (GSP), a consortium of UK and international research organisations providing strategic analysis and academic support to the DCDC within the UK Ministry of Defence (MOD). This paper is intended to capture the findings of the first phase of the project and has been written on the assumption that it will be read by an audience with some familiarity with C2. Equally, it is intended to feed into the subsequent three papers in the series and therefore stops short of providing fulsome coverage of all aspects of thinking about C2 in the future, including the development of concrete recommendations.

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For more information about RAND, the SASC, or this study, please contact:

James Black

Assistant Director – Defence & Security Research Group
RAND Europe
t. +44 (0)1223 353 329
e. jblack@randeurope.org

Summary

This is the first of four concept papers commissioned by DCDC on C2 in the future. The specific focus for this paper is the demands on C2 that arise from the complexity in the future operating environment. Together titled 'Project Mimisbrunnr', the four papers inform an ongoing initiative to identify key themes and concepts relevant to C2 in the future, building on the existing Joint Concept Note (JCN) 2/17 'The Future of C2'. As DCDC also serves as the Swedish Concepts and Doctrine Centre, this conceptual work will inform both UK and Swedish thinking about how C2 could evolve in the coming decades.

Contested definitions

There is no straightforward definition of C2, and there is debate about the term's scope and relevance in the contemporary operating environment. Critiques of traditional definitions of C2 have been informed by wider questions about what constitutes effective leadership in the twenty-first century. In the UK, US and NATO, there has been a recent profusion of new C2-related terminology and a focus on moving from joint to multi-domain thinking. Our study frames C2 as a dynamic and adaptive socio-technical system, necessitating consideration of organisational, technical and human elements.

Similarly, there is no universally agreed definition of complexity. The growing body of academic research into complexity cuts across a variety of scientific disciplines but lacks a unified approach or theoretical framework. One useful starting point is to distinguish between simple, complicated, complex and complex adaptive systems. The literature also describes the so-called 'wicked' or 'super wicked problems' that can emerge from such conditions. An important distinction can also be drawn between finite and infinite games – a useful lens when considering interstate competition as a complex adaptive system. Given these debates, our study eschews adopting a rigid definition of complexity in favour of a DCDC-furnished description of this phenomenon in terms of its key properties (see Box 0.1).

Box 0.1 Understanding of key concepts as provided by DCDC

Command and Control (C2): 'A dynamic and adaptive socio-technical system configured to design and execute joint action' whose purpose is thereby '[to] provide focus for individuals and organisations so that they may integrate and maximise their resources and activities to achieve desired outcomes'.

Complex: 'A system or phenomenon that exhibits emergent properties and often involves non-linearity, hence small changes can have disproportionate or unpredictable effects on the overall behaviour of the system. As a result, the system is often difficult to understand or analyse.'

Source: DCDC based on UK MOD (2017a).

Projected drivers of complexity

The character of the future operating environment – and the types of missions that Defence C2 systems and organisations will be expected to undertake – is clouded by significant uncertainty, requiring caution with any projections. Nonetheless, the literature identifies a variety of political, economic, social, technological, legal, environmental and military (PESTLE-M) trends that are expected to shape evolution of the international system, and thus of Defence operations, out to 2030 and beyond. These include macro-trends such as:

- Increasing interconnectivity, multipolarity and global competition
- The impact of a changing climate
- The impact of technological change and digitalisation
- The blurring of domains, both traditional and novel
- The shifting of international norms and value sets.

Crucially, there is no single or primary trend that is driving change or complexity; rather, it is the confluence of multiple factors and their unpredictable interactions that are of greatest concern. This understanding provides a basis for further examination of the specific mechanisms by which these trends influence the level and characteristics of complexity in the international system and thus creates new challenges for C2, which operates in this same space.

Manifestations of complexity

PESTLE-M trends such as those outlined above contribute to a range of dilemmas and pressures for future organisations to grapple with regarding C2, including but not limited to:

- Uncertainty
- Ambiguity
- Equivocality
- Information overload
- Cognitive bias
- Decision paralysis or insufficient tempo in the face of fast-moving events
- Difficulty assuring decision making (including by AI) or trusting the data, logic and assumptions underpinning it
- Difficulty marshalling all necessary levers of power or coordinating large groups of diverse actors (e.g. Partners Across Government [PAG], industry, international allies, citizens) involved in generating and executing a given strategy or operational plan.

Furthermore, both theorists and practitioners lack robust measures of the effectiveness of decisions made or actions undertaken when dealing with problems that contain non-linear dynamics. This makes it difficult to say definitively whether complexity is objectively increasing (as opposed to taking on different forms) in the future operating environment, but there is clearly a substantial gap between political expectations for the complex tasks the military should handle, and the ability of current C2 approaches to deliver.

Current academic theory provides the tentative outline of a methodological toolkit and some guiding principles for deciding how to configure C2 amidst complexity – but no silver bullet. It emphasises deliberative-analytic approaches, meaning methods that engage varied stakeholders in co-design, draw on insights from multiple disciplines and bodies of knowledge, and build into analytic and decision-making processes the flexibility to iterate and improve them over time based on feedback.[1]

Practical considerations for C2 in the future

Grappling with complex adaptive systems requires a move away from current linear C2 processes and hierarchical structures, though more traditional approaches may retain utility when tackling non-complex tasks and problems. In a competitive world, the UK needs to cultivate both those properties and capabilities that enable it to exert constructive influence on others (e.g. by imposing complexity on opponents' C2) and those which bolster its own capacity to navigate complexity.

Influencing the perceptions, decision making and behaviours of hostile actors begins with a deep understanding of their C2 structures, processes and culture. Informed by this understanding, UK Defence then requires a suite of kinetic and non-kinetic levers to exert constructive influence on adversaries' C2, including to impose complexity. Besides hostile actors, Defence also requires an improved understanding of how to exert constructive influence over PAGs, allies, partners, industry, academia, citizens and others with radically differing approaches to C2.

In terms of bolstering the UK's own capacity to deal with complexity, C2 systems and organisations in the future must promote properties such as flexibility, resilience and a capacity for learning and adaptation. Changes are needed across the decision cycle. For example, advances in sensor and communication technologies provide opportunities to capture increased depth and breadth of data, including on complex problems. Improved cognitive capacity is then essential to make sense of all this data, harnessing the benefits of human and machine while mitigating the drawbacks of each. Changing approaches to decision making will also require changes in styles of leadership, so as to cultivate decision makers more comfortable with navigating complex adaptive systems. Having made a decision or plan, improving the ability to cut across stovepipes or levels and better integrate activities or converge effects in the implementation phase is essential to offset the UK's limitations (e.g. in terms of mass).

Equally, integration is not a silver bullet; even the most efficient C2 systems cannot achieve success in the future if Defence lacks sufficient depth of forces and capability to act credibly or to sustain high-tempo operations in a hostile threat landscape. Defensive measures and reversionary and failure modes are also needed to deter or mitigate the impact of hostile efforts to disrupt C2 systems and organisations. Given the threats faced, and the differing forms of complex problems that UK Defence might be called to address, it is likely that there will be multiple parallel models of C2 in play at once, rather than a monolithic approach.

Tackling complexity means continuous learning, adaptation, innovation and openness to change. Measures of effect, signals and mechanisms for change must thus be built into plans and into C2 systems and organisations from the outset to enable them to learn and adapt over time in response to conditions.

Crucially, the design of C2 systems and organisations in the future is only one part of the challenge – they must also be supported by urgent reforms to the wider Defence enterprise to ensure access to the enablers

[1] Examples of prominent methods in the complexity science(s) literature include cybernetics, systems engineering, soft systems methodology, interpretative structural modelling, design thinking, and critical approaches. Of course, it is important to select the right tool to tackle a given situation, threat or problem, aided by frameworks such as Cynefin. A recurring theme across most approaches, however, is the need for continuous iteration, learning and adaptation, emphasising that approaches to C2 must evolve over time and vary depending on the context and threat environment faced.

needed (people, tech, etc.). This presents its own challenges from a C2 perspective, given changing this enterprise – a complex adaptive system – is itself a wicked problem.

Conclusions and next steps

Academic theorists and governmental, military or industry practitioners have an incomplete understanding of the complexity or complex adaptive systems which will characterise the future operating environment for C2. While the literature provides useful methods and tools for grappling with complexity, as well as some initial design considerations for C2 in the future, modernising and transforming the UK's C2 – a socio-technical system in its own right – will be a highly complex endeavour. It implies a process of co-adaptation alongside the evolving operating environment, and changing threat and technology landscapes, and thus of iteration and continuous learning. Perhaps the most pressing challenge, therefore, is understanding how best to steer this process over time, given the extent and nature of the transformation (technological, structural, process, cultural, educational, etc.) required to position C2 systems for future success in the face of complexity.

Paradoxically, overcoming the barriers to achieving a C2 system geared towards tackling complexity may require that UK Defence already exhibit many of the traits of that system it is seeking to establish. In the face of such circular logic, Defence may either need some sort of external shock to force creative destruction, or else to initiate its own radical reform efforts using (and in spite of) more traditional, linear C2 approaches and pivot over time as changes set in.

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Abbreviations

3HF	Three Horizon Foresight
5G	Fifth-Generation Telecommunications
6G	Sixth-Generation Telecommunications
ABMS	Advanced Battle Management System
ABP	Assumption-Based Planning
ACT	Allied Command Transformation
AGI	Artificial General Intelligence
AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
AR	Augmented Reality
ASI	Artificial Super Intelligence
ATP	Adaptation Tipping Point
BDA	Battle Damage Assessment
BMC2	Battle Management Command and Control
BRICS	Brazil, Russia, India, China, South Africa
C2	Command and Control
C3	Command, Control and Communications
C3I	Command, Control, Communications, and Intelligence
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
C4ISTAR	Command, Control, Communications, Computers, Intelligence, Surveillance, Targeting, Acquisition and Reconnaissance
C5I	Command, Control, Communications, Computers, Cyber, Intelligence
C6I	Command, Control, Communications, Computers, Cyber, Combat Systems and Intelligence
CART	Classification and Regression Tree

CAS	Complex Adaptive Systems
CIS	Communication Information Systems
COA	Course of Action
CST	Critical Systems Theory
CSP	Critical Systems Practice
COVID-19	Coronavirus Disease 2019
CTAF	Cultural Topography Analytical Framework
DAP	Dynamic Adaptive Planning
DAPP	Dynamic Adaptive Policy Pathways
DARPA	Defense Advanced Research Projects Agency
DCDC	Development, Concepts and Doctrine Centre
DIME	Diplomatic, Information, Military, Economic
DLOD	Defence Line of Development
DMDU	Decision Making Under Deep Uncertainty
DoD	Department of Defense
DPA	Deliberative Policy Analysis
Dstl	Defence Science and Technology Laboratory
EM	Electromagnetic
EME	Electromagnetic Emissions
EMS	Electromagnetic Spectrum
EW	Electronic Warfare
FMN	Federated Mission Networking
FMV	Swedish Defence Materiel Administration
FOE	Future Operating Environment
FOI	Swedish Defence Research Agency
GST	Global Strategic Trends
HADR	Humanitarian Aid and Disaster Relief
HAPS	High-Altitude Pseudo-Satellites
HMT	Human-Machine Teaming
HQ	Headquarters

IDF	Israeli Defence Force
IOpC	Integrated Operating Concept
IoT	Internet of Things
IR	International Relations
ISM	Interpretative Structural Modelling
ISR	Intelligence, Surveillance and Reconnaissance
JADC2	Joint All Domain Command and Control
JCN	Joint Concept Note
M&S	Modelling and Simulation
MACA	Military Aid to Civilian Authorities
MCDA	Multi-Criteria Decision Analysis
MCDC	Multinational Capability Development Campaign
MCDM	Multi-Criteria Decision Methods
MDC2	Multi-Domain Command and Control
MDO	Multi-Domain Operations
ML	Machine Learning
MNC	Multi-National Company
MOD	Ministry of Defence
MR	Mixed Reality
NATO	North Atlantic Treaty Organization
NATO C2COE	NATO Command and Control Centre of Excellence
NCW	Network-Centric Warfare
NEC	Network-Enabled Capacity
NGO	Non-Governmental Organisation
PAG	Partners Across Government
PESTLE-M	Political, Economic, Social, Technological, Legal, Environmental and Military
PRIM	Patient Rule Induction Method
R&D	Research & Development
RDM	Robust Decision Making
REE	Rare Earth Elements

RQ	Research Question
SASC	Strategic Analysis Support Contract
SATCOM	Satellite Communications
SD	Scenario Discovery
SME	Small and Medium Enterprise
SOD	Systemic Operational Design
SPA	Strategic Portfolio Analysis
SQEP	Suitably Qualified and Experienced Personnel
SSDM	Soft System Dynamics Methodology
SSIM	Structural Self-Interaction Matrix
SSM	Soft Systems Methodology
SWOT	Strengths, Weaknesses, Opportunities and Threats
TISM	Total Interpretative Structural Modelling
TTP	Tactics, Techniques and Procedures
UAV	Uncrewed Aerial Vehicle
UI	User Interface
UX	User Experience
V&V	Validation & Verification
VR	Virtual Reality
XAI	Explainable Artificial Intelligence

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Despite these valued contributions, any errors or omissions remain the sole responsibility of the authors.

1. Introduction

This chapter introduces the context from which this paper was commissioned, as well as the definition of command and control (C2) used throughout the wider ongoing study for DCDC. It then situates this paper within the series of concept papers, before laying out research questions and methodology.

1.1. Background and purpose

1.1.1. About Project Mimisbrunnr

Effective and resilient C2 is essential to the basic functions of Defence and to the planning and execution of military operations, up to and including warfighting. While the nature of war remains constant, the character of warfare continues to evolve.[2] So too do the types of mission that the military is expected to undertake, the political, legal and ethical considerations that are placed on decision making, and the threats, technologies and human factors that influence approaches to C2.

According to the UK MOD, C2 is the 'pre-eminent Joint Function' and 'critical to enabling joint action'.[3] Ensuring that C2 systems and organisations remain fit-for-purpose in the face of a changing operational demands is thus essential to maintaining the advantage of the UK and its North Atlantic Treaty Organization (NATO) Allies over any competitor. To this end, DCDC is conducting ongoing analysis through an initiative known as Project Mimisbrunnr to inform future thinking about C2, including an update to *Joint Concept Note (JCN) 2/17: Future of Command and Control*.[4]

To support this effort, DCDC tasked the SASC to produce four exploratory concept papers over the course of 2023 to:

- Inform Defence thinking and experimentation about C2 in the future.
- Explore Defence integration with partners across government (PAGs) and international allies and partners to deliver decision advantage from 2030 onwards (i.e. in the time frame of the Capstone Concepts, currently under development).
- Research innovative approaches and revolutionary future understandings of the Integrated Operating Framework.[5]

[2] von Clausewitz (1874).

[3] Commander Joint Forces Command, quote. in JCN 2/17. UK MOD (2017a).

[4] Other JCNs tackle the related topics of human–machine teaming (JCN 1/18), information advantage (JCN 2/18) and Multi-Domain Integration (JCN 1/20). Cf. UK MOD (2018b; 2018c; 2020b).

[5] As outlined in the Integrated Operating Concept (IOpC). UK MOD (2020a).

1.1.2. Concept Paper 1: Grappling with complexity

This first paper sets a baseline for the subsequent research by exploring the future operating environment in which C2 systems will need to operate in the future. Specifically, it explores the drivers, manifestations and implications of the complexity that prior research has shown is likely to characterise that environment. DCDC provided the following research questions (RQs):

- RQ1: Projecting from current global societal and technology trends, what is the likely nature of the operating environment for both Defence and partners where constant competition and multi-domain operations are likely to be in play?
- RQ2: Based on this projected view of the future, what is the likely nature of the complexity that future C2 systems and organisations will face; i.e. what are the likely sources of the complexity and what characteristics will they have both individually and collectively?
- RQ3: Given this characterisation of the future operating environment, what will this demand of future C2 systems and organisations, how will this differ from today, and what will need to change?
- RQ4: What sorts of new capabilities and properties will be required for future C2 systems and organisations to respond effectively to these demands?

To address these questions, the study team undertook a literature review, as well as expert engagement through a DCDC workshop hosted at the Swedish Defence University in Stockholm. This paper thereby builds on previous work in this field and encompasses the latest research and thinking from academic, think tank, industry and governmental sources. Details of the methodology, including search strings, can be found in Annex A. The intention is to provide a foundation for the later papers in the series, which explore in greater detail the ramifications of the future operating environment for the design of the C2 enterprise (Paper 2), the capabilities that are required (Paper 3), and the enablers that must be put in place to deliver on this vision (Paper 4).

1.2. Structure of the document

This paper is structured as follows:

- Chapter 2 discusses the contested definitions of key terms, such as C2 and complexity.
- Chapter 3 presents the drivers of complexity, looking out to 2030 and beyond.
- Chapter 4 discusses how complexity manifests in new pressures on C2 systems and organisations.
- Chapter 5 examines possible methods for analysing, understanding and tackling complexity.
- Chapter 6 draws together the findings of preceding chapters to outline the practical considerations for C2 systems and organisations if they are to be successful in the 2030s and beyond.
- Chapter 7 sets out conclusions and next steps, including areas to explore in subsequent papers.

A full bibliography is also included, along with Annex A, which explains the methodology, Annex B, which discusses in further detail the macro-trends summarised in Chapter 3, and Annexes C and D, which augment Chapter 5's discussion of methods for grappling with complexity and with uncertainty, respectively.

2. Contested definitions

This chapter explores the contested definitions of both 'C2' and 'complexity', as well as related terminology such as 'complex adaptive systems' and 'wicked problems'.

2.1. Summary

The box below gives the understanding of C2 as provided by DCDC as the starting point for this paper and the wider GSP study on C2 in the future.

Box 2.1 Understanding of key concepts as provided by DCDC

Command and Control (C2): 'A dynamic and adaptive socio-technical system configured to design and execute joint action' whose purpose is thereby '[to] provide focus for individuals and organisations so that they may integrate and maximise their resources and activities to achieve desired outcomes'.

Complex: 'A system or phenomenon that exhibits emergent properties and often involves non-linearity, hence small changes can have disproportionate or unpredictable effects on the overall behaviour of the system. As a result, the system is often difficult to understand or analyse.'

Source: DCDC based on UK MOD (2017a).

The following sections elaborate on the logic behind this understanding in more detail, noting the hotly contested debates that exist over both the concept of C2 and the nature of complexity.

2.2. Defining C2

2.2.1. There is no straightforward definition of C2, reflecting debates about the term's scope and relevance in the contemporary operating environment

At the most basic level, C2 can be broken down into its two constituent elements[6]:

- Command: The authority vested in an individual of the armed forces for the direction, coordination and control of military forces.
- Control: The authority exercised by a commander over part of the activities of subordinate organisations, or other organisations not normally under [their] command, that encompasses the responsibility for implementing orders or directives.

[6] NATOTerm (n.d.).

In practice, however, simply combining these two ideas into one term, C2, does not adequately capture the nuanced challenges of exercising authority and direction in the contemporary operating environment, let alone the future one. As recognised in JCN 2/17, 'These terms, and their affiliated concepts and culture, may encourage a rigid hierarchical approach that underplays the need to collaborate and influence, particularly within a full spectrum approach where partners [across government, internationally or in industry] may not understand or agree with the terms and associated concepts.'[7]

2.2.2. Critiques of traditional definitions of C2 have been informed by wider debates about what constitutes effective leadership in the twenty-first century

Given the limitations of traditional definitions of C2, a number of practitioners and analysts have proposed alternative framings, such as 'focus and convergence'[8] and 'leadership and appreciation',[9] or non-hierarchical terms such as 'collaboration and constructive influence'.[10] At the same time, others have provided sharp critiques of the 'myths and modalities' of traditional military approaches to leadership, and argued for a separation of 'ideas of leadership from ideas of organisational hierarchy or positional power', such as are formalised within hierarchical C2 structures.[11] There are calls for greater openness to challenge, conscious of the well-documented failures of the post-9/11 wars in Iraq and Afghanistan, as well as for increasing diversity of thought and innovation through more inclusive, collaborative approaches to C2 and to the recruitment, training, education and promotion of more diverse leaders within Defence.[12]

Others have defended the focus on hierarchy within traditional definitions of C2, arguing that a more directive approach remains essential for many roles or purposes within Defence.[13] This draws in part on military imperatives, such as the need for certainty around orders being followed by subordinates if nuclear deterrence is to be both safe and credible. Historically, it has also reflected limitations in the available technical means of deconflicting friendly forces operating in a crowded battlespace, which has led to reliance on strict adherence to hierarchy and Tactics, Techniques and Procedures (TTPs), for example to avoid incidents of friendly fire.[14] It also reflects policy and ethical considerations, such as the need to maintain civilian control of the military, or to recognise the moral burdens of leadership in the profession of arms, whose members serve under a unique condition of 'unlimited liability' (i.e. unlike the workforce of civilian organisations, military personnel may legally be ordered to endanger their own lives, or to use lethal force against others on behalf of the state).[15]

Some commentators argue – though not without opposition – that the West already has a culture of 'mission command' (derived, in part, from the older German concept of Auftragstaktik),[16] which entails a more decentralised execution within C2 structures when compared to more rigid, top-down approaches typically employed in authoritarian states (e.g. Soviet/post-Soviet Russia, or China).[17] Some analysts thus

[7] UK MOD (2017a, 10).

[8] Alberts (2007).

[9] Osinga (2006).

[10] Adams et al. (2017).

[11] Adams et al. (2017).

[12] UK Parliament (2017); UK MOD (2017b).

[13] Lamb (2020).

[14] In future, of course, new technologies may enable more distributed coordination.

[15] Hackett (1983); US Army Training and Doctrine Command (2010); Mileham (2010); Shepherd (2021).

[16] Deployable Training Division of the US Joint Staff J7 (2020).

[17] Lamb (2020).

suggest that incremental rather than radical change is needed to traditional conceptualisations of C2, while others argue that mission command is more 'myth' or 'infatuation' than reality in most NATO militaries.[18] As such, despite a growing body of research emphasising the need for less rigid and more flexible approaches to C2, especially as part of a comprehensive approach, much of the terminology in common usage still reflects, whether implicitly or explicitly, the 'hard-wired' legacy of military hierarchy.[19]

2.2.3. In the UK, US and NATO, there has been a recent profusion of new C2-related terminology and a focus on moving from joint to multi-domain thinking

The proliferation of new C2-related buzzwords reflects the fact that 'words move money', and that new terminology (even if sometimes largely a repackaging of old ideas) can help unlock new funding and reform initiatives within the defence enterprise.[20] On the one hand, this means revisiting long-established concepts, such as Soviet-era thinking around the integration of C2 with reconnaissance and fires to create a 'reconnaissance-fires complex' to dominate the deep battle.[21] It also reflects a growing focus on networks, information technology and new environments, such as cyberspace, since the advent of 'network-centric warfare' in the 1980s and 1990s.[22] Examples of resultant jargon include, but are certainly not limited to: C3 (command, control and communications), C3I (which adds intelligence), C4ISR (command, control, communications, computers, intelligence, surveillance and reconnaissance), C4ISTAR (which adds target acquisition), C5ISR (which adds cyber) and even C6ISR (which also includes combat systems).[23]

There has also been a strong emphasis on moving beyond 'joint' operations (i.e. those involving more than one service, such as the Army and Navy) towards a more ambitious vision for converging effects across all domains, including not only land, air and maritime, but also cyber and electromagnetic, and space. This is reflected in the current profusion of concept development, experimentation and R&D activities associated with 'multi-domain' or 'joint all domain command and control' (MDC2 and JADC2) in the United States.[24] It is similarly evident in related efforts to pursue integration as a key priority in UK Defence, or to develop a NATO concept for 'multi-domain operations' (MDO) through Allied Command Transformation (ACT).[25] There is also similarly badged work ongoing at the NATO C2 Centre of Excellence (NATO C2COE),[26] through the Multinational Capability Development Campaign (MCDC) programme,[27] and in various think tanks, academic organisations and industry programmes.[28]

[18] Vandergriff (2014); Herrera (2022).
[19] Alberts (2007).
[20] Spirtas (2018).
[21] Black, Lynch, et al. (2022).
[22] Alberts (2007).
[23] Daniel (2020).
[24] US Congressional Research Service (2022); US DoD (2022); Priebe et al. (2020); Zeigler et al. (2021).
[25] NATO (2022).
[26] NATO C2COE (2021; 2022; 2023).
[27] UK MOD (2023b).
[28] For selected examples, see: Team Defence Innovation (n.d.); BAE Systems (n.d.); UK Defence Academy (2022).

2.2.4. Our study frames C2 as a dynamic and adaptive socio-technical system, necessitating consideration of organisational, technical and human elements

The various terms outlined in the previous section are not only overlapping, but also sometimes used interchangeably, with broadly similar concepts articulated slightly differently by individual programmes, services or nations. This can be a source of confusion and a challenge for organisations, such as DCDC or NATO, trying to ensure a common lexicon. Through its four exploratory Concept Papers, this study will seek to explore and critique many of these definitional ambiguities – at least where they are substantive rather than purely semantic – by engaging with the live debates over issues such as the appropriate levels of hierarchy within C2 in the future, or the changing metrics of effective leadership.

To set a baseline, the study adopts as its starting point the definitions provided by DCDC in JCN 2/17[29]:

- C2: 'To provide focus for individuals and organisations so that they may integrate and maximise their resources and activities to achieve desired outcomes.'
- C2 capability: 'A dynamic and adaptive socio-technical system configured to design and execute joint action'. This involves 'essential functions' including but not limited to: 'creating shared awareness (including awareness of command intent); allocating resources to create effects; assessing progress; and recognising the need to change our approach to C2 and/or the plan of action.'

This focus on a 'dynamic and adaptive socio-technical system' entails considering not only the organisational and technical aspects of C2 systems' design, but also the vital human component. In grappling with the future consequences of complexity for C2, this necessitates that our study considers not only the possible role of technology (e.g. artificial intelligence [AI], machine learning [ML] and autonomy) in providing solutions, but also the interaction with human-centred developments such as changing norms, values, ethics and perceptions; evolving approaches to workforce management, training and professional military education; different possible ways of integrating human and machine within the system, given the strengths and drawbacks of each; and trends in leadership, culture, incentives and behaviours.

2.3. Defining complexity

2.3.1. The growing body of academic research into complexity cuts across a variety of scientific disciplines, but lacks a unified approach or theoretical framework

The academic and grey literature reviewed for this report provides many different possible definitions of complexity; if there is one point of agreement, it is that there is no agreed understanding.[30] In the absence of a common definition of complexity, there is also no single unifying theoretical framework to cohere research and analysis on the topic. Instead, there are a series of overlapping and sometimes discordant research fields that tackle similar conceptual or practical questions from different disciplinary perspectives.

This includes activity within both the natural and social sciences, and a mix of more quantitative and qualitative research methods. Work on complexity stems from diverse fields such as mathematics, graph theory, information theory, chaos theory, systems theory, computational science, biology, ecology,

[29] UK MOD (2017a).

[30] Kasser & Zhao (2016); Tran et al. (2015).

evolutionary theory and thermodynamics, as well as from social scientists or arts and humanities specialists applying the lenses of economics, philosophy, anthropology, sociology, critical theory or even art theory.

Brian Castellani and Lasse Gerritts have attempted to map the evolution of some of the major fields within complexity science since the 1940s and 1950s, originating in the pioneering work of thinkers such as Norbert Weiner, Gregory Bateson, Robert Ashby, Margaret Mead and Ludwig von Bertalanffy on topics such as cybernetics and systems theory.[31] As shown in Figure 2.1, this reveals a research landscape that is difficult to comprehend or navigate, and which remains stovepiped despite ongoing efforts to promote more critical, inclusive and interdisciplinary approaches to complexity science(s).[32]

2.3.2. A useful starting point is to distinguish between simple, complicated, complex and complex adaptive systems

While non-specialists – including policy makers – often use terms such as complicated and complex interchangeably, adding to conceptual confusion, the academic literature attempts to draw a distinction between different types of system, as outlined in Table 2.1. From the beginning, the science of complexity has thus been closely associated with the study of systems and their structure, properties, and power/causal dynamics. This includes systems thinking and approaches such as systems engineering. Though there are a variety of disciplines and schools of thought in this area, they share a common interest in understanding:

> '… the arrangement of and relations among the parts, which connect them into a whole. This approach is necessary for two reasons: first, system properties emerge at a higher level as the result of interactions among system components[33] and second, the emergent pattern itself exerts a downward causation on the lower level from which it has emerged.'[34]

Focusing in on complex and complex adaptive systems (CAS) thus entails moving beyond linearity towards concepts such as system or collective dynamics, hierarchy, and non-linearity, randomness and emergence. For example, Lingel et al. (2021) describe how 'something that is complex has many parts that are interconnected and interdependent', meaning that outcomes often have multiple causal factors. Baltaci & Balci (2017) further point out that these parts are organised by 'flexible and volatile hierarchical structures connected through multiple ties'. Dawkins & Barker (2020) emphasise the non-linear nature of these ties and dynamics, as well as resulting feedback systems. Tran et al. (2015) similarly point out that 'complex systems are typically composed of independently acting agents' whose interactions 'result in unexpected, emergent behaviours or features'; this includes both humans and technology within a system.[35]

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[31] Castellani & Gerrits (2021).

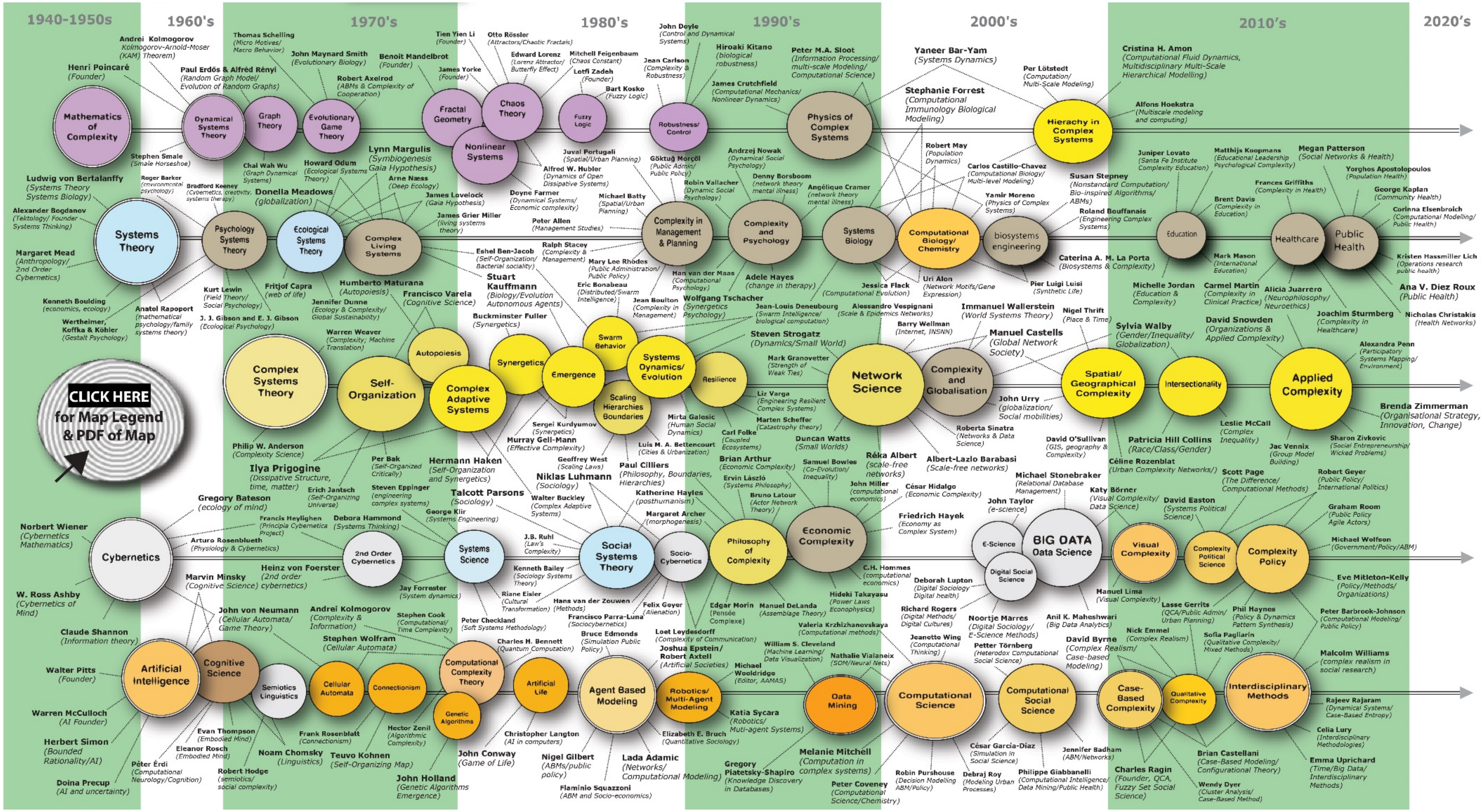
[32] Cairney & Geyer (2017).

[33] Raia (2005), citing von Bertalanffy (1968) and Holland (1998).

[34] Raia (2005), citing Campbell (1974)

[35] Claverie & Desclaus (2022).

Figure 2.1 Map of complexity science, 1940s–2020s



Source: Castellani & Gerrits (2021).

Table 2.1 Distinguishing between simple, complicated, complex and complex adaptive systems

Type of system	Numbers	Non-linearities	Adaptive elements	Emergent phenomena	Description(s)	Examples
Simple	No	No	No	No	• Something which is straightforward to comprehend and solve, e.g. due to linear dynamics with minimal parts or variables.	Plug-and-play printers
Complicated	Yes	No	No	No	• Something which is difficult but ultimately knowable, predictable and solvable, given the manageable number of variables involved and clarity for the observer on cause and effect.	Intricate assemblages
Complex	Yes	No	No	Yes (may be due to inanimate features)	• A system that has 'many parts that are interconnected and interdependent and may create emergent behaviours. The system components are inanimate and do not adapt over time'.[36] • A system 'with numerous components and interconnections, interactions or interdependence that are difficult to describe, understand, predict, manage, design, and/or change.'[37] • A 'group of "agents" […] existing far from equilibrium, interacting through positive and negative feedbacks, forming interdependent, dynamic, evolutionary networks, that are sensitive dependent, fractally organised, and exhibit avalanche behaviour (abrupt changes) that follow power-law distributions.'[38]	Modern automobiles and aircraft; dissipative systems in chemistry
Complex adaptive	Yes	Yes	Yes	Yes (due to animate or artificial intelligence agents)	• A complex system that also has 'components or agents that are animate and adapt. It is not always clear what causes behaviours, and causes are almost always multisource. The system can demonstrate emergence.' [39] • One 'with non-linear interactions involving adaptive animate components, interactions that lead to emergent macroscopic properties… a subset of complex systems more generally.'[40]	Human body, social organisations, nations

Source: adapted from Davis et al. (2021), except where otherwise indicated via footnotes. Note: Snowden similarly distinguishes between that which is clear, complicated, complex and chaotic using his Cynefin framework (see Chapter 5 for further discussion).

[36] Lingel et al. (2021, 5).

[37] Magee & de Weck (2004).

[38] Castellani & Gerrits (2021).

[39] Lingel et al. (2021).

[40] Davis et al. (2021).

Though there is no single definition of complexity or of a complex system, there are common elements that recur across multiple definitions:[41]

- 'Multiplicity of many parts, out of whose interaction "emerges" behaviour not present in the parts alone;
- Coupling to an environment with which information, energy, or other resources are exchanged;
- Presence of both order and randomness in (spatial) structure or (temporal) behaviour;
- Absence of a central control element, either internal or external;
- Robustness of structure and/or behaviour against significant perturbation; and
- Presence of memory and feedback; enabling adaptability according to its history or feedback'.[42]

2.3.3. The literature describes 'wicked problems' that can emerge from such conditions

Proponents of complexity science(s) hope to challenge traditional positivist and 'reductionist' approaches within both the natural and social sciences, and thereby come to an enhanced understanding of the world and be able to make more effective policy interventions (such as through the application of complexity and systems thinking to the field of policy analysis).[43]

Complex systems or systems of systems, such as societies or international relations, often produce challenges known as 'wicked problems': unstable situations that 'resist being solved by classical problem-solving'.[44] Similar to the complex systems from which they derive, wicked problems often lack central authority or coordination that could be applied to solving the problem.[45] Such problems often also resemble a 'social mess', given that they concern multiple stakeholders and there is no single agreed understanding of the problem, let alone how to solve it, and no one actor has access to all the levers needed to achieve systemic change.[46]

Furthermore, some theorists have conceived of a further category, super-wicked problems, denoting those problems, such as climate change, considered to be near-irresolvable due to four main characteristics[47]:

- The time to resolve them is running short
- The resolution is left in the hands of the people that create the problem
- Central authority is weak

[41] Of note, as reflected in the increasing number of agents (human and machine) and variables to consider in decision making; the continuing evolution of networks with both more nodes and more numerous and more diverse linkages; and the increase in threat vectors and vulnerabilities, as well as the scale of the associated attack surface. By contrast, there are enduring constraints on the size and resources of Defence (entailing a relative decline compared to the scale of the tasks expected of it), and a decline in the relative clout of the West vs the East (in terms of population size, GDP, soft power, etc.), and of the public vs private sector (in terms of driving innovation or exerting influence).

[42] Bristol Centre for Complexity Sciences (n.d.).

[43] Davis et al. (2021).

[44] Masys (2016).

[45] Ritchey (2013); Duczynski et al. (2021); Head (2022b).

[46] Sun & Yang (2016).

[47] Levin et al. (2012).

- Any policy response assumes that future decision makers will follow through, which is unlikely due to discounting behaviour which irrationally pushes problems and costs into the future.

Problematically, public sector governance institutions – including Defence as one of the diplomatic, information, military and economic (DIME) instruments of power – are configured around a linear-rational model and designed to address near- rather than long-term issues, primarily through top-down strategies and policy interventions.[48] Such governance systems are subject to the influence of structural factors that conspire against the sort of collaborative, non-linear and systems approaches needed to understand, let alone tackle, wicked and super-wicked problems. In this institutional context, barriers to coordinated action or learning and adaptation include, but are not limited to[49]:

- The influence of political election cycles.
- Limits on the availability and fungibility of financial resources.
- Inflexible and inefficient public procurement processes.
- Institutional infighting and bureaucratic inertia (e.g. between the Services).
- Denial, avoidance and a risk-averse culture, including among political, civilian and military leaders.
- A communication gap and mutual incomprehension between the decision maker and analyst communities, resulting in misaligned expectations around analytical products and evidence, including the role of modelling and simulation.
- Military or civil service career structures (with their frequent rotation of postings and various incentives to focus on near-term activity and outputs rather than long-term outcomes).
- Shortages in technical skills and other knowledge, skills and experience, not least given the financial challenges of competing with the private sector for talent.

Faced with these challenges, the academic literature on complexity and systems thinking offers a number of suggested improvements to analysis, modelling, decision making and, ultimately, C2, as will be explored in Chapter 5. But the inherent uniqueness of each wicked problem means it is not possible to define a single, universal blueprint to guide reform of government and military institutions or their decision-making processes. Furthermore, implementing policy interventions or wider structural reforms to address existing, known problems is likely to create unanticipated new challenges, given the complexity of social systems:

> Every wicked problem is unique due to its social complexity and the diversity of its causes, consequences, and constituent factors. Moreover, in attempting to solve a wicked problem, each proposed solution carries with it the risk of creating new problems that may also be 'wicked'—unlike solutions to simplify or tame problems, which may or may not work, but pose no risk of exacerbating the existing problem. A further dilemma is that it is difficult to trace or predict the 'waves of consequences' caused by a wicked problem, especially as such problems consist of many complex issues or roots that have become tangled together.[50]

[48] Lazarus (2008).

[49] Black, Paille et al. (2021); Head (2022b).

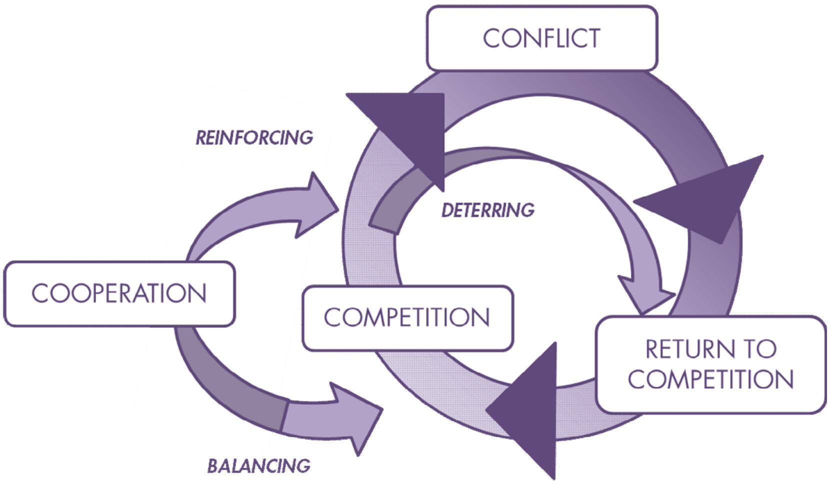
[50] Sun & Yan (2016), citing Rittel & Weber (1973), Whelton & Ballard (2002) and Camillus (2008).

2.3.4. An important distinction can be drawn between finite and infinite games, when considering interstate competition as a complex adaptive system

Besides wicked and super-wicked problems, it is also worth defining the different types of competition in which governments and militaries can find themselves engaged, whether at the operational, military-strategic or grand-strategic levels. Unlike many if not most of the policy problems facing civilian organisations, those responsible for foreign and security policy, as well as the use of the military instrument, are primarily concerned with competition, if not outright conflict, against one or more adversary.

Indeed, many analysts characterise strategic competition – or outright warfare – at the international level as a complex adaptive system (or system of systems) in and of itself.[51] This reflects the many interconnected and independent variables at play, the number of actors (state and non-state) within the system, and the non-linear dynamics and various positive and negative feedback loops that exist. These determine how actors interact with each other across the full continuum of cooperation, competition and conflict, exerting influence and, in turn, being influenced, across all PESTLE-M dimensions, as shown in Figure 2.2.

Figure 2.2 Feedback loops across the continuum of cooperation-competition-conflict



Source: RAND Europe, adapted from McCoy (2018).

Against the overarching backdrop of strategic competition, it is important to distinguish between different types of competition or 'game' that can occur between actors. In recent years, the concept of finite and infinite games has received significant attention in the US defence establishment, distinguishing between[52]:

- Finite games, i.e. contests 'bounded by time, space, and rules regarding what is permitted and prohibited', with 'agreed-on systems for scoring [that] allow players to be ranked and ordered in terms of their performance against each other' and thus 'unambiguous conditions for terminating the game and accepting its outcome.'[53] Here, the aim is to win and success can be measured.[54]
- Infinite games, i.e. contests that are unbounded in terms of time, space and rules. 'Players cannot determine when the game begins, when it ends, or how it is scored' and 'victory conditions cannot

[51] Harrison (2012); Gunitsky (2013); Ragionieri (2016); White (2016); Johnson (2018).

[52] Black et al. (2023).

[53] Frank (2022).

[54] Sinek (2019).

> be known, nor can the ranking of the players be made in an unambiguous fashion'.[55] In such a game, therefore, the aim is not to win but merely to survive and adapt in order to continue play.[56]

Despite the growing interest in these concepts, however, there remains a live academic debate as to whether strategic competition among states is truly an infinite game, or merely a long one. As shown by the historical record, strategic rivalries between great powers can last for decades or even centuries, but they can end and in some cases one or more of the players eventually collapses entirely.[57] These are certainly 'long games' with few clear boundaries and with emergent behaviour and unintended consequences; in turn, they contain a nested series of finite games that play out in relation to specific crises (e.g. wars, or diplomatic or trade disputes), and which inform, and are informed by, the shifting dynamics of the overarching competition.

2.3.5. Our study eschews adopting a rigid definition of complexity in favour of a DCDC-furnished description of this phenomenon in terms of its key properties

As will be discussed further in Chapters 3 and 4, not all problems facing Defence are wicked problems; nor are all the systems and challenges that they face complex. In recent years, there has been pushback against the 'fad in the academic literature' of describing all policy problems as wicked problems, when in fact they may be 'difficult, and perhaps even intractable' but not wicked in a formal sense.[58] Similarly, there is not always clarity among policy makers or those commanding military operations as to whether they are engaged in finite or infinite games and, as such, the relevant and applicable rules and dynamics.[59] Regardless, it is clear that a subset of the challenges facing governments and militaries are indeed wicked and related to complex and/or complex adaptive systems, while others may fall short but still exhibit certain attributes (e.g. the potential for cascading, unanticipated consequences).[60]

To help navigate these nuanced definitional and conceptual debates, and in recognition of the contested nature of language in this area, DCDC have opted to provide a description rather than a formal definition:

- Complex: 'A system or phenomenon that exhibits emergent properties and often involves non-linearity, hence small changes can have disproportionate or unpredictable effects on the overall behaviour of the system. As a result, the system is often difficult to understand or analyse.'

Having summarised the contours of the research landscape and contemporary debates in relation to both C2 and complexity, our paper now turns to understanding their drivers and manifestations, and the implications of relevant trends in the future operating environment.

55 Frank (2022).

56 Carse (1986).

57 Mazarr (2022).

58 Peters (2017).

59 Black et al. (2023).

60 Sieber (1980); Cortrell & Peterson (2001); De Melo et al. (2019); Byrne (2022).

3. Projected drivers of complexity

This chapter identifies and analyses the trends reported to be driving change and complexity in the strategic and operating environment, looking out to 2030 and beyond. This provides the basis for further examination in Chapter 4 of the specific mechanisms by which these trends influence the level and characteristics of complexity within the international system and thus C2.

3.1. Summary

Prominent trends are summarised in the box below and elaborated upon in the sections that follow.

Box 3.1 Key findings: major drivers of complexity

The nature and character of the future operating environment – and the types of missions that Defence C2 systems and organisations will be expected to undertake – are clouded by significant uncertainty, requiring caution with any projections. Nonetheless, the literature identifies a wide variety of PESTLE-M trends that are expected to shape the evolution of the international system out to 2030 and beyond. These include macro-trends such as:

- Increasing interconnectivity, multipolarity and global competition
- The impact of a changing climate
- The impact of technology and digitalisation
- The blurring of domains, both traditional and novel
- The shifting of international norms and value sets.

Crucially, there is no single or primary trend that is driving change or complexity; rather, it is the confluence of multiple factors and their unpredictable interactions that are of greatest concern.

Source: SASC analysis of Chapter 3 findings.

3.2. Understanding trends in the operating environment

3.2.1. The character and nature of the future operating environment is clouded by uncertainty, requiring caution with any projections

It is important to emphasise the caveats associated with futures and foresight analysis. The future is inherently uncertain, and it is beyond the scope of this short study to project what *will* happen out to 2030+. Instead, the focus is on understanding factors and trends that the futures literature suggests *might* impact on the types of problems and levels of complexity that UK Defence may encounter in this period. Furthermore, wider work is ongoing at DCDC and through the SASC to update the MOD's *Future Operating*

Environment 2035 (FOE 35) publication, as well as to produce the latest iteration of *Global Strategic Trends (GST 7)*.[61] This C2-focused paper is not intended to substitute for any of these deeper analyses.

It should also be kept in mind that the widespread perception of the current age being one of increasing complexity does not mean that this is the reality, at least not in all areas. Futures and foresight analysis, or the more general discussion of the future among lay audiences, is subject to various cognitive biases. These include but are certainly not limited to confirmation, availability, projection and ambiguity bias; the recurring trend for individuals and organisations to emphasise the novel over the enduring ('neophilia and presentism')[62]; the tendency to focus on quantifiable risks over broader uncertainty (given the inherent challenges around accounting for 'unknown unknowns' and possible 'Black Swans'[63]); and the habit of policy organisations and planners to consider a certain narrow set of scenarios (e.g. whether the most policy-compliant, the most desirable, or the worst-case, depending on the audience) more than others.[64]

Relatedly, there are well-documented waves of 'hype' and 'counter-hype' around the pace and likely impact of technological innovation,[65] as well as a tendency for some (including the military) to place less emphasis on non-technological factors – especially in Western military traditions, with their focus on qualitative superiority through organisation and technology, as opposed to factors such as mass, ideology or will.[66]

3.2.2. The literature identifies a wide variety of PESTLE-M trends that are expected to shape the evolution of the international system out to the 2030s and beyond

Conscious of the various caveats associated with projecting future trends, the SASC study team undertook a meta-scan of the existing futures literature. This revealed a large number and wide variety of factors and trends perceived to be major drivers of change in the future operating environment. These range across all areas of Political, Economic, Social, Technological, Legal, Environmental and Military (PESTLE-M) or other similar frameworks (e.g. DIME). Of course, not all drivers of change necessarily drive increased complexity. Instead, some factors merely present complicated but ultimately bounded and solvable problems, as opposed to true complexity. A summary of these trends is presented in Table 3.1.

[61] UK MOD (2015); UK MOD (2018a).

[62] Barnes (2019).

[63] Taleb (2007).

[64] Black, Paille et al. (2021).

[65] Painter (2017).

[66] Johnson (2021).

Table 3.1 Summary of trends shaping the future operating environment

Interconnectivity, multipolarity and global competition	Changing climate	Technological change and digitalisation	Blurring of domains	Shifting of international norms and value sets
• Increasing mistrust and revisionism • A broadening of global competition • Increasing multipolarity • Increasing connectivity within and between systems • The continuing rise of non-state actors • The changing impact of time and space • The perception of heightened uncertainty and volatility	• Environmental change and extreme weather • Energy transition • Disruption to food, water, and soil systems and ecology • Bio-security risks • Climate adaptation and weaponization • Demographic shifts and resource scarcity • Migration and urbanisation	• Pace of technological change • Democratisation and proliferation • The shifting locus of innovation • Increasing sophistication and vulnerability of technological systems • The profusion of data • The growth and expansion of networks • Impact of AI, ML and autonomy • Impact of other emerging disruptive technologies • Challenges around workforce skills and barriers to absorption of new technologies • Challenges around costs and legacy systems	• Competition in and through cyberspace • Competition in and through the electromagnetic environment • Competition in and through outer space • Growing focus on multi-domain integration • Growing focus on public-private partnership • Risk of cascading disruption to military and non-military systems • Potential to learn lessons from innovation in new operating domains	• Challenges to trust and legitimacy for governance systems • Challenges to sovereignty • Structural barriers to coordination and consensus • A highly contested information environment • Increased focus on social equity and diversity and inclusion • Uncertainty over future trends in ethics and morality • Lawfare and weaponization of the regulatory environment

Nonetheless, when describing PESTLE-M developments of relevance to future complexity, our literature review suggests that academic and policy sources place particular emphasis on a series of macro-trends. Before we turn to a discussion of how these might shape the levels and character of the complexity in the international system, the paragraphs below give a high-level overview of each macro-trend, with more detailed discussion provided in Annex B.

Increasing interconnectivity, multipolarity and global competition

Geopolitical and geoeconomic trends are seen as driving complexity by heightening the number of concurrent and converging challenges facing societies and, by extension, governments and militaries (see Section B.1).

The impact of a changing climate

Besides geopolitical and geoeconomic change, interlinked social and environmental trends could similarly lead to greater disorder, instability and ultimately conflict out to the 2030s and 2040s (see Section B.2).

The impact of technological change and digitalisation

As digitalisation continues worldwide, technological connections and interdependencies, including both within military C2 systems and organisations and broader society continue to grow (see Section B.3).

The blurring of domains, both traditional and novel

Traditional distinctions between domains could diminish as global systems and networks across the PESTLE-M spectrum multiply and become increasingly interconnected (see Section B.4).

The shifting of international norms and value sets

The literature also emphasises the impact of broader trends occurring within law, ethics and cultural norms, both at the national/societal and international levels (see Section B.5).

3.2.3. Complexity science(s) and systems theory emphasise the need to focus on the interlinkages across PESTLE-M dimensions

Given the complex web of causal links and feedback loops between the myriad PESTLE-M developments outlined across these macro-trends, there is the possibility for cascading crises to occur. These may entail unpredictable second- and third-order effects, which may overwhelm the capacity of governments or whole societies to mitigate or adapt. The next chapter considers how such trends can manifest as heightened or altered forms of complexity in the international system, and thus new pressures and demands on C2.

4. Manifestations of complexity

This chapter explores how the PESTLE-M trends driving change in the contemporary and future operating environment might influence the levels and characteristics of complexity within the international system as a complex adaptive system of systems. It begins by considering the lessons from academic theory in terms of the mechanisms through which change in the international system can manifest as complexity in different ways and at different levels of analysis. It then examines the types of dilemmas and pressures this puts on Defence decision makers and thus on the future design of C2 systems and organisations.

4.1. Summary

Prominent trends are summarised in the box below and elaborated upon in the sections that follow.

Box 4.1 Key findings: manifestations of complexity

Taking international relations (IR) as a complex adaptive system, PESTLE-M trends can contribute to shifts in the character of its complexity in several ways. Applying the lens of academic theory, changes in global politics and competition can be categorised in terms of systems, systemic and interactions change. Applying different IR theories then suggests differing explanations as to why and how changes are occurring. None of these theoretical lenses provides a full explanation for how and why change occurs within the international system, with some approaches matching better the empirical record of certain times of history or parts of the world than others. Nonetheless, it is possible to observe the translation of PESTLE-M trends into greater levels or different forms of complexity through several mechanisms, such as the phenomena of horizontal complexity, turbulence, and self-organisation and the emergence of order.

These and other cross-cutting impacts from the PESTLE-M trends identified in Chapter 3 contribute to a range of dilemmas and pressures for C2 systems and organisations to grapple with in the future, including but not limited to: uncertainty; ambiguity; equivocality; information overload; cognitive bias; decision paralysis or insufficient tempo in the face of fast-moving events; difficulty assuring decision making (including by AI) or trusting the data, logic and assumptions underpinning it; and difficulty marshalling all necessary levers of power or coordinating large groups of diverse actors (e.g. PAGs, industry, allies) involved in generating and executing a given strategy or operational plan.

Furthermore, both theorists and practitioners lack robust measures of the effectiveness of decisions made or actions undertaken when dealing with non-linear dynamics and problems. This makes it difficult to say definitively whether complexity is objectively increasing (as opposed to taking on different forms) in the future operating environment, but there is clearly a substantial gap between political expectations for the complex tasks the military should handle, and the ability of current C2 approaches to deliver.

Source: SASC analysis of Chapter 4 findings.

4.2. Understanding how PESTLE-M trends can drive complexity

4.2.1. Taking international relations as a complex adaptive system, PESTLE-M trends can contribute to shifts in the character of its complexity in several ways

It is important to distinguish between general trends and problems in global society – including those that might drive insecurity and thus be priorities for the future designers of C2 – and those which specifically contribute to the levels and manifestations of complexity within that complex adaptive system. To this end, the academic literature does not currently provide a definitive theoretical framework or set of analytical models for measuring and characterising the complexity of the international system or explaining how developments across the PESTLE-M dimensions contribute to change in this regard.[67] It does, however, provide a range of alternative theoretical lenses for understanding aspects of how changes in IR can relate to complexity, derived from a mix of IR theory and historical case studies.

For example, Robert Gilpin (1981, 39–41) outlines a typology of three types of change in the international system:

- Systems change: a change in the nature of the actors within a system (e.g. states, empires, etc.)
- Systemic change: a change in the governance of the system.
- Interaction change: a change in the interactions between actors and other features.

This can be extrapolated upon to consider the impact of PESTLE-M trends through these three categories at different levels of analysis, for example considering systems, systemic or interaction change in relation to the international system itself, or at the level of the sub-systems and units therein (e.g. blocs such as the EU or NATO, or individual nation-states). It is then possible to begin to understand the changing number and nature of actors in play, the arrangement of governance, normative and power structures that shape their relations, and the processes through which they interact (whether to cooperate, compete or fight).

Applying different IR theories can result in differing explanations as to why and how changes are occurring. For example, Gilpin focuses on objectivism, realism and rational choice theory as explanations for interstate competition, seeking to understand whether the shifting governance of the international system at a given time favours the emergence of a stable equilibrium (e.g. a period of hegemony or of mutually tolerated balance of power between rival states) and hierarchic system, or that of an anarchic system (e.g. the collapse of hegemony and the outbreak of a period of intense multipolar competition and conflict).[68] A Marxist interpretation, by contrast, would focus on economic and class relations as the primary driver and locus of change and competition. Meanwhile, a constructivist interpretation would place more emphasis on how the norms and rules of international politics are socially constructed,[69] and how change in the governance and interaction processes within global society as a complex adaptive system come about through 'cognitive evolution' and shifts in the perceptions and culture of the actors that compose it.[70]

None of these theoretical lenses provides a full explanation for how and why change occurs within the international system, with some approaches matching better the empirical record of certain times of history

[67] Gunitsky (2013); Ragionieri (2016).

[68] Gilpin (1981), cf. Jervis (1997).

[69] Finnemore & Sikkink (1998); Wendt (1999).

[70] Adler (1997).

or parts of the world than others. Nonetheless, it is possible to observe the translation of PESTLE-M trends into greater levels or different forms of complexity through several mechanisms. Crucially, it is important to understand how the aforementioned types of change (i.e. Gilpin's typology) and levels of analysis (i.e. the international system, sub-systems, units, etc.) can interact to drive complexity. For example, Ragionieri (2016) suggests that changes in international politics can lead to complexity through three primary means:

- Horizontal complexity
- Turbulence
- Self-organisation.

The contributions of PESTLE-M trends to these and other cross-cutting manifestations of complexity are outlined in the paragraphs below.

Horizontal complexity

This refers to shifts in complexity at a given level of analysis (e.g. the international system, or a sub-system, or an individual unit such as a given nation, or each of the levels of warfare from the tactical to the strategic). For example, this might refer to PESTLE-M trends that affect the nature and number of actors or their governance and interactions at a given level, and the positive and negative feedback loops that occur due to the various actors and variables involved[71]:

- Positive feedback loops: Examples include arms races that lead to uncontrolled escalation, or the domino effects of insecurity, instability, environmental degradation, economic disruption and migration that can be mutually reinforcing and magnifying, driving cycles of regional conflict.
- Negative feedback loops: Examples include balancing by strategic rivals (e.g. the United States and the Soviet Union) to achieve a stable equilibrium in their competitive relations, with little interest among the key players in changing this status quo or the rules of the existing international system (e.g. as in the period of globalisation in the aftermath of the Cold War).[72]

Turbulence

Derived from fluid dynamics, James Rosenau's (1990) notion of 'turbulence in world politics' refers to the absence of stability in the distinction between levels of analysis (e.g. between the international system and sub-systems or units therein). This focuses in on how complexity at one level interacts with complexity at other levels, affecting their structure.

[71] Of note, 'positive' and 'negative' here do not represent normative judgements of 'good' or 'bad'; rather, they are used in the literature to denote positive feedback loops that enhance and amplify change versus negative feedback loops that dampen or buffer change, encouraging equilibrium. In other words, 'positive' and 'negative' describe a relationship between the feedback and the stability or equilibria of the system in question.

[72] Mazarr et al. (2021).

The PESTLE-M trends discussed in Chapter 3 emphasise the myriad interlinkages that exist between these different levels. When considering competition and conflict among actors within this system of systems, they emphasise the growing emphasis on competitive strategies that explicitly seek to gain the advantage by bringing together all DIME levers, embracing ambiguity and non-linearity, and ignoring or subverting the West's neat conceptual thresholds or institutional boundaries (such as between the global and the local, war and peace, or the tactical and the strategic).[73] In this way, adversaries explicitly seek to exploit the structures, stovepipes and seams found in the Western approach to gain an advantage – necessitating a change.

This also challenges the elegant but arguably reductive models derived from rational choice theory, which are typically based on how actors and their preferences interact within a given structure (i.e. at only one level of analysis). By contrast, rationality is shown to be bounded, with decisions also shaped by cognitive bias, emotion, fatigue, imperfect information and other factors. Furthermore, shifting focus to the growing turbulence within international affairs emphasises the multi-level nature of the games – both finite and infinite[74] – that play out simultaneously, as well as the influence that games occurring at a lower level can have on structures, relationships and interactions at higher levels.[75] Crucially, too, the games occurring as part of strategic competition are not only multi-level (i.e. vertical or turbulent) but also multipolar (i.e. horizontal):

- Multi-level: These games involve all DIME levers of power, including broader society, but with varying levels of C2 (or lack thereof) across these (e.g. Defence can command and control the military instrument, but can only exert constructive influence over PAGs responsible for diplomacy, or over industry responsible for technological innovation and economic trends).
- Multipolar: Multi-level games, and their 'turbulent' interactions, are challenging enough to manage in relation to one actor, let alone multiple ones; however, in an increasingly multipolar world characterised by a large number of actors, that is often the situation facing UK Defence. This is reflected not only in the rise of state actors such as China but also in the growing influence of non-state actors (e.g. multinational corporations, private security companies and terrorist groups). The deepened interlinkages between domestic audiences around the globe through the information environment further heighten the influence of different actors in an increasingly interconnected world. Together, these factors pose a heightened coordination problem, particularly given the growing number and variety of actors involved, their asymmetric goals, values, strengths and vulnerabilities, and the imperfect information available.[76]
- Multi-objective: The challenges of navigating these different forms of competition are further complicated by the simultaneous need to pursue multiple objectives at once. Often, this can include both competition and cooperation simultaneously with the same actors across diverse policy areas (e.g. to manage escalation or to tackle wicked problems of mutual interest, such as the UK working with China on climate change at the same time as competing on technology and military strength). As such, signals and actions undertaken in relation to a given actor may be interpreted in unpredictable and unintended ways by that same actor or by other third parties (e.g. allies,

[73] Kilcullen (2020).

[74] Finite games are contests bounded in time and space, and by rules regarding what is permitted, with objective measures for how actors are performing against each other. Infinite games are contests that are unbounded and where players have different, subjective perceptions of when the game begins/ends or how it is scored. Cf. Carse (1986); Frank (2022).

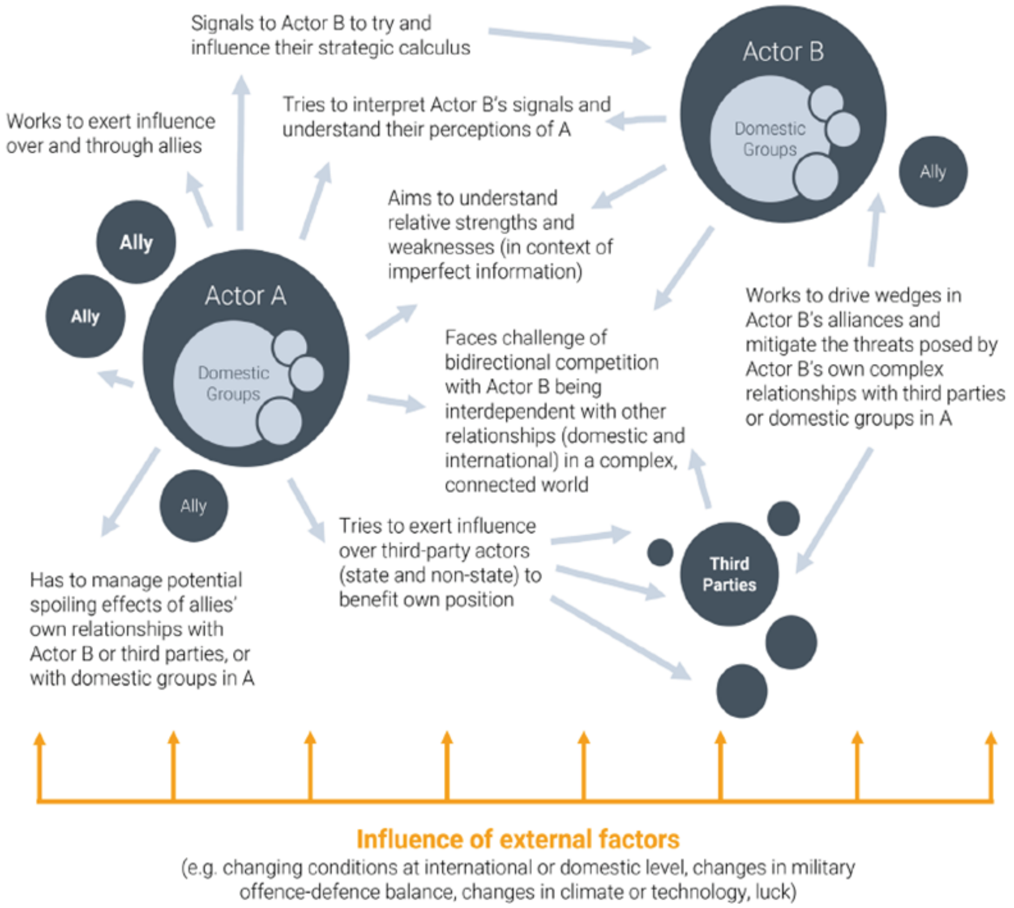
[75] Ragionieri (2016).

[76] Ritchey (2013); Duczynski et al. (2021); Head (2022b).

adversaries, neutrals, domestic audiences) and/or have cascading second- and third-order effects in other areas of international relations as a complex adaptive system of systems.[77]

Even a simplified illustrative depiction of multi-level competition, as in Figure 4.1, underscores the inherent difficulty of navigating these complex dynamics and the risk of misperceptions.

Figure 4.1 Example of multipolar and multi-level games facing UK Defence



Source: Black et al. (2023).

The concept of turbulence further supports the idea of the changing interactions between the grand-strategic, military-strategic, operational and tactical levels. This is driven in part by growing pressure for tactical and operational decision makers to be cognisant of the strategic-level and PESTLE-M implications of their choices, for a mix of political, legal, ethical and military reasons. This pressure builds on decades-old debates about the need for the 'strategic corporal'[78] (as contrasted with the 'tactical general' or 'tactical minister').[79] It also relates to the more recent trend within Defence of promoting a so-called 'campaigning mindset' that frames even low-level activities such as a training exercise as sending signals to allies and adversaries alike and thereby consciously contributing to higher-level campaigns to deter, influence and

[77] Jervis (1976); White (2016); Ellery & Saunders (2020).

[78] Krulak (1999).

[79] Singer (2009).

promote prosperity.[80] (This trend seeks not only to work better within levels, e.g. tactical, strategic, etc., but also across them, though it is unclear if this is feasible or what its consequences will be.)

Self-organisation and the emergence of order

A common concept within wider complexity theory, but less often applied to international politics, self-organisation refers to the spontaneous emergence of spatiotemporal order and of 'phenomena… that cannot be brought back to the characteristics of their elements'.[81] By definition, it is not something that can be easily predicted; it emerges from the collective behaviour of multiple components but exceeds the aggregate behaviour of the elements themselves and cannot be reduced to an examination of them.[82] PESTLE-M trends identified in Chapter 3 nonetheless allude to an expectation of emergence in various forms: for example, in relation to economic developments brought about by environmental change, technological innovation, and exploitation of new domains (e.g. space); or in the normative shifts that occur unpredictably as a result of the growing volume and diversity of interactions between billions of humans (and a growing number of machines) via the information environment; or new self-organising artificial forms of life.[83] This 'paradigm shift' or 'phase transition' is not necessarily negative, of course.[84] For instance, the literature raises the potential for beneficial solutions to emerge in terms of climate adaption, resource management or cooperative strategies.[85] However, given the various threats, risks and hazards discussed, there is also potential for the emergence of new equilibria – such as in geopolitics – that may be hostile to or even catastrophic for the UK's values and interests as they exist today, and difficult to dislodge.

Other cross-cutting impacts

There is a growing awareness of challenges facing C2 systems and organisations (and individual decision makers) in terms of the dilemmas and pressures arising from factors such as:

- Deep uncertainty.[86]
- Ambiguity and equivocality.
- Shortfalls in cognitive capacity, alongside increased data saturation and information overload.[87]
- Cognitive bias and flawed heuristics.
- Decision paralysis and failure to keep up with the tempo of events.[88]
- Failure to keep up with, understand or exert influence over competitors' own decision cycles[89] (e.g. authoritarian regimes operating outside of slow coalition politics, or using AI systems to automate certain decisions the West cannot countenance for policy, legal or ethical reasons).

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[80] UK MOD (2020a).
[81] Luhmann cit. in Ragionieri (2016).
[82] Kalantari et al. (2020).
[83] Gershenson et al. (2020).
[84] Kuhn (1962); Lingel et al. (2021).
[85] Bousquet & Page (2004); Adami et al. (2016).
[86] Black, Paille et al. (2021).
[87] Johnson (2018); Whitler (2018).
[88] Conflict today is arguably 'faster and more complex than any point in history.' Cf. Garamone (2017).
[89] The US DoD endeavours to improve its decision cycle to operate at 'the speed of relevance', while ensuring leadership can make 'high-quality decisions in an increasingly complex strategic landscape'. Cf. Dransfield (2020).

- A lack of explainability, traceability or suitable validation and verification (V&V) methods to assure decision making (e.g. when involving non-deterministic, black box AI).[90]
- A lack of trust in underlying data and evidence, whether due to concerns over the security and integrity of data and networks, or due to wider epistemic issues (e.g. contested notions of truth).
- Difficulty marshalling all necessary levers and coordinating across diverse and large groupings.
- Difficulty understanding and attributing cause and effect (given feedback loops, etc.) and thus prioritising efforts or measuring their effectiveness.
- A crisis of confidence in rationalism, the legitimacy of public institutions and the quality of their strategies, plans or attempts to execute these when faced with complicated problems, let alone complex ones (including wicked or super wicked problems, such as climate change or warfighting).[91]

The identified PESTLE-M trends exacerbate these issues, and have an impact on all the defining features of a complex adaptive system outlined in Table 2.1, namely:

- Numbers: As reflected in the increasing number of agents (human and machine) and variables to consider in decision making; the continuing evolution of networks with both more nodes and more numerous and more diverse linkages; and the increase in threat vectors and associated attack surfaces and vulnerabilities. By contrast, there are enduring constraints on the size and resources of Defence (entailing a relative decline compared to the scale of the tasks expected of it), and a decline in the relative clout of the West vs the East (in terms of population size, GDP and soft power, etc.), and of the public vs private sector (in terms of driving innovation or exerting influence).
- Non-linearities: PESTLE-M trends contribute to feedback loops and non-linear dynamics. Some of the identified trends have a known potential to lead to cascading and exponential crises (e.g. from catastrophic climate collapse, or from a pandemic, nuclear war or unaligned AGI). These can be worsened by poorly understood second- and third-order effects; similarly, other potential crisis triggers may be unknown and unpredictable.
- Adaptive elements: PESTLE-M trends influence the international system as a complex adaptive system of systems (as well as the systems therein, e.g. the economy or war), while also adding to the pressures on defence C2 systems and organisations to adopt new structures, processes and cultures configured around adaptation and learning and, at the same time, making it difficult to do so. These barriers to change run across DLODs and include factors such as political expectations, funding constraints, difficulty accessing the different, more diverse and sophisticated talent and skills required or harnessing technology in a timely manner. These and other issues are explored further in Chapters 5 and 6.
- Emergent phenomena: As already discussed in relation to self-organisation.

[90] The integration of artificial intelligence (AI) and autonomy in the decision-making cycle aims to reduce complexity based on the increased tempo of operations but runs the risk of human cognition being unable to keep up with machine-aided decision making. New technologies such as AI and machine learning (ML) are increasingly used to process and prioritise data, as well as to sense-make on behalf of human decision makers. Algorithmic biases or 'black box' technologies could potentially drive complexity in the decision-making space. Rising complexity and a greater speed of war may make decision making in armed conflicts too fast for humans to handle.

[91] Head (2022a).

4.2.2. Ultimately, given the difficulty of measuring complexity, it is unclear if it is objectively increasing, but the growing burdens on C2 are evident

Ideally, this paper would now draw together the analysis from the preceding sections and provide a firm conclusion as to whether complexity is indeed increasing within the international system, as so many strategy and policy documents and other sources suggest. Certainly, there are a variety of PESTLE-M trends which, collectively and individually, are contributing to new manifestations of complexity, as shown above. Any definitive assessment of trend lines, however, would be illusory, given the inherent difficulties in quantifying complexity, which lacks objective measures.[92] There is, as such, a live debate about whether the complexity of society, warfare and other phenomena is truly increasing, or whether this widespread perception is instead driven by some combination of:

- The human and institutional bias towards viewing the current period and problem set as uniquely challenging.
- An academic or bureaucratic 'fad' of applying the novel lens of complexity and systems theory to new issues outside of the natural sciences, such as international affairs, and labelling policy challenges as wicked problems as a means of funding, citations or other goals.[93]
- A misinterpretation of the difficulties facing C2 systems and organisation, incorrectly framing them as being caused by an increase in objective levels of complexity, as opposed to just a growing subjective awareness of complexity (backed by recent decades' advances in both theory and data, improving understanding of the limitations of reductionism). Alternatively it could reflect a growing gap between the demands that are placed on C2 (e.g. due to unrealistic expectations from 'stakeholder society' about what the military can do, or the possibilities arising from new technologies[94]) and what current hierarchical, linear approaches can deliver.[95] In this sense, complexity may or may not be growing relative to an objective measure of the operating environment; we may simply be increasingly aware of the gap between our ambitions and our capabilities, and of risks, uncertainties and vulnerabilities that have existed but gone underappreciated in recent decades.[96]

There is also a broader question about whether it is even necessary or useful to compare the levels of complexity in the FOE with the current or past periods. The most pressing issue for C2 is not whether complexity is increasing, per se, but rather that current approaches are simply not configured to deal with complex problems or to understand, navigate and influence complex adaptive systems. To this end, the next two chapters outline possible methods for grappling with or exploiting complexity (Chapter 5) and other associated design considerations for C2 in the future (Chapter 6).

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[92] Kavalski (2007); Bousquet & Curtis (2011); Gunitsky (2013); Lineweaver et al. (2013).

[93] Peters (2017); De Melo et al. (2019).

[94] Hallo et al. (2020).

[95] This recalls the original and influential thesis of Rittel & Weber (1973) that most of the easy policy problems (i.e. those that were merely simple or complicated) had already been solved by the second half of the twentieth century, meaning that future challenges would, by default, tend to be more complex and challenging, perhaps even intractable.

5. Methods for tackling complexity

This chapter outlines some of the methods available in the academic literature for understanding, navigating and tackling complexity. Our findings emphasise the inherent limitations of any single approach, and thus the need to develop and apply a toolkit of different methods for grappling with situations of varying levels and forms of complexity, uncertainty, ambiguity and pace of change. This builds on the ideas of 'deliberation with analysis' – i.e. of a deeper and more productive dialogue between the analyst community and the decision maker(s), making use of the latest data sources, technologies, and analysis and modelling techniques – and of approaching complex systems and non-linear problems through a mix of collaboration, iteration, learning and adaptation. Such an approach would likely involve breaking down current stovepipes (e.g. between Intelligence, Planning and Operations) to enable collaboration across and between functions.

As such, this chapter focuses on the higher-order conceptual and methodological considerations, leaving the practical implications of complexity for the design of C2 systems and organisations in the future (e.g. how to ensure survivability of headquarters or access to the necessary people and technology) to Chapter 6.

5.1. Summary

Box 5.1 Key findings: methods for tackling complexity

C2 systems and organisations face significant pressure to perform better in conditions of complexity, ambiguity, uncertainty and rapid change. Past RAND research has explored the potential for consciously imposing complexity on opponents' own C2 systems and approaches to gain a relative advantage even if the UK itself cannot tackle complexity as well as desired.

Current academic theory provides a tentative outline of a methodological toolkit and some guiding principles for deciding how to configure C2 amidst complexity – but no silver bullet. It emphasises deliberative-analytic approaches, meaning methods that engage varied stakeholders in co-design; draw on insights from multiple disciplines and bodies of knowledge; and build into analytic and decision-making processes the flexibility to iterate and improve them over time based on feedback.

Examples of prominent methods in the complexity science(s) literature include cybernetics, systems engineering, soft systems methodology, interpretative structural modelling, design thinking and critical approaches. Of course, it is important to select the right tool from this toolkit to tackle a given situation, threat or problem, aided by frameworks such as Cynefin. A recurring theme across most approaches, however, is the need for continuous iteration, learning and adaptation, emphasising that future approaches to C2 must evolve over time and vary depending on the context and threat environment faced.

Source: SASC analysis of Chapter 5 findings.

5.2. Towards a toolkit for competing effectively in the face of complexity

5.2.1. Applying complexity and systems theory to the future, both friendly and hostile C2 systems and organisations face significant pressure to continuously improve and enhance their performance

Given the manifestations of complexity described in Chapter 4, any concept for the future of C2 must grapple with the simultaneous pressures on Defence C2 systems and organisations to better:

- Understand, influence and shape diverse audiences and events across multiple levels of the international system by bringing purpose and direction to focus and converge effects, using all levers of power that will best promote UK advantage. This includes not only those levers under the direct control of Defence (i.e. the military) but also working with PAGs, allies, partners, industry, academia and wider society, all of which pose their own unique demands from a C2 perspective. It also necessitates understanding which levers or effects will be most relevant to addressing a given problem or achieving advantage in the first place, given the shifting rules and dynamics of global competition (which may favour certain instruments over others).
- Mitigate this complex web of interactions and orchestrate the execution of a strategy or plan, while building in mechanisms to measure the effectiveness of different approaches for managing complexity and enable adaptation and learning.
- Minimise the risk of negative unintended consequences through hedging and mitigating actions, at least to the limited extent possible given the finite resources and levers available to UK Defence and the opacity and incomprehensibility of the systems involved.
- Guide and prioritise these efforts by making the best possible sense of the constantly shifting character of international relations as a complex adaptive system (or system of systems), given the challenges of uncertainty and ambiguity and the impact of PESTLE-M trends in terms of horizontal complexity, turbulence, and self-organisation and emergence.

This would be a difficult task even in a benign threat environment and with ample resources (human, technical, etc.). Looking out to the 2030s and beyond, however, Defence faces a considerably more challenging threat landscape, and a less than favourable one from a funding or workforce perspective. Ultimately, too, the focus should not simply be on how best to configure UK C2 systems and organisations to deal with complexity, but also how to do so in the context of persistent global competition, and occasional overt conflict, with hostile state and non-state actors (the nested set of finite and infinite games discussed in previous chapters). As such, success and failure are not judged against an objective yardstick, but rather in relation to how the UK's C2 does or does not enable it to overcome its adversaries, including by outperforming those opponents' own C2 systems, and thus achieve the UK's objectives – or at least minimise the impact of failure.[97]

Given the constraints faced and the competitive dynamics at play, the following sections consider possible methods and tools that future approaches to C2 could use to understand, exploit or navigate complexity.

[97] This relates not only to game and prospect theory, but also to aforementioned Chinese and Russian thinking around 'systems confrontation' and 'systems warfare', which conceptualises future warfare as a struggle between competing system of systems for information and cognitive advantage. Cf. Engstrom (2018); Black, Lynch et al. (2022).

5.3. Methods for imposing complexity on others' C2

5.3.1. Past RAND research has explored the potential for consciously imposing complexity on opponents' own C2 to gain a relative advantage

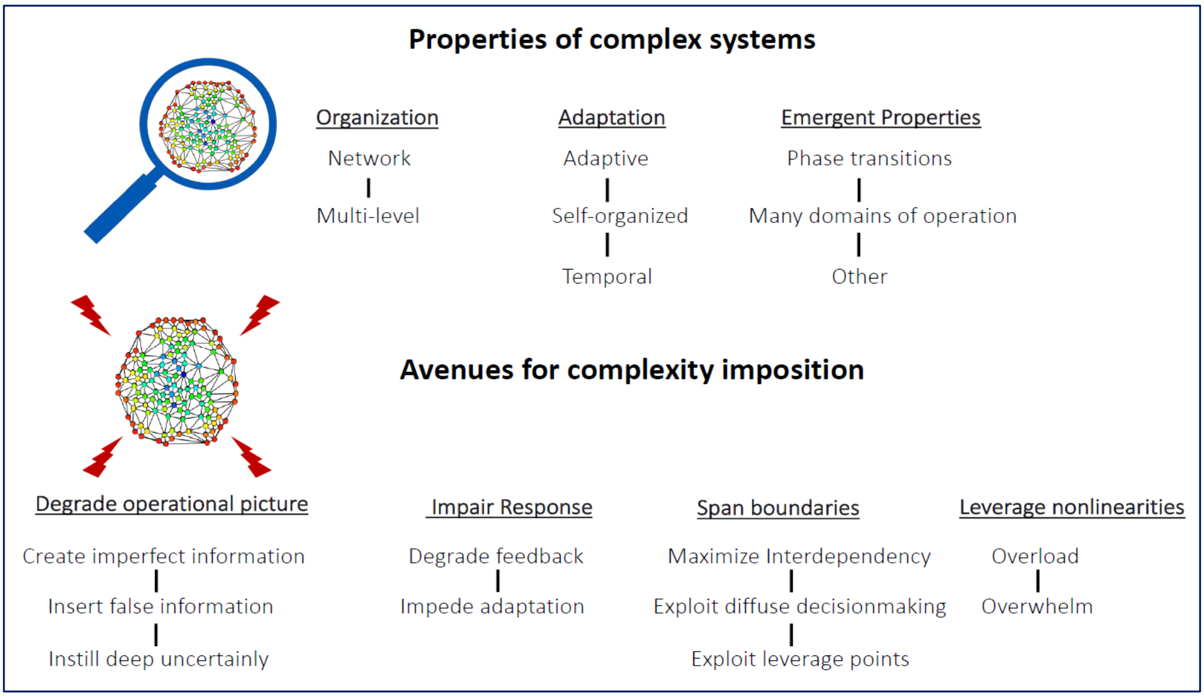
Given the incomplete theoretical understanding of complex adaptive systems, or even an agreed common definition of complexity (see Chapter 2), it is not surprising that there is no academic consensus on whether the best competitive strategy is to focus on minimising the negative effects of complexity on friendly C2 systems and organisations (i.e. to improve performance in absolute terms), or instead to maximise the impact on hostile C2 (i.e. to improve performance in relative terms).

In practice, it is likely that any approach to future 'systems confrontation' or 'informationalised warfare', such as is envisaged by the United States, China, Russia and others, will combine elements of both strategies. Lingel et al. (2021, 2) describe the purpose of more offensive actions:

> To impose or exploit complexity is to take an action that increases an aspect of the complexity of the environment in a way that makes it more difficult for an adversary to make decisions or to operate, essentially shaping conditions to favour [a friendly actor]. Thus, to conduct a complexity attack is to take an action that exploits characteristics of CAS to have a deliberate negative effect on the adversary.

Possible avenues for imposing added complexity on an adversary's own C2 are summarised in Figure 5.1.

Figure 5.1 Complex adaptive systems mapping to competition or (war)fighting



Source: Lingel et al. (2021, 6).

As shown in the graphic, there are multiple ways in which the UK might seek to confuse, paralyse, outpace or otherwise shape its opponents' C2 and decision making in favourable directions (e.g. to impose multiple dilemmas).[98] Practical enablers and capabilities (i.e. means) required to do so are elaborated upon in Chapter 6. Collectively, though, these different avenues focus on gaining the advantage by exploiting the concept of bounded rationality first described by Herbert Simon (1972). This refers to the fact that human and institutional decision makers are goal-oriented, as in game theory, but also limited by imperfect cognitive capacity and information, as well as being shaped by their values, imagination and prior experience.[99]

By this understanding, the UK can seek to exert influence on and through the information environment over its opponents' capacity for effective sense and decision making, and, consequently, for action.[100] Potential approaches to exert such influence include:

- Degrading the operational picture: Degrading the adversary's understanding of the operating environment (a complex adaptive system) and events, let alone causality, therefore impacting their ability to make informed decisions; degrading cognitive capacity; exacerbating distrust of imperfect information or of communications from superiors/peers/subordinates; and maximising opponents' awareness of known unknowns or deepening their uncertainty about unknown unknowns; leading to bad decisions due to a lack of understanding of choices and thus how to prioritise finite resources most effectively.[101]
- Impair response: Proactively hindering the capacity of opponents' C2 (a complex adaptive system in its own right) to identify relevant signals and feedback and thus to learn and adapt over time.
- Span boundaries: Maximising turbulence and disruption by targeting key steps, nodes or linkages in hostile C2 systems and processes – especially if their networks are highly hierarchical in nature, as is the case for most militaries (especially authoritarian ones) – and forcing opponents into actions that depend on effective boundary-spanning and coordination of diffuse nodes, such as those under a different command or those cut off from central C2 by disrupted communications.[102]
- Leverage non-linearities: Overloading C2 structures and processes – for example, by confronting a given node within the network with pressures and dilemmas that exceed their cognitive and information processing capacities – and overwhelming the adversary by exploiting non-linear dynamics and encouraging feedback loops that lead to cascading impacts favourable to the UK.

At the same time, of course, the UK's opponents are likely to be seeking to exert similar influences on UK C2 – whether consciously or implicitly. To this end, the UK requires not only defensive countermeasures to combat this (whether through deterrence or active or passive defences against hostile attempts to influence UK C2), but also methods and tools for better navigating complexity itself. Of note, different modes of C2 will likely be required to handle different forms of complexity. These are discussed in the next section.

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[98] Behzadan & Munir (2017).

[99] Simon (1990); Jones (1999); Triezenberg (2017).

[100] Lingel et al. (2021, 10–14).

[101] Note that the UK may not always want its opponents to make bad decisions, as these may lead to a situation that is unfavourable to all parties. As such, the UK needs some assurance that deep uncertainty will not lead opponents to stumble into actions that are a worse net outcome for the UK even if also damaging to the UK's adversaries. Cf. Lingel et al. (2021, 11).

[102] Any attempt to disrupt less hierarchical, more diffuse network structures, such as terrorist groups, will require a different approach to targeting compared to a traditional military adversary. Social network analysis (SNA) may assist.

5.4. Methods for navigating complexity in the UK's approaches to C2

5.4.1. Current academic theory provides the tentative outline of a methodological toolkit for grappling with C2 in the face of complexity, but no silver bullet

As has been discussed above, there is no unifying theoretical framework for the complexity science(s), nor any silver bullet solution for conceptualising, analysing and shaping complex adaptive systems. Nonetheless, some qualitative and quantitative analytic approaches are candidates for inclusion in a toolkit of methods for grappling with complexity in decision making.

Importantly, proponents of complexity and systems thinking emphasise the need for humility, iteration, learning and pragmatism about the art of the possible, when applying such methods, given the limitations of both theory and data.[103] This reflects wariness about falling into the very same over-confidence and mistakes of the positivist, reductionist scientific approaches that complexity science(s) aims to reject and supplant. Many thinkers in this space advocate for more deliberative and adaptive approaches, meaning methods that engage a range of stakeholders in co-design, draw on insights from multiple disciplines and bodies of knowledge, and build into analytic and decision-making processes the flexibility to iterate and improve them over time based on feedback.

One prominent example of this sort of meta-approach in the literature is 'deliberation with analysis' or citizen science, as advocated by the US National Research Council (2008). This is closely associated with analysing complex problems and non-linear dynamics, including those where decisions are clouded by deep uncertainty. It seeks to move away from linear, positivist approaches to analysis and top-down decision making, conscious that commonly used tools and modelling techniques can provide decision makers with false levels of confidence in the quality of evidence underpinning their choices, leading them astray when tackling complex problems.[104] This necessarily implies a move away from more traditional C2 approaches. Though deliberation with analysis originated in a drive to involve the general public and other stakeholders in analysis and decision making around climate and environmental management, it has since been adapted and applied to a variety of settings, including defence strategy, planning and capability-related decisions.[105] It has also informed, and been informed by, movements such as deliberative policy analysis (DPA), which promotes forms of strategy and policy analysis that are more inclusive and participative, and less technocratic, as a response to dealing with complexity and the realities of a modern networked world.[106]

Clearly, a lengthy process of deliberation is not appropriate in all situations or types of decisions facing C2 systems and organisations. Such an extended process may be feasible, and advisable, when formulating cross-governmental or defence strategy. But faster decisions are sometimes required when planning or executing a military operation, especially in a warfighting scenario. Nonetheless, many of the core guiding principles of deliberative-analytic and robust approaches remain relevant and scalable[107]:

- Being humble from the outset about the limitations on theory, data, tools and cognitive capacity, and designing deliberative-analytic processes with this in mind.

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[103] Head (2020); Peterson St-Laurent et al. (2020).

[104] Lempert et al. (2013).

[105] Davis (2014); Popper (2022).

[106] Li & Wagenaar (2019).

[107] Lempert et al. (2013); Lempert (2019); Marchau et al. (2019); Black, Paille et al. (2021).

- Avoiding short-termism in favour of prioritising consideration of longer-term outcomes and potential second- and third-order effects, aiming not to optimise strategies or plans for a specific scenario, or even a small set of scenarios (e.g. worst-case, best-case) but rather to identify what steps would minimise regret across the widest range of plausible scenarios that could unfold, conscious of the ever-present challenges posed by unknown unknowns and non-linear dynamics.[108]
- Engaging as wide as possible a range of perspectives (e.g. across stakeholders, disciplines, etc.) to understand the problem from different angles, seek feedback and stress-test emerging thinking.
- Using exploratory models as a 'digital campfire' to bring analysts and decision makers together to encourage increased dialogue and mutual understanding between these communities, which typically have different professional backgrounds and approach problems with differing forms of reasoning (with analyst culture, for example, typically favouring deductive logic and numerate-based analysis, compared to decision makers often favouring inductive logic).
- Using technology to supplement rather than supplant debate, with a human-in-the-loop approach to development and exploitation of advanced computational methods, including AI and ML.
- Focusing on avoiding surprise by interrogating assumptions and biases, rather than by seeking to make predictions about the future or to try to reduce complexity down to simplistic analyses.
- Proactively building in mechanisms for identifying signals as to whether a given analytic approach, decision or plan is working, and for learning and adapting accordingly.
- Iterating as needed.

Such an overall philosophy aims to produce strategies, policies, plans or decisions that adhere to the so-called 'FARness principle', meaning they are flexible, adaptive and robust.[109] These properties are recurring themes that will run throughout the various specific methods outlined below.

5.4.2. Guided by these overarching principles, it is important for C2 systems and organisations in the future to select the right tools for different problems

Selecting the appropriate method(s) or tool(s) for C2 systems and organisations in the future to use to navigate a complex problem depends on a range of factors.[110] Above all, it is important to understand the nature of the problem and the types of decisions to be made. Crucially, given complex systems (including

[108] For more information about approaches to minimise regret and the inclusion of regret minimisation in decision-making frameworks, see Yager (2004); Bell (1982).

[109] Davis (2014).

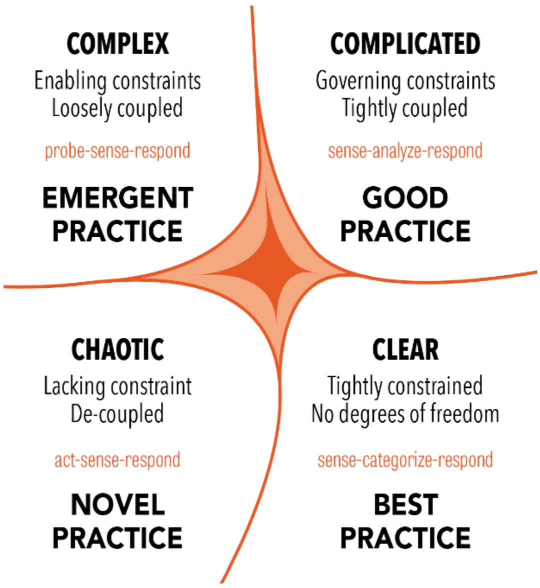
[110] For example: the nature of the problem faced, and the goals being pursued; the nature of the decision(s) to be made (e.g. a strategy, policy, plan, or tactical order); the information available and the level of confidence in it; the required level of confidence in the decision(s) to be made, given known risks (e.g. for political reasons or due to risk to life or some other possible negative impact from any mistake); the timelines available to make a decision, and the consequences of delay or indecision; the resources available by way of decision support (e.g. technology, data, specialist skills, funds); the levers available to execute that decision and time-space considerations for converging effects; the rigor and feasibility of possible measures of effect; the role of other parties in influencing, disrupting, or enabling that decision, the information available, or the execution phase (e.g. adversaries, allies, partners, PAG, industry, academia); the relevance and familiarity of a given method or tool (e.g. qualitative or quantitative models); the strengths and limitations of a method or tool from both a theoretical and empirical perspective and given practical considerations in terms of the required inputs (data, time, money, etc.); and lessons learned from prior application of such methods.

CAS) are dynamic, not static, components within the system can move between these different domains over time. A problem or system may be complex overall but have simple or complicated elements. Here, recalling Chapter 2, it is still essential to ascertain if a problem or a facet thereof is truly complex or if it could be tackled through positivist methods and traditional, linear and hierarchical approaches to C2. David Snowdon's Cynefin (Welsh for habitat) framework offers a well-known tool for making such a determination. As depicted in Figure 5.2, this framework helps the user characterise their environment or problem and thereby determine the appropriate approach for a given situation[111]:

- For simple situations: Sense-categorise-respond.
- For complicated situations: Sense-analyse-respond.
- For complex situations: Probe-sense-respond.
- For chaotic situations: Act-sense-respond.
- For confused/aporetic situations: Exit into any other domain as possible.

Just as complex systems may move between these domains, an unprecedented situation is similarly likely to be chaotic at first, given the lack of any obvious guide from prior experience; however, individuals and organisations will learn with time and the structure and dynamics of the system may become more defined, with emergence of order. The Cynefin framework is thus a sense-making tool for understanding how to react to a given issue at a given time, while acknowledging that applying the same lens in a month or year may produce a different answer.[112]

Figure 5.2 Cynefin framework



Source: IT Revolution (2021).

This framework also helps make sense of how to establish sufficiency, i.e. determining when a decision maker knows enough to decide or act. For ordered systems, this is straightforward, measured by whether the decision maker has collected enough data and expertise to apply best practice (in the case of clear

[111] Snowden & Boone (2007).
[112] IT Revolution (2021).

problems) or good practice (in the case of complicated ones). Sufficiency cannot be pre-determined so easily when grappling with complex systems, however, as it is an emergent property. Equally, delaying a decision forever, or failing to decide at all, may produce negative outcomes or, at the very least, be anathema to military culture and to the expectations placed upon defence decision makers by political leadership. As such, sufficiency emerges from probing, trying to detect feedback loops and patterns, and taking steps to influence the more favourable ones in an ongoing, iterative process. This encourages a more experimental approach, founded in learning and adaptation, as opposed to pursuing a level of confidence in initial decisions about complex problems that is not feasible within current theory or cognitive capacities.[113]

5.4.3. Relevant methods include cybernetics, soft systems methodology, interpretative structural modelling, systems engineering and critical or design approaches

Assuming that a problem or situation is indeed complex, various analytic tools and methods can then be applied based on the context. Prominent examples in the literature include, but are not limited to:

- Cybernetics
- Systems Engineering
- Soft Systems Methodology
- Critical Systems Thinking and Practice
- Interpretative Structural Modelling
- Multi-Criteria Decision Methods
- Design Thinking.

These examples are summarised in Annex B. While each has its own strengths and limitations, recurring themes include application of multiple perspective or disciplinary lenses; iterative engagement with and exploration of the environment or problem; identification of system elements and characterisation of the relationships among them; monitoring feedback to refine any prototypical mental or computer-based model, and any associated strategy or plan of action; and a focus on encouraging creativity and critical, lateral or divergent thinking.[114]

Importantly, proponents of such methods emphasise the need to apply their underlying principles not only to a given strategy or plan, but also to the meta-strategy, i.e. the architecture, system or process through which those strategies and plans are developed, and the metrics framework by which the success or failure of implementation is then monitored. This calls for a continuous effort to co-adapt the UK's C2 systems in light of the prototyping and evolving design of the UK's plans and changing understanding of the external environment (including opponents' own C2).

This self-reflexive meta-approach – iteratively engaging with complexity by applying the analytic principles both externally in the operating environment and internally to the C2 organisation in question, and then learning and adapting the approach over time in response to feedback – also bears some similarities to uncertainty-sensitive planning techniques outlined in the next section.

[113] IT Revolution (2021).

[114] Furtado (2019).

5.4.4. There is a related toolkit of well-documented deliberative-analytic methods for grappling with decision making under deep uncertainty

Besides the various methods focused on complexity, there is also a lively international research community working on methods for grappling with uncertainty. This coalesces around the Decision Making Under Deep Uncertainty (DMDU) Society, which provides education and arranges academic conferences, and has clusters of activity primarily within universities (including the graduate school at RAND).[115]

DMDU methods refer to a mix of qualitative and quantitative techniques for making robust decisions in the face of deep uncertainty. This goes beyond consideration of risk (i.e. where the probability and impact of different choices or events is known and where outcomes can be predicted using models) and known unknowns. Instead, contexts of deep uncertainty, as are often found when dealing with complex adaptive systems, are characterised by the absence of knowledge or agreement on:[116]

> (1) the appropriate models to describe the interactions among a system's variables, (2) the probability distributions to represent uncertainty about key variables and parameters in the models, and/or (3) how to value the desirability of alternative outcomes.

In response, DMDU methods prioritise developing strategies, policies or plans that are flexible, adaptive and robust, as a way of minimising the surprise or regret that might be experienced once they are applied in the real world in a highly uncertain future (i.e. FARness).[117] Though many of the methods make use of exploratory modelling and the latest advances in computational methods, they are intended to be scalable and useful even in contexts where data, time or resources are scarce, on the guiding principle that 'any job worth doing is worth doing superficially', as the basis for further deliberation, analysis and refinement.[118]

Prominent methods in the DMDU toolkit include[119]:

- Robust Decision Making (RDM)
- Three Horizon Foresight (3HF)
- Assumption-Based Planning (ABP)
- Dynamic Adaptive Planning (DAP)
- Strategic Portfolio Analysis (SPA)
- Dynamic Adaptive Policy Pathways (DAPP)

Though each of these techniques differs in its specifics, they share a common focus on stress-testing assumptions, considering feedback loops, and examining the possible robustness of strategies, plans, etc., across a wide range of plausible futures (e.g. potentially many thousands of scenarios, if using an exploratory [computer-based] model in support of deliberation with analysis), rather than optimising for a predicted future set of conditions and thus inviting surprise and regret if that predicted future does not come to pass.

[115] Lempert et al. (2013).

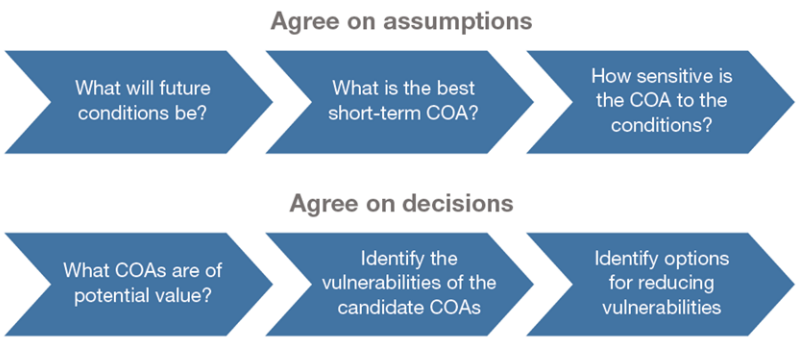
[116] Lempert et al. (2003).

[117] Davis (2014).

[118] Popper (2019a).

[119] Black, Paille et al. (2021).

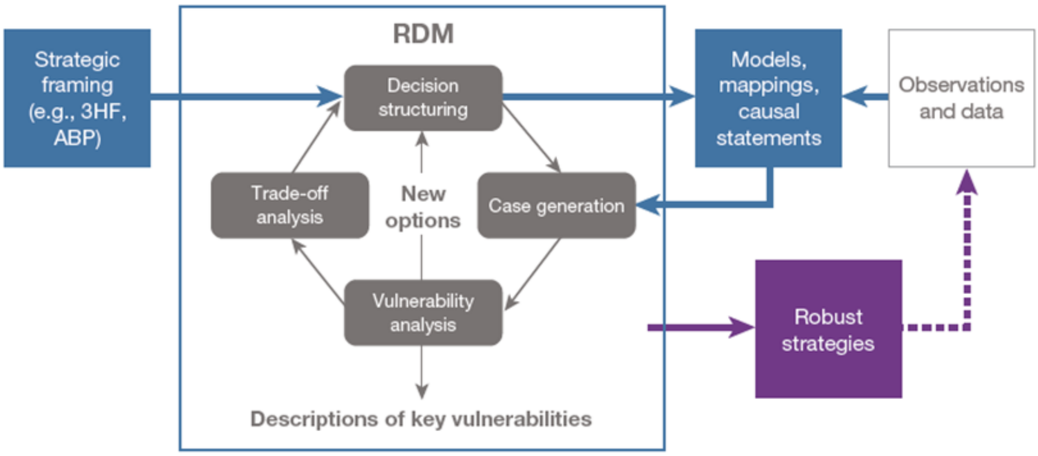
Figure 5.3 Contrast between analytical strategies of optimisation (top) and RDM (below)



Source: Popper (2021, 300). COA: Course of Action.

A summary of each method is provided in Annex D. More detailed discussion of the inputs, steps, strengths and weaknesses of each can be found in a 2021 study commissioned study by Dstl.[120] As with the complexity-centred methods outlined in the previous section, different methods can be used individually or combined to help offset the inherent and recognised limitations of any one approach when grappling with complexity and uncertainty. An example combining RDM, 3HF and ABP is shown below.

Figure 5.4 Defence strategic deliberation combining RDM and other DMDU methods (3HF, ABP)



Source: Popper (2021, 300). Note: 3HF = Three Horizon Foresight. ABP = Assumption-Based Planning.

Of course, for C2 systems and organisations in the future, the application of methods for tackling complexity and understanding does not occur in a vacuum. A military operation is not conducted under perfect laboratory conditions for the application and testing of academic theory. Turning the principles behind these modelling, analysis and strategy or operational design techniques into practice requires compromise, between methodological purism and pragmatism – another of the important lessons from the

[120] Black, Paille et al. (2021).

history of using these techniques in the context of defence C2.[121] Ensuring these methods deliver value also means grappling with a hostile threat environment – including proactive attempts by hostile state and non-state actors to impose complexity, confusion and paralysis on the UK's C2 – as well as the internal barriers to change that hinder any large and complex organisation such as the military. An iterative and adaptive approach is thus required to establish what is most appropriate, recalling the probe-sense-respond model of Cynefin or the notion of sufficiency.[122]

To this end, the next chapter explores some of the major practical considerations for designing C2.

[121] For example, application of the Systemic Operational Design (SOD) methodology, derived from design thinking, within the Israeli Defence Forces led to a debate between purists and pragmatists as to where the optimal balance lay between making the technique as rigorous as possible and making concessions to more traditional planning practices and terminology to build support for SOD among a wider body of IDF officers and other ranks. The US Army's equivalent, the Army Design Methodology (ADM), similarly had some of its language watered down over multiple iterations to make it less esoteric and easier for practitioners to engage with, at the expense of methodological purity. Cf. Annex C and Jackson (2019).

[122] Cynefin.io (2021).

6. Practical considerations for C2 in the future

Building on Chapter 5's discussion of the extant methodological toolkit for grappling with complexity, this chapter examines some of the other practical future design considerations for C2 systems and organisations arising out of PESTLE-M trends in the future operating environment. These reinforce the need to understand C2 as a 'socio-technical system' and a complex adaptive one at that, with changes needed across DLODs to shape this system for the future and cultivate the sorts of properties and capabilities favourable to success.

6.1. Summary

The chapter is summarised in the box below and elaborated upon in the sections that follow.

Box 6.1 Key findings: practical considerations for C2 in the future

Grappling with complex adaptive systems requires a move away from current linear C2 processes and hierarchical structures, though more traditional approaches may retain utility when tackling non-complex tasks and problems. In a competitive world, the UK needs to cultivate both those properties and capabilities that enable it to exert constructive influence on others (e.g. by imposing complexity on opponents' C2) and those which bolster its own capacity to navigate complexity.

Influencing the perceptions, decision making and behaviours of hostile actors begins with a deep understanding of their C2 structures, processes and culture. Informed by this understanding, UK Defence then requires a suite of kinetic and non-kinetic levers to exert constructive influence on adversaries' C2, including to impose complexity. Besides hostile actors, Defence also requires an improved understanding of how to exert constructive influence over PAGs, allies, partners, industry, academia, citizens and others with radically differing approaches to C2.

In terms of bolstering the UK's own capacity to deal with complexity, C2 systems and organisations will need to promote properties such as flexibility, resilience and a capacity for learning and adaptation. Changes are needed across the decision cycle. For example, advances in sensor and communication technologies provide opportunities to capture increased depth and breadth of data, including on complex problems. Improved cognitive capacity is then essential to make sense of all this data, harnessing the benefits of human and machine while mitigating drawbacks of each. Changing approaches to decision making will also require changes in styles of leadership, so as to cultivate decision makers more comfortable with navigating complex adaptive systems. Having made a decision or plan, improving the ability to cut across stovepipes or levels and better integrate activities or converge effects in the implementation phase is essential to offset the UK's limitations (e.g. in terms of mass).

Equally, integration is not a silver bullet; even the most efficient C2 cannot achieve success if Defence lacks sufficient depth of forces and capability to act credibly or to sustain high-tempo operations in a hostile threat landscape. Defensive measures and reversionary and failure modes are also needed to deter or mitigate the impact of hostile efforts to disrupt C2 systems and organisations. Given the threats faced, and the differing forms of complex problems that UK Defence might be called to address, it is likely that there will be multiple parallel models of C2 in play at once, rather than a monolithic approach.

Tackling complexity means continuous learning, adaptation, innovation and openness to change. Measures of effect, signals and mechanisms for change must thus be built into plans and into C2 systems and organisations from the outset to enable them to learn and adapt over time in response to conditions.

Crucially, the design of C2 systems and organisations in the future is only one part of the challenge – they must also be supported by urgent reforms to the wider Defence enterprise to ensure access to the enablers needed (people, technology, etc.). As outlined in Chapter 7, this presents its own challenges from a C2 perspective, given changing this enterprise – a complex adaptive system – is itself a wicked problem.

Source: SASC analysis of Chapter 6 findings.

6.2. Demands on C2 systems and organisations in the future

6.2.1. Complex adaptive systems require a move away from current thinking, though traditional approaches may retain utility when tackling non-complex tasks

As discussed in Chapter 4, complexity poses a series of interrelated challenges to Defence C2 systems and organisations, which are not currently configured to deal with complexity or complex adaptive systems, or for the future threat environment. While there is a range of conceptual frameworks for thinking about and grappling with decision making in the fact of complexity, as outlined in Chapter 5, turning this theory into practical reality requires changes across DLODs. The following sections outline how these might be manifest in a future operating environment defined by complexity, uncertainty and continuous global competition. They begin by considering the offensive dimension discussed in Section 5.3 (i.e. how to influence opponents' C2), before turning inwards (to UK C2).

6.3. Properties and capabilities for exerting influence on others' C2

6.3.1. Influencing the perceptions, decision making and behaviours of hostile actors begins with a deep understanding of their C2 structures, processes and culture

To achieve cognitive and decision advantage over an adversary in this manner necessitates not only improving the UK's C2, but also maximising its ability to shape, slow, disrupt or paralyse opponents. As discussed in Chapter 5, the UK can seek to impose complexity on other actors' C2 through several routes.[123] Exerting such an influence starts with understanding. The literature emphasises the need to understand the

[123] Behzadan & Munir (2017); Lingel et al. (2021).

factors that influence the target actor's bounded rationality, not only in terms of C2 structures and processes, but also the values, norms, culture, behaviours and assumptions that inform their decision-making calculus.[124] Here, it is possible to draw on the extensive literature around strategic culture. This emphasises the need to understand the key stakeholders and processes that shape decision making in a given national or organisational context, their complex web of interrelationships, and the political, ethical, legal and cultural lenses through which information is processed, assumptions are drawn and choices are made.[125] Various methods and tools can be used to achieve such an understanding, involving both intelligence and open-source information, such as the Cultural Topography Analytical Framework (CTAF).[126]

An actor's strategic culture and, relatedly but at a lower level, its approach to operational art do not exist in a vacuum. They are also influenced by external developments, not least in terms of the perceived threat. There is an extensive body of theory and empirical research into the role of perception and signalling in shaping the assumptions that the UK and its opponents make about each other (e.g. as part of deterrence theory).[127] Crucially, this literature emphasises the decisive role of imperfect information in decision making, and the importance of ever-changing asymmetries in the levels of knowledge and certainty available to each party about their respective intentions, capabilities and levels of mutual understanding. This introduces various opportunities to exert constructive influence to shape others' thinking, and potential pitfalls in terms of misguided interventions that lead to unintended escalation.[128]

This extends to understanding specifically how the adversary understands contemporary competition or conflict dynamics, and the role of complexity and systems theory in their conceptual or planning approach.[129] By understanding in detail how its opponents understand and seek to shape complex adaptive systems, if they do at all, the UK can thereby target interventions to confound those hostile actors' efforts (e.g. by reducing the function of any monitoring systems they have established to monitor signals of changing conditions, or by targeting key nodes or linkages that affect their capacity for adaptation on the basis of those signals) as well as to reduce the likelihood of sending the wrong signals and thus causing accidental escalation or some other negative outcome. This forms the basis for an informed and robust approach to 'systems confrontation' or 'systems warfare' tailored to the target audience in question.[130]

Importantly, the potential for manipulation also extends to machine agents. There is an extensive literature on the threat of hostile actors manipulating or poisoning the training data used to develop AI and ML systems, in addition to the risk of accidental and non-malicious introduction of biases.[131] This includes a subset of the literature specifically focused on understanding the attack surface and threat vectors associated with adversarial attacks on complex adaptive systems. Examples include dynamic attacks with AI that are designed to fool and induce the adversary's deep reinforcement learning systems (a type of neural network) to come to policy or planning decisions hostile to the interests of their owners/users.[132]

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[124] Grisogono (2019).

[125] Snyder (1977); Lantis (2009); Covington (2016).

[126] Johnson & Maines (2018).

[127] Schelling (1966); Jervis (1976).

[128] Triezenberg (2017).

[129] Mazarr (2022).

[130] Engstrom (2018).

[131] Hofman & Kim (2022).

[132] Behzadan & Munir (2017).

6.3.2. Informed by this understanding, UK Defence requires a suite of levers to exert constructive influence on adversaries' C2, including to impose complexity

Having understood the culture, structures, processes and algorithms that shape hostile actors' C2, including both its human and machine elements as a combined 'socio-technical system', the UK can then seek to target key nodes and linkages with relevant effects to influence those opponents' capacity to make and enact decisions in the UK's favour. As detailed by Lingel et al. (2021), this broader attempt at C2 warfare[133] can include, but is certainly not limited to, conscious efforts to impose complexity on other actors, such as through proactive measures to degrade their operational picture, impair their response, span boundaries or leverage non-linearities.

To achieve this across the differing levels of warfare (i.e. from the tactical to the strategic) and in differing contexts, C2 systems and organisations in the future will require access to a broad range of kinetic and non-kinetic effects. It is beyond the scope of this short study to assess the optimal balance of investment across different DIME levers or, within the military instrument, across domains and capability areas. Nonetheless, the literature expects not only continued development of more traditional effectors (e.g. platforms, missiles, etc.) but also novel ones (e.g. directed energy weapons, hypersonic glide vehicles, etc.), as well as improved offensive capabilities in the emerging domains (cyber and electromagnetic, and space).[134] This includes a focus on increasing the UK's ability to deliver effects at standoff ranges, as well as at speed, and ideally with scalable (and in some cases even reversible) effects. Such investment and innovation should yield a wider range of potential means for delivering effect, both military and non-military in nature.[135]

As will be expanded upon in Section 6.4, the UK requires not only a suite of improved effectors, but also the ways and means of integrating these with sensors, networks and C2 to maximise their impact on the adversary's decision making by converging effects at the right time and place.

6.3.3. UK Defence also requires an improved understanding of how to exert constructive influence over partners and allies with differing approaches to C2

Just as the UK needs to understand other actors' approach to C2 in order to disrupt or shape them, so Defence needs to better understand how to exert constructive influence over partners as part of its own C2.[136] The literature emphasises the need for whole-of-government or even whole-of-society responses to complex problems such as warfare, terrorism, disinformation or climate change.[137] Official documents are replete with references to this concept, variously labelled integrated delivery by the UK (replacing the terminology of Fusion Doctrine[138]), the comprehensive approach by NATO, or the integrated approach by the EU[139] – with related notions of Total Defence or comprehensive security found in northern European

[133] Hutcherson (1994); Struble (1995); High (1997); Granasen et al. (2011).

[134] UK MOD (2023a).

[135] For a recent DCDC-commissioned study on the topic, see: Black, Lucas & Stockwell (2021).

[136] Priebe et al. (2020); Cook et al. (2022).

[137] Gentzel et al. (2021); Rasmussen (2021).

[138] UK MOD (2018d).

[139] Slapakova, Stockwell et al. (2022).

countries and elsewhere.[140] The recent experience of COVID-19 also provides relevant lessons in C2 and health systems engineering.[141]

Such approaches emphasise the need to break down stovepipes between the military and other parts of government, as well as to integrate international allies and partners and various categories of non-state actor (e.g. private security companies, proxy groups, industry, academia, NGOs, media, individual citizens).[142] They cut across sectors to encourage information sharing, collaborative problem-solving among a diverse set of stakeholders and experts, and the collective implementation of actions using all available levers. If successful, this would subvert many of the common problems posed by complexity. Traditionally, for example, C2 constructs driven by component-centred planning can risk insufficient expertise in all domains. Additionally, they can promote preferences against all-domain solutions of the kind needed to apply a systems thinking lens. Additionally, control over multi-domain or wider DIME capabilities is often divided among components, which increases internal complexity. Widening the scope of decision making and implementation to external entities could secure greater domain expertise and decrease internal complexity.[143]

Conversely, achieving effective interagency working within government, let alone coordination with other types of actors, remains a significant challenge. Overcoming it necessitates spanning boundaries in terms of organisational structures, technical systems, working cultures, language and more – a major contributor to increased complexity in C2 systems, recalling Lingel et al. (2021). This challenges the military view of C2, given Defence can neither command nor control the rest of government (let alone partner nations or non-state actors) in the traditional manner, and must instead seek to understand how it can influence, shape, encourage, incentivise and collaborate in a more flexible, non-hierarchical and fluid manner.

To inform such efforts, as the basis for integrated action of the kind expanded upon in Section 6.4, Defence must start with an improved understanding of C2 approaches and culture within other types of organisation, viewing these as complex adaptive systems in their own right, and seeking to better inform Defence personnel on how to navigate and influence these, as well as how military and non-military components of an integrated approach can best co-adapt over time. Recent research for Dstl has developed guidance for improved collaboration with PAGs.[144] This emphasises the need for a comprehensive understanding of the similarities and differences between the goals, assumptions, biases, values, structures, processes, culture, career pathways and incentive structures of PAGs to inform Defence personnel's efforts to shape these in a constructive and targeted manner (and minimise the risk of pushback or territorialism).

At the same time as better understanding the complexities of interfacing with and exerting influence over the complex adaptive systems of partner C2 systems, or civilian equivalents, Defence will also need to reflect on how it is perceived by those with whom it is seeking to collaborate. The literature emphasises not only barriers to working with Defence (e.g. reticence by civilian agencies to see the securitisation or militarisation of a policy problem, or opposition from tech firms to working with the military on ethical grounds), but also the risks of doing so in the wrong manner (e.g. civilians wrongly deferring to and

[140] Finnish Security Committee (n.d.); Swedish Government (2021).

[141] During the COVID-19 pandemic, several countries including the UK attempted with varying levels of success to adopt a whole of society approach, often including comprehensive testing and quarantine protocols, a nationwide vaccination programme, widespread school closure, public education through mass media, enhanced border controls, and protections for the economy and households. This involves extensive engagement of military personnel in planning and coordination functions. Cf. Dubb (2020); Bremmer (2021).

[142] Dubb (2020); Cook et al. (2022).

[143] Priebe et al. (2020).

[144] Slapakova, Stockwell et al. (2022).

assuming that military planning processes and C2 structures are appropriate for a given problem, just because civilian agencies lack equivalents – e.g. to a J5 – or the same level of experience and codified doctrine for running operations).[145] UK Defence thus requires an understanding of its 'value proposition' to other entities it wants to integrate within C2 systems and processes in the future: what does it offer, where does it bring something unique to the table, and what are the incentives for others to work with UK Defence given their own goals and values?[146]

6.4. Properties and capabilities for navigating complexity in our own C2

6.4.1. C2 systems and organisations in the future must promote key overarching properties such as flexibility, resilience and a capacity for learning and adaptation

The literature highlights a variety of implications from change and complexity for the design of C2 systems and organisations in the future. This includes some relatively mature – or at least part-funded – visions for the United States, such as the DoD's concept for JADC2 and its associated implementation strategy and change programmes.[147] There is, however, less clarity on the future vision for C2 in the UK, or among other medium powers (e.g. France), given constraints on funding, people, technology and other essential inputs. The UK arguably faces one of the toughest dilemmas: achieving sufficient size to be a globally deployable and highly capable military force, though unable to replicate the US approach in full. However, it lacks the scale, redundancy or many of the input resources needed to make more ambitious visions of C2 a success without extensive cooperation. Additionally, the UK must still maintain sufficient size to be able to avoid having to accept a more junior or passive role in adopting, rather than shaping, circumstances imposed upon it by the United States and/or NATO.

Nonetheless, there are several recurring themes in the literature, in terms of properties for any future approach to C2 to promote. These include attributes such as:

- A systems-thinking approach and ability to leverage tools such as those discussed in Section 5.4
- Robustness
- Agility
- Flexibility in structure and process (e.g. hierarchical where needed, non-hierarchical where not)
- Resilience
- Improved cognitive capacity
- Improved awareness of assumptions and potential shocks
- Improved comfort with uncertainty, risk, ambiguity and non-linear dynamics
- Improved data and information sharing, fusion and security
- Improved monitoring of signals and feedback loops

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145 Ellery & Saunders (2020).

146 This applies also to 'own-collaborate-access' decisions about developing C2 capability. Retter et al. (2022).

147 US Congressional Research Service (2022); US DoD (2022); Priebe et al. (2020); Zeigler et al. (2021).

- The capacity for learning and adaptation over time, in response to those signals
- The capacity for innovation and more rapid acquisition or development of new capability
- The ability to leverage a greater diversity of perspectives, skills, expertise and inputs, both from within and beyond Defence itself (e.g. to include PAGs, allies, partners, industry, academia, other)
- Affordability and feasibility (technical, bureaucratic, legal, ethical, political, etc.).

These cut across the full cycle of sensing, sense-making and action, as explored in the sections below.

6.4.2. Advances in sensor and communication technologies provide opportunities to capture increased depth and breadth of data, including on complex problems

Sense-making is impossible without sensing. Access to accurate, real-time data on the environment and the entities and events therein is essential for any military operation. As stressed by the Cynefin framework, however, effective sensing is especially important when tackling situations of complexity or chaos, given the lack of expertise or established good or best practice to guide decision making. Instead, tackling such situations rests on an ability to rapidly gather, fuse and act on sensor data to begin to understand the pertinent system dynamics and feedback loops, thereby informing iterative learning and adaptation of a strategy or operational plan over time (through the model of probe-sense-respond).[148]

Continuing advances in sensor technology open new possibilities for the 2030s and beyond. These include improvements in established types of sensors (e.g. radar, sonar, electro-optic), as well as the emergence of novel categories such as quantum sensing. Crucially, innovation is not focused solely on improving sensor performance, but also on reducing space, weight and power requirements as well as cost, including through use of novel materials, advanced manufacturing techniques and dual-use technologies. It is also leveraging comparatively under-utilised domains and environments, such as through use of satellite constellations in low-Earth orbit or other regimes, or uncrewed high-altitude pseudo-satellites (HAPS) within the Earth's atmosphere, in lieu of traditional airbreathing ISR platforms, or use of wearable or biosensors on personnel.

For C2 systems and organisations in the future, this implies not only the deployment of an increasing variety of military sensors with improved performance (e.g. range, fidelity, ability to operate in adverse conditions), but also a need to navigate the benefits and risks associated with operating in an environment pervaded by civil and dual-use sensors. These include not only today's smartphones and civilian uncrewed assets (drones), but also the proliferation of cyber-physical systems and the Internet of Things, along with mass digital surveillance using Big Data and associated technologies of the kind outlined in Section 3.2.

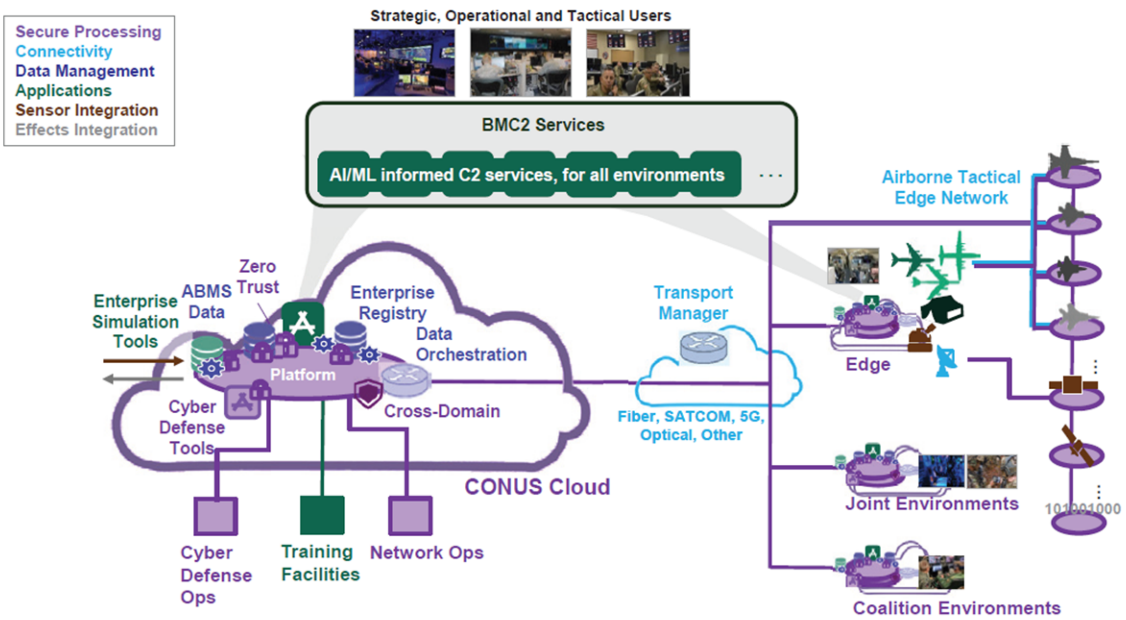
This proliferation of sensors and data presents substantial potential benefits to C2 in terms of understanding complex and complex adaptive systems, capturing a huge volume and variety of data which C2 systems can use to feed modelling, simulation and decision support tools. But it also introduces a variety of risks, ranging from cognitive overload to the obvious survivability challenges of operating in a more transparent battlefield, as will be discussed in more detail below. First and foremost, however, future demands on C2 require systems being able to collate and move sensor data in a timely and secure manner to then make sense of and exploit it.

Within this requirement, different levels of hierarchy, flexibility, agility, connectivity and resilience may be necessary depending on the operating environment in question and the nature of the data, networks, entities

[148] Cynefin.io (2021).

and threats involved.[149] Advances in ICTs (e.g. 6G, SATCOM, fibre, optical), cloud and edge computing, encryption, cybersecurity and other technologies could all help to improve bandwidth, reduce latency and enhance the size, efficiency and resilience of networks. They could also enable a shift in the fundamental philosophy around sharing and security (e.g. to secure the data rather than the network, to enable networks to heal and reconfigure themselves in the event of attack or disruption, and to move to a zero-trust model while also enabling allies, PAGs and others to contribute to and access relevant subsets of data, including open-source, even without security clearances).[150] This opens the potential of connecting a sensing grid across all domains to relevant processing and effector nodes to enable rapid sense and decision making and then convergence of multi-domain effects on the relevant targets. To this end, the United States is seeking to develop a 'military Internet of Things' and Advanced Battle Management System (ABMS) architecture, as part of ongoing efforts to develop JADC2 (see Figure 6.1), while NATO is exploring similar technologies as it considers the future of Federated Mission Networking (FMN).

Figure 6.1 Concept for US Advanced Battle Management System architecture



Source: US Department of the Air Force's Rapid Capabilities Office, cit. in National Academies of Sciences, Engineering and Medicine (2022, 38). Note: CONUS = Continental United States; BMC2 = Battle Management Command and Control; SATCOM = Satellite communications; 5G = Fifth-generation telecommunications.

If brought to fruition, advances in sensor, computing and network technologies and architectures could contribute to tackling complexity in a variety of ways: enabling a common operating picture and improved understanding of complex systems and their underlying dynamics and non-linearities; more proactive recognition of risks and uncertainties; and enhanced monitoring of feedback loops and measures of effect to inform iterative improvements to plans. Realising this ambitious vision of C2, however, requires navigating substantial risks and putting in place a range of enablers, as discussed below.

[149] Tran et al. (2015); Lucas et al. (2022).
[150] Cook et al. (2022).

6.4.3. Improved cognitive capacity is needed to make sense of all this data, harnessing the benefits of human and machine while mitigating the drawbacks

A profusion of data, and challenges to the integrity and trustworthiness of that data, strain finite cognitive capacity and risk information overload and decision paralysis. The first challenge for C2 is bolstering raw processing power and the ability to clean, fuse and analyse this data. To this end, continuing advances in information technology offer the potential for improved processing power, along with Big Data analytics, as well as new options over whether this occurs at the edge or in the cloud.[151] While there is uncertainty over whether the rate of growth in processing power, hitherto characterised by Moore's Law,[152] can be sustained using classical computing paradigms and silicon-based manufacturing, there are potential new opportunities for C2 associated with quantum computing or other innovations (e.g. biocomputing).[153]

Besides ensuring that C2 organisations in the future have access to improved data fusion, storage and processing capabilities, there follows the vital question of how that data is turned into analysis and insight, and subsequently into a decision – or whether this is even the right paradigm for thinking about information science and management.[154] Here, the literature emphasises the need to integrate people and technology, harnessing the benefits of human–machine teaming, rather than to merely emphasise one over the other.

- Combating cognitive bias: To tackle complex problems, personnel will need to be selected, developed and trained to minimise the impact of cognitive biases, and analysis, planning and decision-making processes designed accordingly. This will require greater comfort with challenge, uncertainty, ambiguity and thinking about non-linear dynamics. (See Section 6.4.4 for further discussion of the types of traits required among future leaders and others involved in C2.)
- Building diverse and effective teams: Relatedly, C2 systems and organisations will need to cultivate effective cross-disciplinary teams, bringing together expertise not only from across the Services or domains, but also the DIME levers more broadly, and to include both human and machine agents, if they are to understand, navigate and shape complex adaptive systems.[155] These teams should lead on proactive learning and sharing lessons learned as they accumulate knowledge and various points of view related to problem-solving.[156]
- Modelling, simulation and data visualisation: Advances in fields such as modelling and simulation (M&S), virtual, augmented or mixed reality (AR/VR/MR) or synthetic environments and the metaverse, offer potential new ways of supporting informed and efficient decision making in future HQs – if implemented correctly.[157] Such technologies offer potential benefits in terms of sifting and prioritising the information fed to decision makers based on context and the need to avoid cognitive overload. They can also support visualisation of the dynamics of a complex system and development of a simulation of the possible cascading consequences of alternative courses of action, especially if the underlying models can be run many times faster than real time, to enable robust approaches to decision making (see Annex D). Such tools also open up opportunities in

[151] Bouhafa & Hess (2017): Williams & Hess (2017); Saur (2021); Rieks & Mannheim (2022).

[152] This refers to a prediction by Gordon Moore in 1965, since popularised as 'Moore's law', that circuit complexity – and thus processing power – can be expected to double every 18–24 months. Cf. Encyclopaedia Britannica (2023).

[153] Krelina (2021).

[154] Frické (2009).

[155] Balis & O'Neill (2022).

[156] Gitelman et al. (2020).

[157] Eversden (2022).

terms of remote and collaborative working with distributed teams, and use of wearable sensors and other aids to track, analyse and enhance the individual and group performance of those personnel involved in C2 processes, informing continuous improvement.[158] Equally, there are a host of potential dependencies introduced by increasing use of – and reliance upon – new technologies, as well as the enduring risk that these will bake in further biases. For instance, this could be an issue if the user interface or experience (UI/UX) leads decision makers to place too much focus on or trust in certain data feeds over other sources, or if the use of modern visualisation tools leads to overconfidence in people's ability to comprehend or predict emergent behaviours. Here, there are potential lessons to be learned from the observed pros, cons and risks of integrating data visualisation tools in other high-pressure, high-risk contexts (e.g. pilots, surgeons, nuclear safety). Importantly, too, C2 organisations will need access to and familiarity with reversionary modes – balancing resilience and efficiency as appropriate (see Section 6.4.8).

- Exploiting the benefits of AI and autonomy: Recent years have seen significant advances in AI and ML, including most recently the high-profile rollout of large language models such as ChatGPT-4. It is expected that AI and autonomy will play a growing role in C2 activities across the spectrum of operations. However, it is important to note that such technologies should not be seen as a 'silver bullet' for either data analysis or decision making. C2 systems will involve anthropotechnic elements as technological and human elements interact on, and between, multiple levels.[159] Autonomous systems are also likely to be present in increasing number and variety across all domains, serving as sensing nodes or strike assets. This deepening use of AI for decision support or decision making, and autonomous systems for execution, presents both opportunities and challenges, as even human oversight may not prevent misuse. Similarly, the possibility of increasing dependency on machines, and the possibility that their function may be poorly understood, or their underlying training data poisoned, is likely to unintentionally lead to further complexity.[160]
- Maintaining a human in or on the loop: There is an extensive and ongoing debate within the academic literature, as well as in international institutions, over the appropriate governance of AI (focusing on narrow AI in the near term, but also considering the severe, potentially existential, risks associated with AGI or ASI). This is not only a pressing policy, legal and ethical question for society in general. It also specifically relates to the question of complexity as applied to C2. As emphasised in the literature, managing AI within C2 systems and organisations will itself be a highly complex endeavour.[161] A recent Center for Security and Emerging Technology report gives examples of how AI may, ironically, drive greater complexity and uncertainty into decision making, contributing to problematic feedback loops, cascading effects and escalation risks:

> Offensive operations incorporating AI or interfering with an adversary's AI systems could result in unforeseen system failures and cascading effects, triggering *accidental escalation*. AI systems that are insecure, inadequately trained, or applied to the wrong types of problems could inject bad information into decision-making processes, leading to *inadvertent escalation*. Discovery of a compromise of an AI system could

[158] For a practical example, see NATO C2COE's Multi-Domain Operations C2 Demonstrator, which aims to demonstrate how a future command post might make use of virtual reality. Source: NATO C2COE (2020).

[159] Claverie & Desclaux (2022).

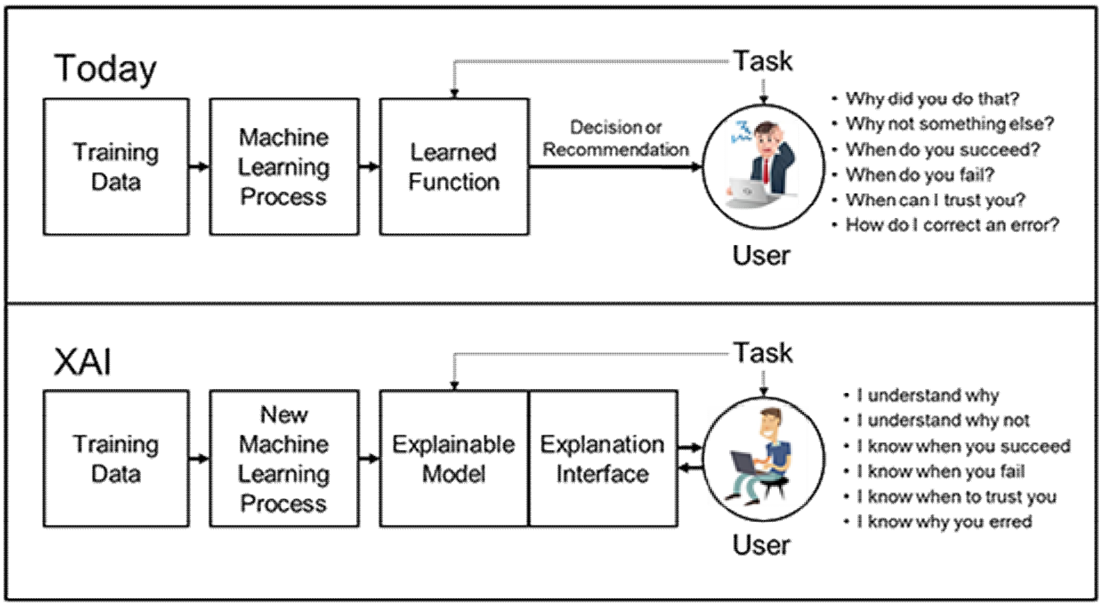
[160] Balis & O'Neill (2022).

[161] Segran (2021).

generate uncertainties about the reliability or survivability of critical capabilities, driving decision makers toward *deliberate escalation* if conflict appears imminent.[162]

This leads to a dilemma: 'decision makers want to use AI to reduce uncertainty, especially when it comes to their awareness of the battlefield, knowing their adversaries' intentions and capabilities, or understanding their own capacity to withstand an attack… [but] they introduce a new source of uncertainty in the likelihood and consequences of technical failures in AI systems.'[163] To offset this, the literature emphasises the enduring need for a human 'in' or 'on the loop' for major operational decisions, especially where these relate to use of force.[164] In addition, C2 systems and organisations will need appropriate governance, standards, guidance and training in place to ensure there are appropriate safeguards around the use of AI in different contexts (e.g. building on the Ethical Principles for AI outlined in the UK MOD's first *Defence AI Strategy*).[165] Personnel will also be required to have appropriate understanding of the strengths and limitations of AI and how to identify and mitigate any system failures. Advances in fields such as AI safety and explainable AI can also help here (see Figure 6.2), combating the 'black box' effect and making it easier for humans to understand the logic behind, and flaws in, AI systems' decision making, and thereby contributing to greater traceability and trust.[166] Nonetheless, significant further work will be required to address the enduring issues around validation and verification (V&V), and thus to enable Defence to sign off on the risks associated with using AI systems in certain mission contexts, especially when considering the inherent challenges of V&V for non-deterministic AI.[167]

Figure 6.2 DARPA's Explainable AI (XAI) model



162 Hoffman & Kim (2023, 1).

163 Hoffman & Kim (2023).

164 Scharre (2018); Payne (2022).

165 UK MOD (2022b).

166 Turek (2018); Rudner & Toner (2021); Scheerer & Reussner (2021).

167 Nielsen (2019).

Source: Turek (2018).

- Mitigating adversaries' more permissive approaches to HMT: Crucially, the UK's integration of AI and autonomy into its C2 systems and organisations will not be occurring in a vacuum. This development process will be shaped not only by broader societal uptake of, cultural responses to and governance approaches for AI, but also by the continuous competition for advantage and other actors' incorporation of AI into their own C2.[168] As such, the UK will require ways of identifying and mitigating the vulnerabilities that its own use of AI and autonomy introduces into its C2 systems, and simultaneously seeking to counter opponents' own use of AI, especially since it is likely that the UK and its Allies will face adversaries with fewer policy, legal or ethical restrictions on maintaining a human in or on the loop. Such situations may provide adversaries with significant tactical benefits (e.g. faster decision-making times, unencumbered by the need to reach back to and wait on a human commander), in which case the UK will require ways and means of nullifying opponents' advantage. These can and should be asymmetric (e.g. seeking to deter, disrupt or otherwise counteract hostile use of AI and fully autonomous systems, or to gain advantages in other areas), rather than necessarily involving watering down the UK's own constraints on the use of such technologies, which could be incompatible with its values or its legal and regulatory obligations.[169]

6.4.4. Changing approaches to decision making also requires changes in leadership to cultivate decision makers comfortable with navigating complexity

Effective HMT also entails cultivating effective analysts, decision makers and other categories of generalist or specialist personnel who will be involved in C2. The literature emphasises qualities such as:

- Leadership over management: This is seen a necessary property for dealing with complex situations and problems.[170] Leadership in the face of complexity requires a flexible and dynamic hierarchical structure to adapt and respond to new conditions, rather than a rigid focus on standardisation, bureaucracy and compliance. Leaders should be capable of coordinating complex dynamics and establishing group interactions which generate creative ideas and are open to challenge.[171]
- Diversity of expertise: New forms of technical knowledge and skills are likely to be required to exploit new technologies (e.g. AI) and domains (e.g. space) and apply the latest tools and techniques for grappling with complex problems (see Annexes C and D). Professional military education and training should evolve accordingly, with examples including greater emphasis on data literacy, as well as adaptability, problem-solving, communication and cross-domain effects.[172]
- Diversity of thought: There is also a growing body of empirical research highlighting the benefits of increased diversity of thought in a military context. This increases the range of perspectives brought to bear on a complex problem, encourages constructive challenge, counters groupthink

[168] Allison & Schmidt (2020).

[169] UK MOD (2022a).

[170] White (2016).

[171] Baltaci & Balci (2017).

[172] Nisperos (2020); Balis & O'Neill (2022).

and other cognitive biases, and offers other practical benefits such as a larger recruiting pool.[173] This includes also harnessing neurodiversity, especially in roles well-suited to such viewpoints.[174]

- Diversity of approaches to collaboration: The literature suggests that multiple leadership styles may need to be promoted within a more federated system that supports the flexible allocation of roles and responsibilities to those best placed to effectively respond (as with Cynefin). Leaders should further reduce internal complexity as much as possible through changing structures, processes and governance systems for their C2 cell or headquarters. Power and responsibility within the team or organisation should be reallocated as needed to ensure timely and appropriate reactions to changes, whilst also upskilling staff to perform new and unfamiliar tasks, as is likely in complex situations.[175]
- Creativity, experimentation and imagination: A key future capability will be C2 networks containing staff who are intellectually and psychologically prepared to confront wicked problems. The lack of experience on which to gauge actions is one prominent element of such a problem. Open-mindedness and non-linear thinking are therefore important, alongside a willingness to conceive of the issue at hand beyond existing frames of reference when facing complexity.[176]
- Culture of informed risk management rather than risk avoidance: Personnel involved in C2 should have a sense of clear purpose and ambition, and should be able to take risk and bear responsibility for unconventional solutions. Failure should not be conflated with incompetence; instead, 'failing fast' to test radical ideas should be commonplace as the basis for iterative learning.[177]

6.4.5. Having the ability and authority to cut across stovepipes or levels and converge effects is essential to offset limitations in the implementation phase

Once a strategy or operational plan has been developed, or a tactical decision made, this then needs to be translated into efficient and timely effect. Here, the literature emphasises the need for improvements to how C2 systems and organisations will function[178]:

- Orchestrate multi-domain operations across the joint force and beyond (i.e. through an integrated or comprehensive approach).
- Integrate effects occurring through or across multiple domains and environments.
- Concentrate distributed forces or effects at the decisive point (assuming there is one), accounting for time and space considerations (including the unique dynamics of environments such as cyberspace and outer space, which can have long or uncertain lead times to deliver certain effects).

[173] Slapakova, Caves et al. (2022).
[174] Weinbaum et al. (2023).
[175] Gitelman et al. (2020).
[176] Duczynski et al. (2021).
[177] Meddings (2020); Narbutovskih (2020); Tucholski (2021).
[178] Stegall (2020); Segal (2023).

This places central importance on the concept of convergence.[179] It also speaks to the need to address not only technical or cultural barriers to interoperability within an interagency taskforce or coalition (see Section 6.3 on exerting constructive influence on different categories of actor and achieving effective non-hierarchical collaboration, as opposed to linear C2), but also to clarify and delegate authorities.[180] Realising the ambitious visions of C2 and their integrated delivery of multi-domain effects in this manner relies on overcoming any issues associated with policies and permissions, especially for those capabilities typically held at a higher level (e.g. offensive cyber) and/or requiring PAG, allied or political approvals. This also includes clarifying the delegated authorities and permissions for machine agents, including lethal autonomous weapons systems as an especially contentious subset of this policy, legal and ethical problem.[181]

Crucially, too, C2 systems and organisations will need to deal with authorities and permissions changing rapidly, perhaps repeatedly, not only as FOEs evolve but also as shifting threats and conditions enable a more or less networked and thus more centralised or distributed approach to C2 (see Section 6.4.8).

6.4.6. Even the most efficient C2 cannot achieve success if Defence lacks the capability to act credibly or to sustain operations

Though better integrating C2 (whether across domains, nations or the DIME levers) offers many benefits, it is important to remember that there is an irreducible minimum level of capability and mass required to withstand the pressures of the future operating environment. Defence could develop a fully optimised C2 system and set of processes fully capable of understanding and navigating complexity, and of achieving information and decision advantage over the adversary, but these would still be insufficient if not supported by adequate deployable forces held at readiness for the onset of an operation and with a commensurate ability to sustain and, if necessary, re-arm and replenish them over the course of a sustained fight.[182]

For the UK, pursuing qualitative advantage through, inter alia, superior C2 and decision making in the face of complexity is a prudent asymmetric response to adversaries with quantitative advantages (in terms of population, GDP, military forces, etc.). Nonetheless, the logic of an offset strategy can only be pushed so far. The literature emphasises the importance of resilience and redundancy to cope with shocks and the need for sustained, long-term campaigns to tackle complex problems; this suggests an enduring need for mass as well as quality. To this end, new technologies, such as uncrewed systems and AI/ML, offer potential help in the form of lower-cost means of building mass, but do not erase the need for sustained investment. This is especially pertinent when discussing the effectors that reconnaissance-fires complexes can employ, with the literature revealing an enduring debate about the appropriate balance between (highly expensive) precision fires and (cheap but plentiful) massed fires.[183]

Ultimately, however, precision vs. mass is a false dichotomy. Instead, C2 systems and organisations will likely need to integrate a heterogeneous 'high-low mix'; with a small number of nodes in the sensing or effector grids being expensive but exquisite high-end capabilities, and a larger number being lower-cost, attritable, or even single-use.[184] Here, the literature explicitly links growing pressures on defence budgets

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[179] According to the US Army's *Field Manual (FM) 3-0 Operations*, 'Convergence is an outcome created by the concerted employment of capabilities from multiple domains and echelons against combinations of decisive points in any domain to create effects against a system, formation, decision maker, or in a specific geographic area.' Cf. US Department of the Army (2022).

[180] Black & Lynch (2022).

[181] Hoffman & Kim (2023).

[182] Barnes & Stickings (2018).

[183] Alman & Venable (2020); Gouré (2022); Hasik (2023).

[184] Seip (2020); Bledsoe & Benitez (2017a).

and procurement to increasing complexity – specifically, the non-linear dynamics and problematic feedback loops that are associated with the increasing technological complexity of military platforms and, relatedly, the industrial programmes that deliver them. This 'rampant and self-reinforcing spiral of cost, complexity, and capability'[185] contributes to both inter-generational cost escalation and intra-programme cost growth.[186] 'If complexity is the disease, then high cost, low production rates, low readiness, and low adaptability are the symptoms.' Future success will thus rest not only on improved C2 to deal with external drivers of complexity, but also on improved management of internal drivers such as misaligned bureaucratic and industrial incentives around designing and developing a new capability. Only a revised approach to force and capability development that finds a better balance between complexity, cost, mass, risk and schedule can provide the outputs (i.e. force elements at readiness) needed to make any future vision of C2 a reality.

6.4.7. Defensive measures and reversionary and failure modes are needed to deter or mitigate the impact of hostile efforts to disrupt C2

C2 systems will need to be designed with a deteriorating threat environment in mind. There is extensive literature on the growing kinetic and non-kinetic threats from both state and non-state actors.[187] Meanwhile, the academic research on complexity and, relatedly, on deep uncertainty, emphasises the need for C2 systems and organisations to deal with the likelihood of disruption, surprise or shocks caused not only by anthropogenic threats but also broader hazards, risks and uncertainties.[188]

To deal with the anthropogenic threats, there are several response options available[189]:

- Non- or counter-proliferation: Preventing opponents from developing or acquiring the capabilities needed to threaten key nodes or linkages within, or imposing complexity upon, UK C2 systems and organisations. While some of the levers associated with achieving this sit outside of direct Defence control (e.g. use of diplomacy), there are also more active interdiction options available.
- Deterrence: Seeking to dissuade hostile actors from undertaking actions that would disrupt the UK's C2 or increase complexity (e.g. by degrading the operational picture, etc.).
- Counter force: Targeting hostile actors' counter-C2 capabilities before they can be employed.
- Active defence: Intercepting or countering counter-C2 capabilities before they affect a target.
- Passive defence: Reducing the impact of counter-C2 capabilities, for example by dispersal, camouflage or physical hardening of C2 nodes, improved cyber defences and electronic countermeasures, or broader efforts to improve resilience (e.g. redundancy, reversionary modes).

Tailoring an appropriate suite of defensive measures across these categories will necessitate a strong level of self-knowledge from C2 systems, as to the threat vectors, attack surface, vulnerabilities and dependencies inherent in their organisational structure, processes, technologies and other aspects. This again underscores the need to conceive of C2 as a socio-technical system, and a complex adaptive one at that, and thereby guide analysis of possible cascading second- and third-order effects from any threat.

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[185] Retter et al. (2017).

[186] Bledsoe & Benitez (2017b).

[187] Donaldson & Sciarini (2019a; 2019b).

[188] Davies (2014); Lempert (2019); Marchau et al. (2019).

[189] These categories reflect the Five Pillars Framework developed by the UK's Missile Defence Centre, in relation to ballistic missile defence, but are more broadly applicable.

6.4.8. It is likely that there will be multiple parallel models of C2 in play at once, rather than a monolithic approach

Resilience is not simply about improved defences against hostile efforts to disrupt the UK's C2 or to impose complexity upon it. It is also about the robustness of the UK's strategies and operational plans to deal with complexity, change and uncertainty more generally; identifying early warning signs; building in mechanisms for learning and adapting over time; and having sufficient enablers in terms of people, technology and infrastructure (see Sections 6.4.8 and 6.4.9). Importantly, efforts to enhance C2 resilience must be balanced against the countervailing imperative to maximise C2 efficiency. This is because it is neither possible nor desirable to protect C2 networks and systems against all threats all the time. Instead, there are trade-offs:

- Undertaking extensive efforts to harden C2 nodes (e.g. headquarters) against physical, cyber or electronic attack, for example, may mean they are less mobile or easy to conceal. Any investment in defences for these key nodes would also consume finite resources that could otherwise have been devoted towards developing many smaller, dispersed C2 nodes to ensure resilience and fall-back options should these defences fail.
- Conversely, distribution and dispersal may boost survivability by complicating the adversary's targeting decisions, but physical distance between forces entails a greater need for secure communication information systems (CIS). This requirement, in turn, drives new demands for signature management, electronic and cyber defences, and reversionary modes, as well as for a resilient network architecture and approach to data management and security.
- While advances in technology of the kind described above can assist here, they also add complexity to the overall C2 system and introduce new critical dependencies and vulnerabilities, which may be poorly understood. Any redundancies are also, by definition, potentially redundant, placing added strain on the finite financial, technical and human resources allocated to developing C2 capability – even if they may offer greater value for money in the long term compared to an efficiency-optimised, cost-minimising approach.

Determining the balance to strike between C2 resilience and C2 efficiency is thus not straightforward. The literature suggests that there is no single answer. Rather than optimising C2 systems and organisations for a narrow set of criteria, missions or operating environments, Defence may need to cultivate FARness[190] by developing the ability to employ multiple forms of C2 at once, each variant's compromise between resilience and efficiency tailored to its specific context (in particular, the complexity of the problem at hand and the nature of the threats faced), and with in-built capacity to transition between forms as conditions change.[191]

This recalls work within Dstl to develop a C2 Resilience Response Framework, envisaging multiple 'C2 states' that would apply depending on how benign, contested or denied the operating environment is in a given space and time, both in terms of kinetic threats and the ability of UK forces to securely and safely use the electromagnetic spectrum.[192] In this vein, C2 systems grappling with complex, changing and uncertain conditions will need to take multiple parallel forms and be flexible and adaptive to shift between these as required. C2 in a more benign setting (e.g. strategic HQ in the UK Homeland, or on an uncontested HADR mission) should thus optimise for efficiency, so as to bring together sensors, data, analysts, decision makers and effectors to tackle complex problems through a common operating picture and a broad range of levers. Meanwhile, in much more contested or denied environments, C2 networks and the associated

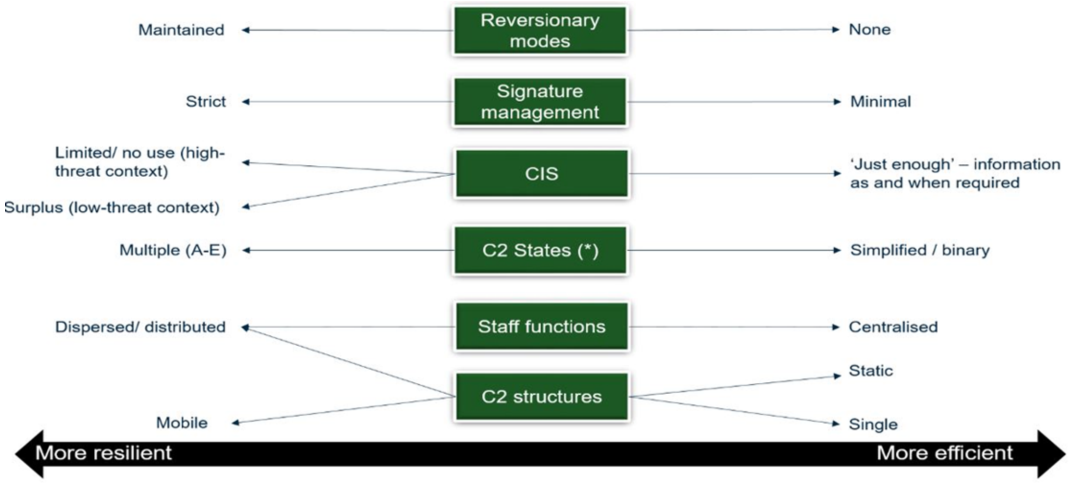
[190] Davis (2014).

[191] Clerici & Kaemper (2021).

[192] Bain et al., cit. in Clerici & Kaemper (2021).

Tactics, Techniques and Procedures (TTPs) will need to enable layered C2 to 'fail forward' if key nodes or linkages are compromised; ensure that tactical commanders and formations can function effectively even if cut off from higher levels and operating dispersed and on the move; manage their signatures; deconflict their activities and concentrate forces or converging effects across domains in the appropriate windows of opportunity; improvise their plans based on command intent, in the absence of reach-back; and exploit reversionary modes as needed, so as to remain resilient in the face of kinetic and non-kinetic threats.[193]

Figure 6.3 Examples of trade-offs between C2 resilience and efficiency



Source: Clerici & Kaemper (2021).

In this sense, there is likely no such monolith as 'future C2'. Instead, future C2 is likely to entail a flexible toolkit of heterogeneous and context-specific approaches to making resilience–efficiency trades, which can be employed either in sequence or in parallel depending on changes in the mission, operating environment and the threats faced. Furthermore, these various future approaches to C2 will manifest in different ways at differing levels; for example, C2 (or MDO/MDI) at the grand-strategic level will look different to that at the Corps or Divisional level or that of smaller tactical formations all the way down to a squad or section. This differentiation by threat and layering by the levels of warfare or by the military's internal unit structures adds further complexity and fluidity to defining the C2 enterprise in the future.[194]

This introduces obvious challenges in terms of developing the necessary enablers across the DLODs to realise not one but multiple variants of C2 in the future. Furthermore, there are likely to be acute challenges, both for Defence as a whole and for individuals' mindsets, in transitioning from one C2 state or model to another; from a complexity theory perspective, these phase transitions entail increased turbulence and uncertainty, and necessitate spanning boundaries, posing a risk that adversaries may exploit this moment of vulnerability, disorganisation and confusion to sow chaos or influence system dynamics in their favour. The alternative, however, is a single, optimised but rigid approach to C2 – resource-efficient but lacking resilience and dynamism and thus inviting cascading failures if adversaries or events conspire to disrupt the UK's C2.[195]

[193] Schweiker (2017); Seip (2020).
[194] Segal (2023).
[195] Seip (2020); Smith & Atwell (2022).

6.4.9. Measures of effect, signals and mechanisms for change must be built into plans, systems and organisations to enable them to learn and adapt over time

The literature suggests that C2 organisations need to move away from inadequate strategy making or planning philosophies, such as the linear and prescriptive 'ends, ways and means' approach, which are inadequate to deal with complexity in defence decision making. As discussed in Chapter 5 and Annexes C and D – including in relation to methods such as ISM, RDM and DAP – navigating complexity requires:

- More robust strategies and plans focused on iteration in the face of complexity and uncertainty, understanding and exploiting feedback loops and non-linearities, and avoiding surprise or shock.
- Early and explicit identification of the critical underpinning assumptions about system dynamics and the theory of success for shaping or exploiting these.
- In-built monitoring systems for detecting early warning signs that these planning assumptions and/or external conditions are changing in a manner that risks failure of the initial plan.
- The organisational capacity to learn and adapt at speed once that tipping point has been reached.

Crucially, C2 systems and organisations in the future will need to understand and monitor relevant measures of effect.[196] This poses several challenges, for example:

- Causality is not currently sufficiently well understood or modelled when dealing with the non-linear dynamics and phenomenon of emergence within complex adaptive systems. It is difficult to anticipate, let alone to monitor or attribute, cascading second- and third-order effects from a given intervention, especially when these only manifest over the longer term.
- This is made more difficult when considering turbulence, i.e. measuring the impact of a given intervention on one level of analysis (e.g. at the tactical level) at higher levels (e.g. the strategic).
- Furthermore, traditional approaches to Battle Damage Assessment (BDA), or to combat indicators and combat assessment more generally, are much more mature for kinetic effects delivered in the land, air or maritime domains, than for non-kinetic effects – including those in cyberspace and the EMS, or outer space, as subsets of this problem – and for information operations.[197]

Assuming that a monitoring system has been put in place to track identified signals of possible changes in key assumptions or conditions needed for success, and to consider the possible relevance of other signals not specified in advance, C2 systems and organisations then need processes in place to ensure that these tipping points trigger a change in the plan or strategy towards an alternative pathway (e.g. through defensive, corrective or capitalising actions, as outlined in Annex D).[198] This reassessment may need to occur outside of the typical battle rhythm and planning cycle, given time sensitivity. To put this approach of continuous testing and iteration (probe-sense-respond, in the language of the Cynefin framework[199]) into practice, C2 systems and organisations will need greater capacity for learning, adaptation and innovation.[200] This ability to not only identify Adaptation Tipping Points (ATPs) in a timely manner, but also to decide upon, resource

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[196] Gitelman et al. (2020).
[197] US Joint Chiefs (2019); Kim et al. (2022).
[198] Johnson (2018).
[199] Snowden & Boone (2007); IT Revolution (2021).
[200] Baltaci and Balci (2017).

and implement the necessary changes at speed, is the essence of turning lessons identified into lessons learned, and achieving FARness (flexibility, adaptiveness and robustness).[201]

This requires overcoming barriers to learning and continuous change at both the organisational level (e.g. rigid structures and processes, technical systems with long lead times to adapt, cultural aversion to change or risk taking, misalignment of incentives around career progression, etc.) and the individual level (e.g. cognitive biases such as the sunk cost fallacy, or discomfort with uncertainty).[202] Here, there are obvious links to the extensive body of theory and good practice that exists in relation to increasing the ability of teams or organisations to absorb innovation, promote continuous improvement and manage change. This includes literature on well-documented commercial practices such as DevSecOps, agile or scrum, as well as broader research on how to promote innovation within Defence specifically.[203] This includes recognition of the need to apply a complexity and systems thinking lens to the question of building an 'innovation ecosystem' within Defence that cultivates creativity, experimentation, challenge, informed risk taking and FARness at all levels, encouraging both top-down and bottom-up innovation.[204]

While the innovation literature also speaks to wider, though not unrelated, issues such as improving the development and integration of software and emerging technologies, many of the underlying insights about how to make Defence, as a complex socio-technical system, more conducive to learning and adaptation are likely transferrable to thinking about such properties in the future context of C2.

6.4.10. The future design of C2 must be supported by urgent reforms to the wider Defence enterprise

Recognising the scale and urgency of the challenge that complexity poses to C2 entails that DCDC considers the potential need for sweeping changes across the decision cycle, as well as to the wider C2 enterprise and thus to Defence or, beyond that, the apparatus of government at large. These issues go beyond questions of structure or process – though those remain important – and incorporate broader debates about workforce and career management, the pace of acquisition of new technologies, the evolution of education and training, and the organisational capacity and cultural willingness of the UK to innovate in the face of mounting threats, constrained resources and other pressures.

Such overarching considerations are summarised in Chapter 7, which also provides brief final reflections and outlines next steps for this ongoing project.

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201 Davis (2014).

202 Baltaci & Balci (2017); Causey (2020).

203 Freeman et al. (2015);

204 Hulter (2019); Lewis (2021); Kotila et al. (2022); Pickett (2022).

7. Conclusions and next steps

This final chapter outlines the SASC team's reflections on the first of the four papers within this wider study, as well as the next steps in further research into the detail of future design considerations for C2, in terms of the overall C2 enterprise, the associated capability, and the underpinning enablers.

7.1. Summary

The chapter is summarised in the box below and elaborated upon in the sections that follow.

Box 7.1 Conclusions and next steps

Academic theorists and governmental, military or industry practitioners have an incomplete understanding of complexity or complex adaptive systems, such as will characterise the future operating environment for C2. While the literature provides useful methods and tools for grappling with complexity, as well as some initial design considerations for C2, changing C2 – a socio-technical system in its own right – will be highly complex. This implies a process of co-adaptation alongside the evolving operating environment, and changing threat and technology landscapes, and thus of iteration and continuous learning. Perhaps the most pressing challenge, therefore, is understanding how best to steer this process over time, given the extent and nature of the transformation (technological, structural, process, cultural, educational, etc.) required to position C2 systems for future success in the face of complexity.

Given the challenges of achieving a C2 system that can tackle complexity, Defence may either need some sort of external shock to force creative destruction, or else to initiate its reform efforts using (and in spite of) more traditional, linear C2 approaches and pivot over time as changes set in.

7.2. Final reflections

7.2.1. There is an incomplete understanding of the complexity that will characterise the future operating environment for C2

As outlined in Chapters 2, 3 and 4, the nature, drivers and manifestations of complexity all remain topics of considerable uncertainty and debate. Although there has been a profusion of research into complexity theory and related fields since the 1940s, this remains an area which lacks common agreed definitions, let alone a codified blueprint for successfully navigating complex problems such as those that Defence C2 is expected to face out to the 2030s and beyond. Advances in computational modelling and the application of AI and ML, as well as innovation in more qualitative areas, are driving continuing advances in our understanding of complex adaptive systems. But in many ways the research landscape remains diffuse, disjointed and at a comparatively early stage of maturation. Recalling Cynefin, complexity remains the domain of probing and emergent insights, not of best practice guided by definitive expertise.

For DCDC, this incompleteness of the collective understanding of complex adaptive systems implies that their own ongoing work to apply the lens of complexity thinking to Defence C2 – with its traditional approaches to sense- and decision-making being so at odds with this non-linear mode of thinking – is near the cutting edge of research and concepts development on this theme. This can be viewed as an opportunity, and an exciting one at that; however, it also entails a need for humility, probing, iteration, feedback and continuous learning in the face of substantial uncertainty. This will be necessary to meet Defence's ultimate goal of achieving a decisive advantage over the UK and its allies' adversaries through improvements to its ability to command and control operations in a future operating environment characterised by complexity.

7.2.2. While the literature provides useful methods and tools for grappling with complexity, changing C2 will be highly complex and iterative

As outlined in Chapters 5 and 6, and explored in more detail in Annexes C and D, this paper has identified a series of tools and techniques for understanding complex systems or problems, and thereby coming to decisions that better satisfy the FARness principle (the need to be flexible, adaptive and robust). It has also identified broader practical considerations affecting the design of C2 systems and organisations, including the challenges posed by external threats and internal barriers to change, as well as the need to strike an ever-shifting balance between C2 efficiency and C2 resilience depending on the operating context.

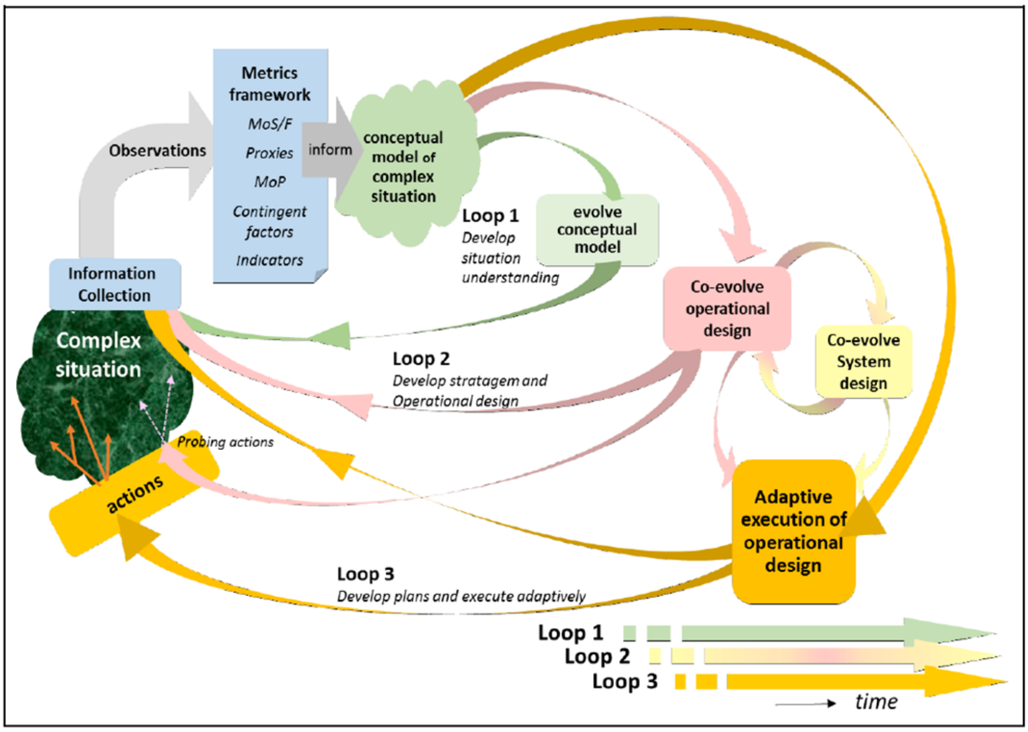
For DCDC, this implies that there is no single monolith known as 'future C2'; rather it will likely be a series of different potential C2 states, which UK Defence will need to shift between in an agile manner as conditions change. This introduces a series of design dilemmas requiring further consideration, such as:

- How to manage the pivot between states, given the added risks of turbulence, chaos and confusion during this phase transition, or of adversaries exploiting this window of opportunity for advantage.
- How to strike a balance between traditional, hierarchical and linear approaches to sense-making, planning and execution which are optimised to simple or complicated problems (and which will retain their relevance in some situations) and the more novel approaches needed for complex ones.
- Whether to focus on developing people, technical systems, organisational structures and processes that are generalist in nature, thereby risking an inadequate response to the unique demands of complex problems, or to focus on cultivating specialists tailored to specific C2 states, thereby risking spreading finite resources too thin and/or a bifurcation of the force into those elements configured to deal with the complicated and those trained and cognitively equipped for the complex.
- Whether to position the UK at the leading edge of implementing novel approaches to C2 – which could yield first-mover advantage and prestige if successful but also implies carrying substantial risk by trading existing strengths in traditional C2 approaches for investment in untested ideas – or to wait for others (notably the United States) to ascertain and demonstrate the most efficient path forward.
- How to balance between designing an approach to C2 configured to the UK's unique needs and designing one that maximises interoperability with Allies (e.g. the US's vision of JADC2), especially given the political and operational risks that divergence entails for Alliance cohesion.

This paper has emphasised that C2 is a complex socio-technical system in its own right and thus that its future will be shaped by the phenomenon of emergence. For DCDC, this means that any concept for C2 in the future should not be a vision of a fixed end-state, but rather a set of aspirational goals and guiding principles with which to approach a fluid, uncertain and self-reflexive process of co-adaptation of the C2 enterprise alongside continuous evolutions in the operating environment and in the variables affecting both the demand (e.g. any shifts in the political expectations placed on Defence C2 or in the objectives that the UK seeks to achieve) and supply sides of C2 (e.g. changes in the technology or workforce skills available).

This sort of nested, iterative approach is illustrated in Figure 7.1, and could be applied both to configuring the C2 approach for a specific operation and to DCDC's higher-level task of developing a revised JCN.

Figure 7.1 Nested loops of co-evolution of conceptual model, system and operational designs, and the adaptive implementation and execution of those designs



Source: Grisogono (2019, 81).

7.2.3. Perhaps the most pressing challenge is understanding how to steer this process of co-adaptation over time

For DCDC, the challenge is not only to set out a concept of C2 better suited to grappling with complexity, but also to ensure there are realistic implementation pathways to make that vision a reality. This paper has described significant debate within the literature and expert workshop as to whether Defence will be able to make the transition from its current industrial-age structures, processes and culture towards the types of thinking needed for organisations to succeed in the information age – and, if so, how.

In one school of thought, Defence may need an external shock to force change, given the levels of institutional and cultural inertia inherent in a risk-averse and hierarchical organisation such as the military. At the same time, it could be observed that even the shock of defeat in Afghanistan, a global pandemic, the onset of war in Ukraine, the mounting impacts of climate change or the pacing threat from China, have together not proven to be a sufficient impetus to engender radical change in UK or Allied approaches to C2. Furthermore, relying on a strategic shock to sweep aside internal barriers to change implies a passivity which will likely be unpalatable to Defence. Consequently, a proactive and iterative approach is required.

Paradoxically, however, a C2 system geared towards tackling complexity may be precisely what is needed to implement the sort of transformative pan-DLOD, cross-governmental, whole-of-society and multinational change programme needed to realise a C2 system geared towards tackling complexity. Such circular logic implies a need, instead, for an adaptive and learning-focused approach, starting with targeted changes (e.g. to training, exercises or interagency working) implemented initially using current C2 approaches and then refined over time as the C2 enterprise begins to exhibit improvements in properties relevant to influencing complex adaptive systems, such as creativity, innovation, agility or capacity to learn.

7.2.4. Subsequent papers in this GSP study build on this initial paper's themes, exploring the future trade-offs and design decisions for C2 in more detail

Following this paper, further research was needed to help DCDC address the C2 design and change management dilemmas raised in this final chapter. As outlined in the introduction to this report, this has been only the first paper within a larger GSP study in support of DCDC's Project Mimisbrunnr. The remaining three papers focus on the future of the C2 enterprise, of C2 capability, and of the associated enablers, respectively. On the theme of C2 enterprise, the second paper considers the following questions:

- RQ1: Based on current best forecasting of the future operating environment (i.e. the demand placed upon the C2 enterprise) and the likely state of S&T and workforce trends (i.e. the potential supply of technical and people solutions to enhance C2), what are the opportunities, challenges and dilemmas for designing the future C2 enterprise?
- RQ2: What are the most significant properties that collectively drive the effectiveness of this enterprise? How might these properties interact with each other?
- RQ3: What barriers need to be overcome to realise these properties within Defence?
- RQ4: What barriers need to be overcome to realise these properties in a whole-of-society approach?
- RQ5: What new requirements (new capabilities, concepts, functions and necessary activities, etc.) does such an approach entail?

These questions build upon the initial analysis provided in Chapters 5 and 6 of this first paper. In adopting such an iterative approach of exploration, analysis and refinement, the team behind Project Mimisbrunnr thereby hope to apply some of the complexity and systems thinking principles explored in this paper to the study itself.

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Annex A. Methodology

A.1. Literature review

Based on consultation with RAND Knowledge Services[205] as well as DCDC, the study team agreed upon a series of Boolean search strings as listed in Table A.1. The initial search was limited to articles from 2015 to the present, and to sources in the English language.

Table A.1 Literature review search strings

Search	Search string	Descriptor
A	TS=(defen*e OR military OR "armed force*" OR army OR armies OR naval OR navy OR navies OR "air force*" OR maritime OR "marine corps" OR "national security" OR "counter-intelligence" OR counterintelligence OR "intelligence community" OR aerospace OR aeronaut* OR aviation OR warfare OR weapon* OR battlefield OR joint) AND TS=(War* OR crisis OR conflict OR operation OR operating OR situation OR situational OR "situation* awareness" OR "situation* understanding" OR sensemaking OR "cross-domain" OR Hybrid OR "grey zone" OR competition OR "hyper competition" OR "sub-threshold")	Defence + situation
B	TS=(defen*e OR military OR "armed force*" OR army OR armies OR naval OR navy OR navies OR "air force*" OR maritime OR "marine corps" OR "national security" OR "counter-intelligence" OR counterintelligence OR "intelligence community" OR aerospace OR aeronaut* OR aviation OR warfare OR weapon* OR battlefield OR joint) AND TS=("complex network*" OR "wicked problem*" OR complex* OR chaos OR chaotic OR diverse OR diversity OR "hard problems" OR "challenging problems" OR "multi-domain challenges" OR wickedness OR "coercion campaign" OR measures OR maskirovka OR "reflexive control" OR "messy problems" OR "tame problems" OR "critical problems" OR "complex adaptive system*" OR "CAS" OR "complexity theory" OR uncertainty OR "complex system*" OR "complex organisation*" OR "complex organization*")	Defence + problem context

[205] RAND Knowledge Services is a team of information professionals, many of whom have graduate degrees in library science, information science, or archive studies, which provides information resources and services across the different RAND offices.

C	TS=(defen*e OR military OR "armed force*" OR army OR armies OR naval OR navy OR navies OR "air force*" OR maritime OR "marine corps" OR "national security" OR "counter-intelligence" OR counterintelligence OR "intelligence community" OR aerospace OR aeronaut* OR aviation OR warfare OR weapon* OR battlefield OR joint) AND TS=(C2 OR "command and control" OR "command & control" OR “crisis management” OR “conflict management” OR multi*domain OR “multi-domain operations” OR “integrated whole of non-nuclear” OR “integrated approach” OR “whole of government” OR “whole of society” OR fusion OR “fusion approach” OR “fusion doctrine” OR “comprehensive approach” OR “effect* based” OR “integrated effect*”)	Defence + capability
D	TS=(defen*e OR military OR "armed force*" OR army OR armies OR naval OR navy OR navies OR "air force*" OR maritime OR "marine corps" OR "national security" OR "counter-intelligence" OR counterintelligence OR "intelligence community" OR aerospace OR aeronaut* OR aviation OR warfare OR weapon* OR battlefield OR joint) AND TS=(War* OR crisis OR conflict OR operation OR operating OR situation OR situational OR “situation* awareness” OR “situation* understanding” OR sensemaking OR “cross-domain” OR Hybrid OR “grey zone” OR competition OR “hyper competition” OR "sub-threshold") AND TS=(“complex network*” OR “wicked problem*” OR complex* OR chaos OR chaotic OR diverse OR diversity OR "hard problems" OR “challenging problems” OR “multi-domain challenges” OR wickedness OR “coercion campaign” OR measures OR maskirovka OR “reflexive control” OR “messy problems” OR “tame problems” OR “critical problems” OR “complex adaptive system*” OR "CAS" OR “complexity theory” OR uncertainty OR "complex system*" OR "complex organisation*" OR "complex organization*")	Defence + situation + problem context (subset of Search A)
E	TS=(defen*e OR military OR "armed force*" OR army OR armies OR naval OR navy OR navies OR "air force*" OR maritime OR "marine corps" OR "national security" OR "counter-intelligence" OR counterintelligence OR "intelligence community" OR aerospace OR aeronaut* OR aviation OR warfare OR weapon* OR battlefield OR joint) AND TS=(War* OR crisis OR conflict OR operation OR operating OR situation OR situational OR “situation* awareness” OR “situation* understanding” OR sensemaking OR “cross-domain” OR Hybrid OR “grey zone” OR competition OR “hyper competition” OR "sub-threshold") AND TS=(“complex network*” OR “wicked problem*” OR complex* OR chaos OR chaotic OR diverse OR diversity OR "hard problems" OR “challenging problems” OR “multi-domain challenges” OR wickedness OR “coercion campaign” OR measures OR maskirovka OR “reflexive control” OR “messy problems” OR “tame problems” OR “critical problems” OR “complex adaptive system*” OR "CAS" OR “complexity theory” OR uncertainty OR "complex system*" OR "complex organisation*" OR "complex organization*") AND TS=(C2 OR "command and control" OR "command & control" OR “crisis management” OR “conflict management” OR multi*domain OR “multi-domain operations” OR “integrated whole of non-nuclear” OR “integrated approach” OR “whole of government” OR “whole of society” OR fusion OR “fusion approach” OR “fusion doctrine” OR “comprehensive approach” OR “effect* based” OR “integrated effect*”)	Defence + situation + problem context + capability (overall subset of search A/search D)

F	TS=(War* OR crisis OR conflict OR operation OR operating OR situation OR situational OR "situation* awareness" OR "situation* understanding" OR sensemaking OR "cross-domain" OR Hybrid OR "grey zone" OR competition OR "hyper competition" OR "sub-threshold") AND TS=("complex network*" OR "wicked problem*" OR complex* OR chaos OR chaotic OR diverse OR diversity OR "hard problems" OR "challenging problems" OR "multi-domain challenges" OR wickedness OR "coercion campaign" OR measures OR maskirovka OR "reflexive control" OR "messy problems" OR "tame problems" OR "critical problems" OR "complex adaptive system*" OR "CAS" OR "complexity theory" OR uncertainty OR "complex system*" OR "complex organisation*" OR "complex organization*")	Situation + problem context
G	TS=(War* OR crisis OR conflict OR operation OR operating OR situation OR situational OR "situation* awareness" OR "situation* understanding" OR sensemaking OR "cross-domain" OR Hybrid OR "grey zone" OR competition OR "hyper competition" OR "sub-threshold") AND TS=("complex network*" OR "wicked problem*" OR complex* OR chaos OR chaotic OR diverse OR diversity OR "hard problems" OR "challenging problems" OR "multi-domain challenges" OR wickedness OR "coercion campaign" OR measures OR maskirovka OR "reflexive control" OR "messy problems" OR "tame problems" OR "critical problems" OR "complex adaptive system*" OR "CAS" OR "complexity theory" OR uncertainty OR "complex system*" OR "complex organisation*" OR "complex organization*") AND TS=(C2 OR "command and control" OR "command & control" OR "crisis management" OR "conflict management" OR multi*domain OR "multi-domain operations" OR "integrated whole of non-nuclear" OR "integrated approach" OR "whole of government" OR "whole of society" OR fusion OR "fusion approach" OR "fusion doctrine" OR "comprehensive approach" OR "effect* based" OR "integrated effect*")	Situation + problem context + capability (overall subset of search F)
H	TS=(War* OR crisis OR conflict OR operation OR operating OR situation OR situational OR "situation* awareness" OR "situation* understanding" OR sensemaking OR "cross-domain" OR Hybrid OR "grey zone" OR competition OR "hyper competition" OR "sub-threshold") AND TS=(C2 OR "command and control" OR "command & control" OR "crisis management" OR "conflict management" OR multi*domain OR "multi-domain operations" OR "integrated whole of non-nuclear" OR "integrated approach" OR "whole of government" OR "whole of society" OR fusion OR "fusion approach" OR "fusion doctrine" OR "comprehensive approach" OR "effect* based" OR "integrated effect*")	Situation + capability

Source: RAND Knowledge Services with input from DCDC.

Each of these searches was made across five databases, as shown in Table A.2. RAND Knowledge Services recorded the top 250 hits (where available) based on each databases' ranking of relevance. For searches that resulted in less than 1000 hits, the entire set of results was recorded. EndNote was then used to identify and remove duplicates, first within a single database and subsequently across all five databases. The initial hit count as well as the number of articles from each search reflected in the initial list of sources provided to the project team are given in Table A.2.

Table A.2 Literature review search hits

Search	Database	Total hits	Number of titles included
A	Scopus	172,082	249
	Web of Science	127,577	183
	ProQuest Military Database	1,106	249
	Policy File Index	7.148	247
	Business Source Complete	3,878	246
B	Scopus	165,251	247
	Web of Science	161,021	132
	ProQuest Military Database	581	201
	Policy File Index	2,696	213
	Business Source Complete	4,718	199
C	Scopus	23,534	243
	Web of Science	17,923	123
	ProQuest Military Database	110	80
	Policy File Index	294	253
	Business Source Complete	436	391
D	Scopus	36,576	173
	Web of Science	32,297	118
	ProQuest Military Database	217	115
	Policy File Index	1,248	112
	Business Source Complete	1,009	182
E	Scopus	1,549	219
	Web of Science	1,102	141
	ProQuest Military Database	15	0
	Policy File Index	59	0
	Business Source Complete	29	0
F	Scopus	623,075	227
	Web of Science	680,848	121
	ProQuest Military Database	7,978	241

Search	Database	Total hits	Number of titles included
	Policy File Index	3,915	160
	Business Source Complete	46,693	243
G	Scopus	16,599	208
	Web of Science	13,334	113
	ProQuest Military Database	240	214
	Policy File Index	91	28
	Business Source Complete	1,292	226
H	Scopus	69,105	211
	Web of Science	46,497	118
	ProQuest Military Database	1.098	179
	Policy File Index	338	88
	Business Source Complete	5,378	176

Source: RAND Knowledge Services.

These results were then given to the study team for further refinement, which involved two reviewers combing through the initial search lists. Based on previous discussions with the client, they each independently indicated which articles might be most relevant, based on title, abstract and authors/source; this resulted in agreed-upon list of 50 articles. The team then went through those articles and selected 25 for detailed review and extraction. This final shortlist was then verified with DCDC before information was extracted. Following the initial extraction, 'snowballing' occurred to identify additional articles of interest based on the references and bibliographies of the sources consulted and thereby fill any gaps in coverage of the research questions that remained after the initial review.

A.2. Expert engagement

In addition to the literature review, the study team engaged with a variety of Anglo-Swedish stakeholder and expert perspectives through an in-person workshop convened by DCDC and hosted at the Swedish Defence University in Stockholm on 7 March 2023. A list of attendees is provided in Table A.3.

Table A.3 List of workshop participants

Name	Organisation
Air Cdre Anders Persson	Deputy Vice-Chancellor, Swedish Defence University
Björn J.E. Johansson	FOI
Christina Ekenstierna	Swedish Armed Forces, Defence Staff
Lt Col Daniel Thenander	Swedish Defence University
Elsa Lindstedt	Swedish Armed Forces, Joint Operation
Cdr Fabian Tamm	Swedish Armed Forces, Joint Operation
Isabell Andersson	Swedish Defence University
James Black	RAND Europe
Jason Poole	Aperture Strategy
Lt Col Johan Ivari	Swedish Defence University
Jonas Herkevall	FOI
Cdr Leif Hansson	DCDC
Linnea Hjalmarsdotter	Swedish Armed Forces, Defence Staff
Magdalena Granasen	FOI
Lt Col Michael Aust	Swedish Armed Forces, Joint Operation
Nicholas Fernholm	Public speaker
Niklas Hallberg	FOI
Paddy Turner	QinetiQ
Lt Col Patrik Sandstrom	Swedish Armed Forces, Defence Staff
Peter Houghton	Dstl
Lt Col Rob Kace	DCDC
Lt Cdr (R) Roy Johansson	FMV
Lt Col Stefan Cako	Swedish Armed Forces, Defence Staff

Annex B. Drivers of change in the operating environment

This annex expands on the macro-trends briefly summarised in Chapter 3, based on the literature review.

B.1. Increasing interconnectivity, multipolarity and global competition

Government strategy and policy documents and academic or think tank sources are replete with references to intensifying great power competition, an increasingly multipolar and anarchic world, and revisionist challenges to the supposed post-1945 liberal rules-based international order based on bodies such as the UN and NATO, the Bretton Woods system and principles such as the sanctity of sovereign borders.[206] These geopolitical and geoeconomic trends are seen as driving complexity by heightening the number of concurrent and converging challenges facing societies and, by extension, governments and militaries. Examples include:

- Increasing mistrust and revisionism: Aggression by Russia, the systemic challenge from China, and enduring difficulties presented by regimes such as North Korea and Iran have seen the re-emergence of competition as the primary lens through which decision makers view global politics.[207]
- A broadening of global competition: Competition is occurring through use of all levers of power (e.g. DIME) and using a mix of covert, ambiguous, deniable and overt means. Authoritarian actors such as Russia and China envisage a single continuum of global competition on all fronts and in all areas.[208] As such, they consciously seek to exploit the 'grey zone' and ambiguity around the thresholds (e.g. Article 5 in NATO) and stovepipes (e.g. between domestic and foreign, or between military and non-military issues) that still persist in the approaches of liberal democracies.[209]
- Increasing multipolarity: At the same time, increasing multipolarity is brought about by the rise of BRICS[210] countries and others, and the consequent lack of a clear hegemon or stable balance of power (e.g. between the United States and China).[211] This implies a shift to a more confrontational and anarchic world. It also poses added challenges in terms of navigating the complex web of international relations with adversaries, allies, partners and neutral third parties (e.g. posing

[206] Kundnani (2017); Mearsheimer (2019); Cimmino & Kroenig (2020).

[207] Mazarr et al. (2022).

[208] Duczynski et al. (2021); Black, Lynch et al. (2022).

[209] Kilcullen (2020).

[210] Brazil, Russia, India, China and South Africa.

[211] Mazarr et al. (2021).

questions about the relevance of Cold War-era bipolar approaches to deterrence in a newly multipolar world).[212]

- Increasing connectivity within and between systems: Equally, deepening interconnectivity across politics, economies and societies at the global, regional, national and sub-national levels – driven by globalisation and continuing advances in information communications technologies – is eroding the traditional distinctions between home and away, or the global and the local. This does not mean the emergence of a single cohesive world culture or agreed set of norms and values (see below); rather, there is an increasing risk of social, political and economic fragmentation.
- The continuing rise of non-state actors: The private sector is expected to continue to play an ever-larger role in international affairs, not only a driver of economic growth and technological innovation, but also key in shaping the information environment (e.g. through moderation of content on social media platforms) and even wars (e.g. as with the Wagner Group or Microsoft and SpaceX in Ukraine).[213]
- The changing impact of time and space: In an age when an increasing number of actors can deliver an increasing variety and scale of kinetic or non-kinetic effects to the other side of the globe with the simple click of a button (e.g. to launch a cyber-attack, promote a narrative on social media, or deliver a missile over tremendous distances), the role of time and distance in shaping planning, decision making and execution is also changing. This combination of deepening connectivity and the erosion of time and space limitations presents both new possibilities and new risks, such as an increased attack surface for malicious actors, myriad dependencies and vulnerabilities (e.g. to supply chains) that may not be properly understood, and new sources of tension between actors.
- The perception of heightened uncertainty and volatility: As a result of these and other trends (see below), the political landscape at both the international and national levels is increasingly volatile and uncertain and characterised by a constant shifting of coalitions. While global competition intensifies, a proliferation of 'wicked problems' requiring greater international consensus as the basis for collective action adds another layer of complexity to the future operating environment, with fears that current governance structures are simply inadequate for this task.[214] There are concerns that this could potentially presage a decisive future breakdown of the current international or domestic political order in favour of some other new equilibrium – potentially one hostile to the interests and values of self-identified status quo powers such as the UK.[215]

B.2. The impact of a changing climate

Besides geopolitical and geoeconomic change, interlinked social and environmental trends could similarly lead to greater disorder, instability and ultimately conflict out to the 2030s and 2040s. Examples include:

- Environmental change and extreme weather: Accelerating climate change, as well as pollution and other drivers, could result in sweeping and unpredictable changes to all regions of the globe in this time period. The impacts are likely to be varied and non-linear; for example, the

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[212] Cimbala (2015).

[213] Reynolds (2019); Uberti et al. (2022).

[214] Levin et al. (2012).

[215] For example, the Integrated Review emphasises the need for the UK to defend the rules-based international order.

melting of the ice caps and permafrost is projected to reduce the 'albedo effect', meaning that the Arctic would be less bright and thus reflect less sunlight, leading to more energy absorption and thus runaway regional and global warming. Simultaneously, southern Europe could be affected by increasingly hot summers and desertification, even as the interruption of the Gulf Stream across the Atlantic might lead to extremes of cold in other parts of Europe and the UK.[216] All of this is likely to affect Defence not only directly, in terms of the missions it is called to undertake (e.g. Military Assistance to Civil Authorities [MACA] and Humanitarian Aid and Disaster Relief [HADR] tasks of increased frequency and intensity) but also indirectly through the environmental conditions in which it will operate, thus determining everything from training and infrastructure to the specifications of military kit.[217]

- Energy transition: Both the climate emergency and the increasing awareness of the potential risks to energy security (e.g. in the wake of the Russia-Ukraine War) are projected to drive continued investment in renewable energy, though oil and gas are expected to retain a significant role for the coming decades. In turn, electrification and, potentially, the advent of disruptive new technologies such as fusion power could lead to sweeping changes in infrastructure, economies, societies and global relations (e.g. reducing the significance of oil and gas exporting regions).[218]
- Disruption to food, water, and soil systems and ecology: Relatedly, climate change, pollution and overuse are projected to lead to disruption of food and water supplies, potentially driving migration, instability and communal violence, especially in already fragile regions. Similarly, soil erosion caused by deforestation and a reduction in the nutrient quality of the soil due to poor agricultural practices, extreme weather and other factors could lead to falling food yields in some regions, or the cascading collapse of complex regional ecosystems. Similarly, this could lead to mass extinctions (beyond those already experienced), with unpredictable consequences for both nature and humankind.[219]
- Bio-security risks: A major additional risk emerges from the production of manmade bioweapons (the proliferation of which is being aided by the democratisation of technologies such as gene editing and synthetic biology), as well as from natural pandemics, with the potential for cascading disruption across the PESTLE-M dimensions already made clear by the COVID-19 pandemic.[220]
- Climate adaptation and weaponisation: Given the trends outlined above, governments, businesses and families are already investing in ways of combating climate change (e.g. by reducing emissions) and/or mitigating, adapting to or reversing its effects. Looking out to the 2030s and 2040s, this raises the potential for sweeping changes to economies and societies, but also knock-on effects for international politics and global security.[221] Possible drivers of instability include a divergence in approaches to dealing with climate change; pressure to coerce or compel free-riding states and major polluters to cut emissions, potentially by force; or the weaponisation of the

[216] Jouan, Ogden et al. (2022).
[217] Cox et al. (2020); Retter et al. (2021).
[218] Hammelehle (2021).
[219] Pozza & Field (2020); Environment Agency (2021).
[220] Johnson et al. (2023).
[221] Pfluger (2020).

climate, such as through use of geoengineering technologies (e.g. to seed rains that damage crops in a rival country).[222]

- Demographic shifts and resource scarcity: An increasing global population is likely to lead to more demand for resource sharing and competition for land and raw materials. Combined with dwindling stocks of certain finite resources and disruption to supply chains due to climate change and other sources of instability (e.g. terrorism, war), this is likely to place growing stress on supplies of critical raw materials. These may, in turn, increasingly become the focus for competition and conflict among states, as is already becoming the case with rare earth elements (REEs). At the same time, demographic trends will be uneven across regions, with a youth population boom in Sub-Saharan Africa, for example, contrasting with ageing populations in Europe and China. This is likely to prompt sweeping social, political, economic and cultural changes domestically and affect the competitiveness of different states and thus their role and influence internationally.
- Migration and urbanisation: Climate-related events such as floods and desertification are expected to increase internal and cross-border migration and refugee flows in the coming years.[223] This will include migration towards Europe and the UK, placing additional strain on both transit and recipient countries and provoking tensions and even violence. At the same time, hostile actors may proactively seek to weaponise illegal migration as a coercive or disruptive tool (as with Russia and Belarus in recent years[224]), or to promote narratives hostile to migrants or to governments' responses to migration. Equally, the futures literature emphasises the growing distribution of the world's population towards coastal areas (at risk from rising sea levels) and to cities, including mega-cities. These are likely to be major political and economic centres of power in their own right, but also complex and challenging operating environments for military forces deployed in the area.[225]

B.3. The impact of technology and digitalisation

As digitalisation continues worldwide, technological connections and interdependencies, including both within military C2 systems and organisations and broader society, continue to grow,[226] driven by trends including:

- Pace of technological change: Policy documents and academic literature make repeated reference to the accelerating pace of innovation, which may continue to increase in the future as new technologies enhance the ability to design, prototype, manufacture and deploy new hardware solutions as well as to automate the generation of software. Whether innovation maintains or increases its current rate or not, there is a widespread perception that it already far outstrips the absorptive and adaptive capacity of public sector (and many other) institutions, which were ultimately configured for the industrial age rather than the information one.[227] This raises concerns about the ability of the state to comprehend, let alone regulate, the cascading second- and third-order PESTLE-M implications of disruptive new technologies; potential of dependencies that are

[222] Sovacool et al. (2023).
[223] Duczynski et al. (2021).
[224] Galeotti (2021).
[225] Lacdan (2018).
[226] Masys (2016).
[227] Barrons (2018).

not fully understood or vulnerabilities that are not properly mitigated are likely. It also suggests an urgent need to radically overhaul current approaches to capability development and acquisition within Defence to keep pace with the latest generation of technology and the threat posed by others (e.g. China).[228]

- Democratisation and proliferation: Along with speed, technological innovation is characterised by its diffuse and globalised nature. This implies not only proliferation of key technologies to a wider range of countries (threatening the technological advantage of the UK and its allies), but also the democratisation of many of the underlying tools that enable actors to develop, acquire, use and maintain these technologies. For example, individuals are now able to access and employ AI, ML, cloud computing and 3D printing or other advanced manufacturing equipment to design and produce hardware that would have required a factory in previous decades; similarly, individuals can also access biotech previously found only in sophisticated and secure labs.[229] The emergence of the citizen and open science movements accentuates these trends, bringing both benefits and risks.[230]
- The shifting locus of innovation: There is an ongoing shift in the locus of innovation away from the public sector (including defence laboratories) towards the private sector, and from large, vertically integrated firms to a diffuse, globally distributed network of innovative companies and specialist small and medium enterprises (SMEs). Today, the research and development (R&D) budgets of large multinational companies (MNCs) already far outstrip those of the UK MOD; this trend is expected to continue in the future, with a growing focus on civil and dual-use technologies (i.e. those with both civil and military applications) as opposed to bespoke military ones.[231] This implies a diminished role for government, and Defence specifically, in shaping innovation trends and markets, and challenges in terms of being an intelligent customer for or regulator of technology. Big Tech is projected to become increasingly influential within society and across the PESTLE-M dimensions, demanding new forms of public-private partnership.[232] The military is also expected to need a different approach to technology integration, incorporating industry into its activities and C2 structures and making greater use of dual-use systems, ideally whilst avoiding risks such as dependency or vendor lock-in (e.g. by embracing open systems architectures and modularity).[233]
- Increasing sophistication and vulnerability of technological systems: Military systems, and those in society more generally, are becoming more complex as new technologies are introduced and integrated, and both incremental and radical changes are made to existing systems and processes.[234] The possible threat vectors and attack surfaces are similarly increasing, given the proliferation of both vulnerabilities and dependencies, and new kinetic and non-kinetic means of causing disruption (e.g. space, cyber, electronic). While there are advances underway in defences and countermeasures (e.g. using AI to automate cyber defence), the increasing complexity of

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228 Schoff & Ito (2019); Popper et al. (2020); Waltzman et al. (2020).

229 Cameron (2017).

230 Smith et al. (2017).

231 Kepe et al. (2018).

232 E.g. the role of Starlink in Ukraine. SpaceX (2022); Jaso (2022); Tett (2022); Verbyany & Krasnolutska (2022).

233 Priebe et al. (2020).

234 Chen et al. (2022).

technical systems and the deepening of digital society's dependencies upon them raises the possibility that threats will outstrip the capacity of defenders to protect critical infrastructure.[235]

- The profusion of data: Recent decades have seen an exponential increase in the volume (and variety) of data generated by human society, and this trend is expected to continue into the 2030s and beyond. This has profound ramifications across the PESTLE-M dimensions, with an expectation that data will be one of if not the primary commodity of value in the future economy and the basis for sweeping changes to society, enabling everything from changes to education to mass surveillance. Advances in Big Data and data analytics, as well as cyber-physical systems and the Internet of Things[236] (and associated models such as the Internet of Bodies[237]), are coupled with progress in data visualisation and simulation technologies, such as synthetic environments, virtual, augmented and mixed reality (VR/AR/MR) and the metaverse. This offers potential benefits, including through the use of AI, synthetic environments and digital twins for decision support. At the same time, there is a heightened risk that data may be targeted, poisoned or misused, or that the overwhelming volume of data may outstrip the cognitive capacity of decision makers.[238]
- The growth and expansion of networks: Secure, resilient and efficient networks are a crucial capability for data and information sharing and system collaboration amidst greater technological sophistication. However, network-centric warfare (NCW) and network enabled capacity (NEC) have led to military systems becoming increasingly dependent on such networks.[239] Russian, Chinese and other nations' doctrines make clear that they perceive future war as a 'systems confrontation', where the primary intent is to target, disrupt and paralyse networks and C2 systems and organisations via key nodes and linkages, rather than to destroy all or even most of the forces that they connect and direct.[240] At the same time, the growing impetus to incorporate new and diverse actors into networks (e.g. PAGs, allies, partners, industry, citizens) poses new challenges for architecture design and how to balance security and accessibility.[241]
- Impact of AI, ML and autonomy: Of all technologies, advances in AI and related fields are expected to have the most profound potential impact on human society, as well as on Defence in general and C2 specifically. This reflects the near-term impact of growing use of AI, ML and autonomy across society and the military (including not only frontline but also back-office functions), with sweeping ramifications across DLODs. Such technologies are especially important from the perspective of complex adaptive systems, expanding the number and variety of machine agents within the system, the interaction of which with human and inanimate features of the system is not yet fully understood.[242] Similarly, they raise challenges around law and ethics (see below) as well as around explainability, traceability and AI safety. This includes the potential existential threat of exponential growth in AI capabilities towards the so-called singularity and Artificial General

[235] Duczynski et al. (2021).

[236] For more on the related Internet of Military Things (IoMT), see Poulter & Mackay (2018).

[237] Irving (2021).

[238] Lingel et al. (2021).

[239] Tran et al. (2015).

[240] Engstrom (2018).

[241] Black & Lynch (2021).

[242] Beautement (2015); McNeese et al. (2021).

Intelligence (AGI) or Artificial Super Intelligence (ASI).[243] Even short of this, autonomy and automation could cause sweeping disruption to society, though the impacts are uncertain, with some suggesting AI will lead to mass joblessness and hyper-inequality between AI 'haves' and 'have nots', but others being more positive (e.g. with visions of 'fully automated luxury communism'[244]).

- Impact of other emerging disruptive technologies: Significant disruption and change are projected to arise from advances in diverse areas such as sensors, computing, ICTs, effectors (e.g. hypersonics, directed energy weapons, cyber, counterspace technologies), synthetic biology, quantum, space, energy and other fields.[245] These not only affect wider society and the balance of power within the global economy and politics, but also have a direct impact on the military, including C2. For example, technology is expected to drive an increase in lethality and the ability to deliver effects at scale and range, and new challenges in terms of survivability, camouflage or deception, including the possibility of all-pervasive sensors creating a transparent battlefield.
- Challenges around workforce skills and barriers to absorption of new technologies: As noted in Chapter 2, the focus for this paper and study is on C2 as a complex 'socio-technical system'. Technology must be integrated alongside other DLODs to constitute a new capability. This includes the vital human element. New technologies are likely to exacerbate existing shortages in terms of technical skills (e.g. for AI or cyber), even as automation reduces the need for certain older skills and causes sweeping change and disruption to the workforce and economy. Government and Defence are projected to continue to struggle to compete for and retain the top talent in niche skill areas, given demand and salaries in the private sector, necessitating continuing innovation in approaches to recruitment, development and retention, and use of the Whole Force (e.g. reserves).
- Challenges around costs and legacy systems: Crucially, Defence C2 systems and organisations will need to overcome cost constraints, as well as to consider how to integrate new tech alongside legacy systems as part of an overall system of systems. This includes ensuring interoperability with allies and partners, including a United States that is likely to be running further ahead with its high-tech vision of future JADC2, even as smaller European allies still struggle to wean themselves off Soviet-era equipment, posing the risk that NATO may find itself with a fragmented, patchwork approach to C2 in the future or caught in a dilemma of 'buy American' for military advantage or 'fall behind' if prioritising domestic technical and industrial solutions to ensure sovereignty.[246]

B.4. The blurring of domains, both traditional and novel

Traditional distinctions between domains could diminish as global systems and networks across the PESTLE-M spectrum multiply and become increasingly interconnected:

- Competition in and through cyberspace: The aforementioned dependencies of both militaries and societies on data and networks increase the need for effective cybersecurity and cyber defence, as well as the potential to achieve cognitive and decision advantage by targeting

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[243] McLean et al. (2021); Rudner & Toner (2021).

[244] Bastani (2019).

[245] UK MOD (2019).

[246] Black & Lynch (2021).

competitors' systems using offensive cyber capabilities. Cyberspace is increasingly contested, not only by peer rivals (e.g. China, Russia) but also rogue states seeking to deliver disproportionate effects with finite resources (e.g. North Korea, Iran) and by non-state actors ranging from terrorist groups to hacktivists.[247] There is also growing concern over the potential impact of AI and quantum technologies (e.g. optimisation and automation of cyber-attacks with AI or moves to post-quantum cryptography).[248]

- Competition in and through the electromagnetic environment: Comparatively overlooked for decades, especially in Western militaries, the EME is also a focus of increasing activity and contestation. This is reflected in continuing advances in ICTs, including 5G and 6G technologies, as well as in electronic warfare (EW) capabilities (e.g. cognitive EW systems, jamming or spoofing signals). This increases the risk of accidental fratricide, as the spectrum becomes more congested and heavily used, as well as deliberate disruption of networks and systems by hostile action.[249]
- Competition in and through outer space: Recent decades have seen an exponential growth in the number and variety of objects in orbit, aided by trends such as commercialisation, miniaturisation and falling costs of launch (e.g. due to reusable vehicles). This has led to the emergence of the NewSpace economy, with sweeping ramifications not only for activities in space but also the provision of data and services to terrestrial users. Development is projected to accelerate into the 2030s and beyond,[250] leading to sweeping changes to the economy as well as new threats, risks and dependencies in a domain that is becoming increasingly congested, contested and competitive.[251]
- Growing focus on multi-domain integration: Formal recognition of new domains such as cyber and EM, or space, and the ambition to better integrate activities across all domains and environments, have led to concepts of multi- or joint all domain operations, as outlined in Chapter 2. Though there are no direct Russian or Chinese analogues, there are overlaps in terms of the underlying principles within the military thinking of the UK's potential adversaries. This is driving investment activity and experimentation and concept and capability development work, looking to the 2030s and beyond. At the same time, there are enduring conceptual and practical challenges to bringing together effects across the domains through joint planning and execution, including the differing nature, ownership, time frames and measures of effect for, say, kinetic as opposed to cyber-attacks.[252]
- Growing focus on public-private partnership: The distinction between the civilian and military sectors is becoming more blurred, particularly in domains and environments such as cyber and EM, and space, given the emphasis on 'dual use' technologies. This necessitates alternative, more collaborative approaches to C2 as well as new dynamics within complex adaptive systems.
- Risk of cascading disruption to military and non-military systems: Decision makers will need to navigate a growing number of strategic choices to anticipate and respond to greater risks and uncertainties within individual domains as well as those emerging from their interlinkages. Any

[247] Bellasio & Silfversten (2021); Welburn & Strong (2021).
[248] NCSC (2020).
[249] Casey (2020); Healey (2021).
[250] Black, Slapakova & Martin (2022).
[251] DIA (2022).
[252] Black, Lynch et al. (2022).

decision made in one area is likely to cause unpredictable effects elsewhere in the international system. There is a particular concern in the literature over the limited understanding of how to manage cross-domain effects from a deterrence and escalation management perspective.[253]

- Potential to learn lessons from innovation in new operating domains: There are opportunities to learn from novel approaches to C2, interagency, multinational and public-private partnerships, or technology development and acquisition in the newer domains of cyber and space. Organisations in these domains are relatively unencumbered by legacy systems or processes, providing scope to try out novel approaches that might then inform change in more established areas (e.g. land).[254] At the same time, activity in new domains may be constrained by the immaturity of understanding of their unique nature and characteristics, as well a tendency to draw false parallels to established domains (e.g. by viewing space power primarily through the lens of air or maritime analogies).[255]

B.5. The shifting of international norms and value sets

The literature also emphasises the impact of broader trends occurring within law, ethics and cultural norms, both at the national/societal and international levels. Examples include:

- Challenges to trust and legitimacy for governance systems: Failure to fulfil pledges on economic growth, mitigate the negative impact of technology, or combat climate change, as well as the fact that costs and risks are expected to fall unevenly across populations (affecting the poor and marginalised in particular), may undermine public trust in state institutions. This could drive political extremism (e.g. the rise of ecoterrorist groups or fringe political parties), and push some groups to turn to citizen movements and private actors to provide support and action where states have failed. Hostile actors may seek to exploit this, for instance to promote authoritarian models of governance or otherwise challenge and reshape the rules-based international system.
- Challenges to sovereignty: Along with the continuing democratisation of technology and empowerment of extremist groups and even individuals with capabilities that were reserved to states in previous decades or centuries, comes the erosion of the monopoly of the state on legitimate violence and the basic principles of the Westphalian system of global politics.[256] As NGOs, MNCs, media and Big Tech become increasingly influential, they are projected to play an increasing role in shaping international norms, laws and regulations, including around governance of new technologies such as AI. Similarly, interstate conflict (e.g. in Ukraine, or potentially over Taiwan) may further undermine the sanctity of post-1945 principles such as resolving issues through diplomacy rather than armed aggression. The growing range of ways and means to deliver subversive or coercive effects in the 'grey zone' provides additional challenges, such as normalising certain hostile behaviours or encouraging the securitisation of a growing range of policy problems (which may not always be beneficial or appropriate).[257]

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[253] Mallory (2018); Gartzke & Lindsay (2019); Sweijs & Zilinick (2019).

[254] Retter et al. (2022).

[255] Mendenhall (2018).

[256] Lake et al. (2021).

[257] Mazarr et al. (2019).

- Structural barriers to coordination and consensus: Achieving change in this context of increasingly diffuse power (e.g. to address a super-wicked problem such as climate change) is progressively more difficult, given the coordination problems inherent with a large number of actors.[258] Progress requires achieving compromise and a balance of interests between multiple competing audiences (both domestic and foreign), which is a challenge when faced with increased global connectivity.
- A highly contested information environment: Trends in this area include the ongoing digitalisation of society and proliferation of ICTs and relevant technologies (e.g. social media) to global audiences; the fragmentation and contestation of the concept of truth, leading to misinformation, disinformation and contested facts[259]; changes in the media sector, including both traditional players (e.g. newspaper and TV) and newer outlets, and both the promotion of state-backed voices (e.g. by China, Russia, Iran, etc.) and the powerful grip of partisan private outlets on certain markets (e.g. Fox); and the use of AI, deepfakes, Big Data and various other tools and technologies to expand the potential reach and impact of messages targeted at different audiences.[260]
- Increased focus on social equity and diversity and inclusion: The literature emphasises not only continuing shifts in political, economic and cultural power at the global level (e.g. with a growing role for voices from the East or Global South), but also enduring power imbalances in the international system that favour Western nations. There is an ongoing discourse around equity and equality at the international, national and local level, including a wave of social movements tackling injustices, critiquing established power structures, and promoting the rights and interests of marginalised groups (e.g. based on ethnicity, sex, gender, sexuality, belief, etc.). Local issues can inspire a global backlash or sympathy, depending on group identity or other factors, making use of digital technologies to mobilise support from individuals, businesses or NGOs. Culture wars may also reduce the scope for nuanced dialogue and compromise on complex but politicised issues, leading to further fragmentation, paralysis and potentially even civil strife, public disorder or violence. This poses both direct and indirect challenges for the military, for example in terms of mobilising domestic or foreign audiences' support for operations or accessing talent from diverse backgrounds.[261]
- Uncertainty over future trends in ethics and morality: More generally, there is uncertainty in the futures literature as to how broader values, culture and systems of ethics and morality may evolve out to the 2030s and beyond. There is particular discussion of the role of technology in shaping – and in turn being shaped by – these shifting norms. A prominent example of obvious relevance to Defence C2 is the ongoing debate about how ethics and norms will evolve in relation to AI and autonomy, up to and including the role of lethal autonomous weapon systems. Such trends raise fundamental questions about humanity, its relationship with technology and the environment, the organisation of politics, the economy and society, and how leadership styles and military ethics should evolve in the future operating environment.[262]

258 Ritchey (2013); Duczynski et al. (2021); Head (2022b).

259 Kavanagh & Rich (2018); Devaux, Grand-Clement & Hoorens (2022).

260 Hybrid CoE (2020).

261 Slapakova, Caves et al. (2022).

262 Krause (2021).

- Lawfare and weaponisation of the regulatory environment: Norms and cultural values are also reinforced through legal and regulatory instruments, both at the national and international level. These continue to evolve, for example through ongoing work at the international level to develop new governance regimes for global commons (e.g. space, cyberspace). However, actors can exploit legal systems in malicious ways (so-called lawfare) and are seeking to influence the development of international law and regulation to favour their own interests amidst strategic competition.[263]

Annex C. Complexity-focused methods

This annex provides a brief description and, where relevant, visualisation of prominent examples of methods for analysing complexity and complex adaptive systems, building on the discussion in Chapter 5:

- Cybernetics
- Soft Systems Methodology (SSM)
- Systems Engineering (SE)
- Critical Systems Theory (CST) and Practice (CSP)
- Interpretative Structural Modelling (ISM)
- Other Multi-Criteria Decision Analysis Methods
- Design Thinking.

C.1. Cybernetics

As outlined in Chapter 2, cybernetics has been a major influence on the development of complexity and systems theory.[264] Cybernetics has been defined by its early proponent, Norbert Weiner, as 'the science of control and communication, in the animal and the machine'.[265]

A foundational concept within the cybernetics literature is Ashby's Law of Requisite Variety, also sometimes known as the First Law of Cybernetics.[266] This postulates that 'when the variety or complexity of the environment exceeds the capacity of a system (natural or artificial) the environment will dominate and ultimately destroy that system' and that, as a consequence, 'the complexity of a control system must be

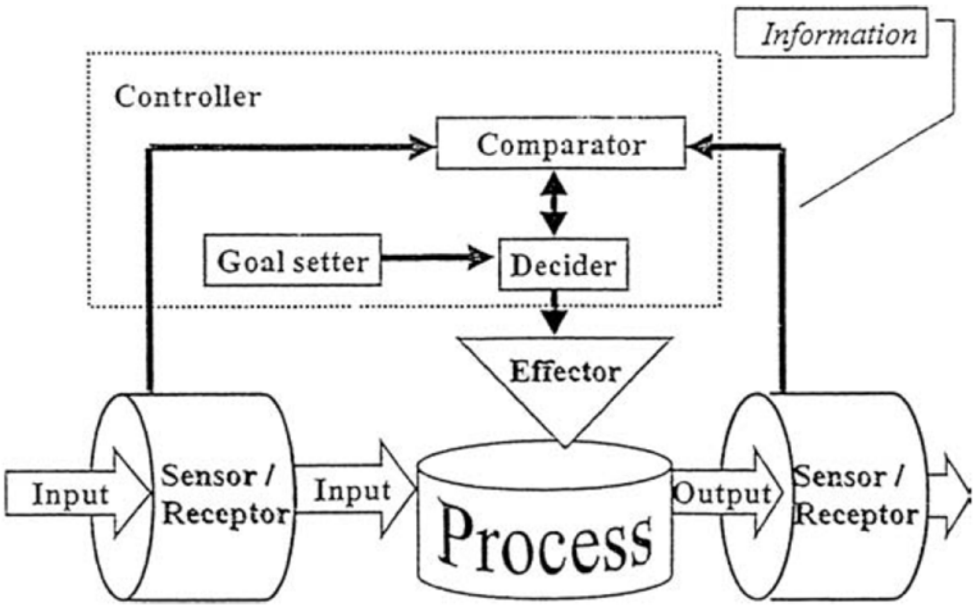
[263] Ormsbee (2021); Brackup et al. (2022); Lafontaine (2022).
[264] Castellani & Gerrits (2021).
[265] Weiner (1948).
[266] For more information about the derivation of the Law of Requisite Variety, see Boisot & McKelvey (2011).

equal to or greater than the complexity of the system it controls'.[267] This hypothesis implies that C2 systems and organisations in the future will need to be sufficiently complex, and able to draw on a wide variety of potential nuanced responses, if they are to grapple with complex problems.[268] Or, as Ashby put it, 'only variety can absorb variety'.[269] Other relevant concepts within cybernetics include[270]:

> 1.) Cybernetic models describe the behaviour of control systems. They comprise a 'controller,' which specifies system goals, and a 'control object.' 2.) Adaptive systems are open, interacting with their environments. They must be able to modify structure and function to adapt to environmental change. 3.) The state that a system is in at any point in time depends on past states and the goal state specified by the 'controller.' 4.) System performance is monitored in time, and information on actual performance is fed back to a comparator, which contrasts what is happening with what is wanted. 5.) Resources are allocated as required to ensure that actual system performance is within the limits specified by the controller. 6.) The range of adaptability is limited by the variety of available resources. If the system is subjected to a variety of environmental disturbance, but has a limited variety of resources, its adaptive capability is limited. 7.) The lowest levels of the system must be able to function autonomously because centralized control is limited. Man, for example, has both a central and autonomic nervous system. The autonomic system controls variables such as blood pressure, body temperature, and blood sugar level. The central nervous system is not involved at this level of control unless the autonomic system malfunctions.

Cybernetics can thus be used as the basis for generating an understanding of a control system and its ability to exert – or not – influence over an external system or process, as shown in Figure C.1 below.

Figure C.1 Schematic of a general control system



[267] Ashby (1956).

[268] Dabell (2018).

[269] Quot. in Dabell (2018).

[270] Howland (1988), cit. in Oluvie (1997).

Source: Skyttner (2005).

Cybernetics thus emphasises the need for C2 systems and organisations to increase their FARness (flexibility, adaptiveness and robustness), so as to maximise the variety of responses they can call upon, and to make use of improved sensor and sense-making capabilities (e.g. using AI and Big Data) to attenuate (filter) any variety in the environment which is irrelevant to what they are seeking to observe, and better understand what is known and controllable.

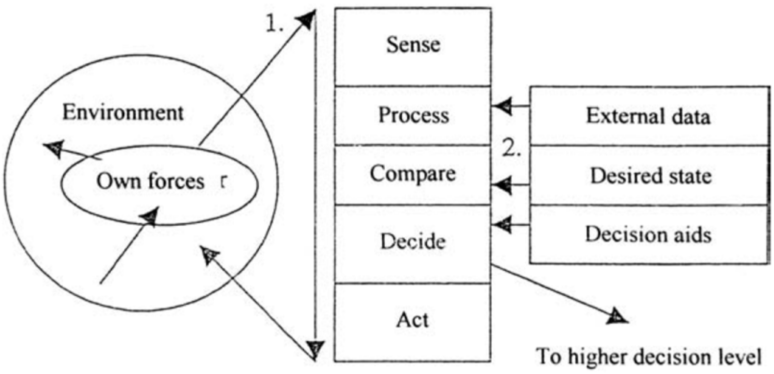
Figure C.2 Knowledge-control matrix

	Know	Don't Know
Control	Know that you control a system variable	Don't know that you control a system variable
Don't Control	Know that you don't control a system variable	Don't know that you don't control a system variable (or that it is even present)

Source: Schuck (2021).

In turn, it is possible to map this generalised model of a control system to the specific context of decision making within military C2. A prominent example is Lawson's model, as shown in Figure C. 3 below.

Figure C.3 Lawson's model for C2



Source: Lawson (1978), cit. in Skyttner (2005).

The cybernetics literature thus holds a range of relevant insights and potential guiding principles for designing C2 systems and organisations. It emphasises the need for improved information flows and communications, enhanced cognitive capacity, agility and ability to innovate, and a flexible range of levers to use to exert an influence (control) on the external environment.[271] It also emphasises the fundamental trade-offs that exist between meaningful insights and precise language, models or plans when dealing with the messy realities of complex systems such as society, geopolitics or warfare – Lotfi Zadeh's concept of 'Fuzzy Logic' (the Law of Incompatibility) stressing 'as complexity rises, precise statements lose meaning

[271] Oluvie (1997); NATO STO (2014).

and meaningful statements lose precision.'[272] This has thus led to the emergence of various so-called fuzzy techniques for modelling and analysis, examples of which are included in Section C.6 below.

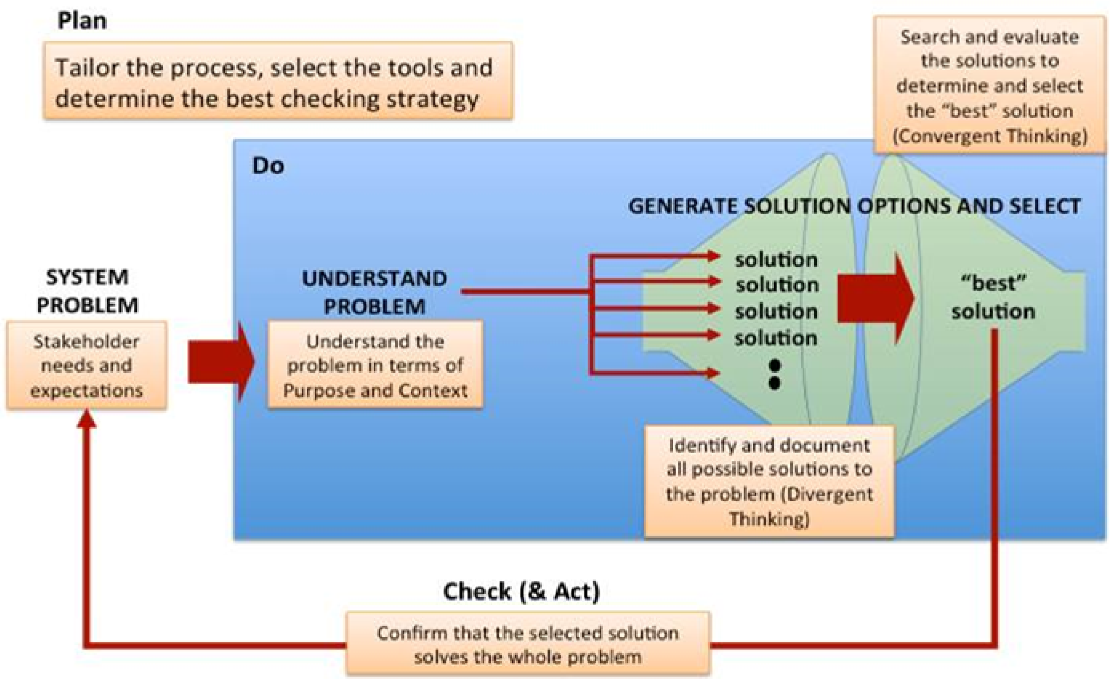
These insights can also be pushed even further and applied recursively as a critique of the practice of cybernetics itself – known as second-order cybernetics. Originating in the work of Heinz van Foerster in 1974, this cybernetics-of-cybernetics examines the 'control of control and the communication of communication' and explores the recursive nature of relationships with and among the observers (or other actors such as designers, users, etc.) engaging with and trying to understand an observed system.[273] In turn, there have been tentative attempts to develop a theory of third-order cybernetics, which would push this logic even further by trying to embed second-order cybernetics within a broader social or ecological context, but this promotion of higher orders has had more limited uptake.

C.2. Systems Engineering

Systems Engineering (SE) can be defined as 'a methodical and multi-disciplinary approach for the design, realization, technical management, operations, and retirement of a system' and 'the art and science of developing an operable system capable of meeting requirements within often opposed constraints'.[274] While there are questions over whether SE is an appropriate tool for understanding all complex systems or CAS, or is instead best applied only to manmade systems which can be designed and engineered, SE has emerged as a popular body of theory and practice across academia, the private sector and to an extent government.

SE seeks to balance a series of interactions within complex systems, such as between organisational structure, the performance of a technical solution, cost, and stakeholder buy-in to a given programme.

Figure C.4 Systems approach



272 Zadeh quot. in McNeil & Freiberger (1993).

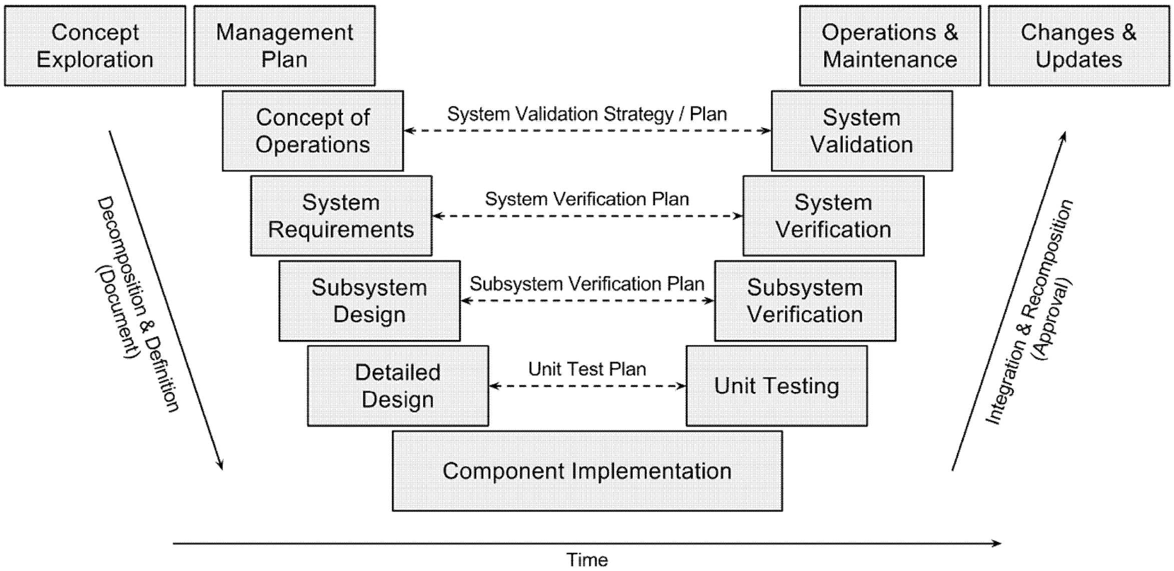
273 Scott (2004).

274 NASA (2019).

Source: BHW (2023).

To achieve this balance between opposing, potentially conflicting, constraints and objectives, SE emphasises the need for system engineers to consider the big picture while also diving deep into specifics, before repeatedly resurfacing to test and adjust the approach over time. This begins with defining a concept of operations, before moving through the architecture, system and sub-system levels down to the granular detail, before working back up and revisiting plans and assumptions as needed in response to multiple levels of testing and verification activities. This 'combination of "top-down" design and "bottom-up" build and check' is often depicted as a V-diagram, as shown in Figure C.5 below.[275]

Figure C.5 Indicative V-diagram for systems engineering



Source: Wikimedia (n.d.). Note: such an approach may not be appropriate or useful for complex systems or CAS.

Various tools and techniques are associated with SE as an overarching approach. These include but are not limited to the analytic hierarchy process (AHP) (see Section C.7 for further discussion); function means analysis; holistic requirements modelling; matrix diagrams (including the Pugh Matrix); stakeholder or systems mapping; and viewpoint analysis. SE is now a well-established management practice in many large and complex organisations, such as those responsible for designing and implementing programmes relating to industrial production, healthcare, nuclear or transport. Equally, it has its acknowledged limitations, including difficulty grappling with more unstructured situations, leading to the emergence of alternative approaches, such as Soft Systems Methodology and Critical Systems Thinking, as discussed below.[276]

[275] BHW (2023).

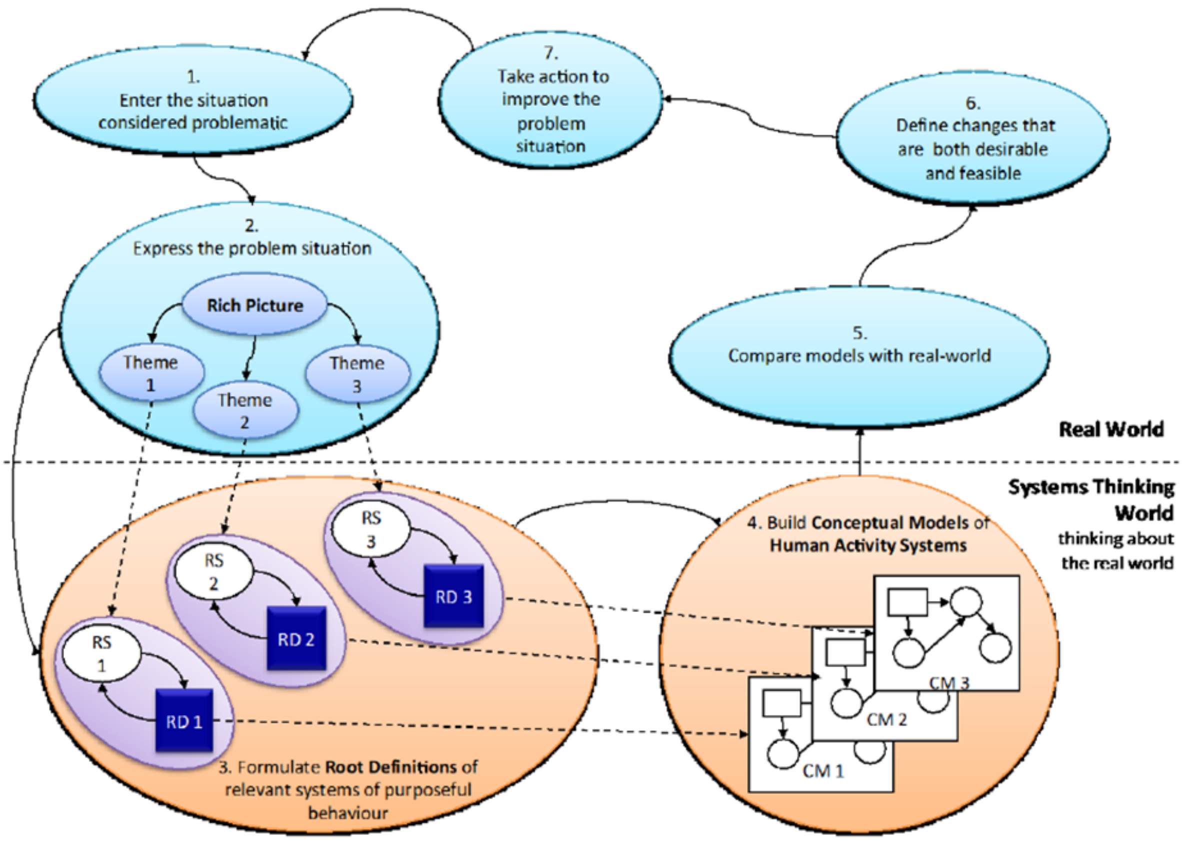
[276] Flood (1988).

C.3. Soft Systems Methodology

Soft Systems Methodology (SSM) is an alternative and widely applied approach to thinking about and grappling with complex problems. It emerged out of research at the Lancaster Systems Department in the 1970s into the struggles of 'hard' systems engineering approaches to solving business management or policy challenges, positing that more success could be had with a 'soft' approach to such messy and ill-defined real-world problems.[277] SSM differentiates between the real world and the systems thinking world, postulating that the latter is best understood as a domain of abstract concepts (holons) which, when used against the real world, can help to inform interventions that achieve positive change.[278]

Over time SSM has evolved to encompass a well-documented seven-step process, as outlined in the figure below.

Figure C.6 Seven Steps of SSM



Source: Burge (2015).

This process is associated with a variety of tools, including[279]:

- Rich Picture: A visual depiction of a complex situation which enables identification of differing interpretations of the situation, the relevant systems and elements, and their interrelationships. These should not be constrained by formal notations or symbology.

[277] Checkland (1981); Wilson (2001).

[278] Rodriguez-Ulloa & Paucar-Caceres (2005).

[279] Burge (2015).

- Root Definitions: A statement of purpose that captures the essence of a particular situation.
- CATWOE: A framework for defining and analysing different stakeholder perspectives and roles within any change programme, comprising a mnemonic for Customer, Actor, Transformation, Worldview (or the German 'Weltanschauung'), Owner and Environmental Constraints.
- Conceptual Models: Defensible logical models of Human Activity Systems, i.e. the possible changes that could be undertaken to achieve a desired transformation in the real world.

These have a common focus on drawing out different perspectives on, and mental models of, the world, fleshing out and refining these, and then defining a transformation programme and series of operational activities that appear rational and logically defensible within the constraints of having incomplete information and bounded rationality. SSM also emphasises the need to compare these models with the real world, and to establish a monitoring and control system (or, argue some theorists, a two-tiered system[280]) to implement refinements to the approach as needed based on feedback from the environment. This focuses on evaluating systems performance in terms of the so-called three E's, namely[281]:

- Effectiveness: Is the system doing the right thing – contributing to higher-level goals?
- Efficacy: Is the system providing the desired result?
- Efficiency: Is the system using the minimum of resources?

As such, SSM offers a structured yet flexible approach to look at complex problems and encourage debate among a variety of stakeholder or expert perspectives. At the same time, such a 'soft' approach is inherently limited in terms of its ability to leverage 'hard' systems engineering or modelling techniques. In particular, its models are not descriptions of the real world and thus cannot be treated as offering robust or normative guidance on how to solve a given problem. As a result, there have been various attempts to merge elements of SSM with other approaches, such as outlined below.

C.4. Soft System Dynamics Methodology

Given the abovementioned limitations to SSM, it has been combined with insights from Systems Dynamics to form the Soft System Dynamics Methodology (SSDM). This focuses on three worlds rather than the two counterposed in SSM: the Real World, the Problem-Situation-Oriented System Thinking World and the Solving-Situation-Oriented System Thinking World. SSDM involves ten steps rather than seven, moving back and forth between these three worlds[282]:

Real World:

1. Looking at the Unstructured Problem-Situation
2. Structured Problem-Situation or 'Rich Picture'

First SSDM Systemic Loop: Problem-Situation Systems Thinking World

[280] Wilson argues that there should be only one level of monitoring and control, since any operational activities derived via defensible logic from the Root Definition must be aligned to the intended purpose and thus effective. By contrast, Checkland argues that an additional layer is required, beyond the monitoring and controlling of operational activities (which determines their efficacy and efficiency), to account for the wider environment (to determine effectiveness). Cf. the discussion in Burge (2015, 9–10).

[281] Checkland (1981); Wilson (2001).

[282] Rodriguez-Ulloa & Paucar-Caceres (2005).

3. Problem-Oriented Root Definitions
4. Building System Dynamics Models of the 'Problematic Situation'

Real World:

5. Compare Stage 4 Against Stage 2

Second SSDM Systemic Loop: Solving-Situation Systems Thinking World

6. Determine Culturally Feasible and Systematically Desirable Changes
7. Building System Dynamics Models of the 'Solving Situation'
8. Solving Situation-Oriented Root Definitions

Real World:

9. Implementation of Feasible and Desirable Changes in the Real World
10. Learning Points

C.5. Critical Systems Thinking and Practice

Critical Systems Thinking and Practice (CST or CSP) address similar themes to deliberation with analysis, another meta-approach that focuses on broadening the number and variety of voices and disciplinary perspectives brought to bear on a problem. This is based on a critique of enduring stovepipes and failures to engage with a greater diversity of perspectives even within mainstream complexity and systems thinking, despite the avowed rejection of positivism, reductionism and hierarchical approaches within those fields.

Proponents of CSP advocate a guiding rubric known as EPIC[283]:

- E: Exploring the problem situation
- P: Producing an appropriate intervention strategy
- I: Intervening flexibly (and revisiting the previous two steps as needed)
- C: Checking on progress.

As is a recurring theme, this again proposes an iterative, adaptive approach to manage complexity over time.

C.6. Interpretative Structural Modelling

Various modelling techniques can be employed to help understand and navigate complex adaptive systems. A prominent example is Interpretative Structural Modelling (ISM), a method which emerged from the work of John Warfield in the 1970s. ISM provides a structured approach to analysing complex systems by first deconstructing them to their system elements (nodes) and then exploring and modelling the relationships among them (links), thereby obtaining a hierarchical structural model of the overall system[284]:

> ISM deals with the interpretation of the embedded object or representation system by systematic iterative application of graph theory resulting in a directed

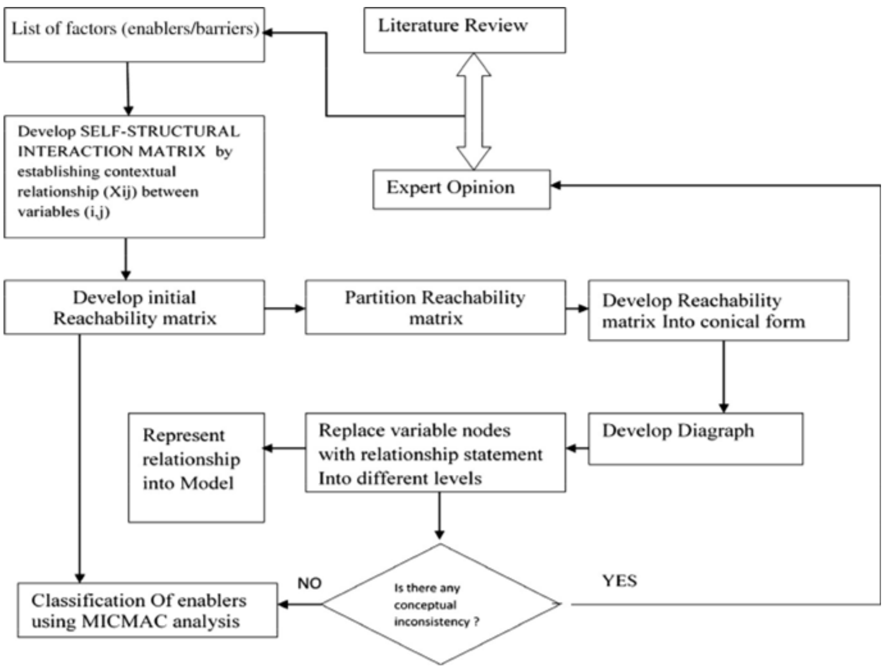
[283] Jackson (2020).

[284] Sushil (2012).

> graph for the complex system for a given contextual relationship amongst a set of elements. Interpretive structural modelling, can, therefore, be defined as a process that transforms unclear and poorly articulated mental models of systems into visible, well-defined models useful for many purposes.

Importantly, ISM is intended as an iterative and, often, group process.[285] It seeks to bring together multiple actors' perspectives and interpretations – the I in ISM – of a complex issue or system, and to refine mental models over time through analysis and learning.[286] Algorithmic steps include development of structural self-interaction (SSIM) and reachability matrices, and then a digraph to depict the system elements and their relationships, and thus feedback loops (though these may sometimes be eliminated, to produce a digraph of minimum edges, if the intention is to focus only on direct rather than indirect relationships).[287]

Figure C.7 Steps of Interpretative Structural Modelling



Source: Thakkar (2021).

ISM has been employed in a wide range of civilian settings but has also specifically been used to help understand military–civil integration and other questions of C2.[288] It benefits from enabling the 'first-cut' visualisation of a complex system in a simplified manner – and thus one more digestible to policy makers or military officials – and facilitating deliberation and analysis among experts to move towards a better understanding of the structure of that system.[289] However, ISM also suffers from drawbacks. These include the reliance on computing modelling and specialist knowledge to interpret the data, as well as the fact that ISM can depict the what and how of a system, but not the why (i.e. the causality of the links depicted).[290]

[285] Janes (1988).
[286] Kumar & Singh (2019).
[287] Sushil (2012).
[288] Yang & Zhang (2019).
[289] Kumar & Singh (2019).
[290] Sushil (2012).

A more recent iteration of the ISM approach is Total Interpretative Structural Modelling (TISM), which seeks to generate a deeper understanding of the why, while so-called ISM* seeks to combine elements of both classical and TISM approaches.[291]

C.7. Multi-Criteria Decision Methods

ISM is one of the more prominent examples among a broader toolkit of methods known as Multi-Criteria Decision Analysis (MCDA) or Multi-Criteria Decision Making (MCDM). This field has seen significant research and practitioner interest in recent decades, including applications within UK Defence and PAGs (e.g. to inform force and capability development decisions).[292]

Besides ISM, examples of MCDA methods include, but are not limited to:

- Analytic Hierarchy Process (AHP)
- Analytic Network Process (ANP)
- Fuzzy Set Theory (FST)
- Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)
- Decision Making Trial and Evaluation Laboratory (DEMATEL)

A more complete list of MCDA methods, including original sources and citation numbers as of 2022, can be found in Taherdoost & Madanchian (2023).

Though these methods differ in their respective steps, strengths and limitations, a recurring theme is a focus on improving problem structuring; understanding the decision and trade space; scoring alternative courses of action based on evaluation criteria; and, ultimately, assigning weighting to those different criteria and thus coming to a final decision. MDCA techniques are thus intended to help decision makers face the messy reality that their choices are likely to be a compromise between several competing impulses and will have contradictory, even counterintuitive, impacts, but still need to be as robust and defensible as possible even though they cannot optimise for one single criterion.[293]

Though they are not all explicitly tailored to – or appropriate for – dealing with CAS,[294] MCDA methods offer potential utility in their focus on providing structured approaches to grappling with uncertain and imperfect information, exploring multivariate and non-linear dynamics, providing weighting for different data inputs (including stakeholder or expert opinion[295]), and striking more informed compromises in strategic or operational decision making (of interest when seeking to align the overlapping, perhaps competing, goals of cross-governmental or multinational partners within a C2 system of systems).[296]

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[291] Sushil (2012); Sorooshian et al. (2023).

[292] DCLG (2009); Bailey & Pitinanondha (2016); HM Treasury (2022).

[293] Taherdoost & Madanchian (2023).

[294] Voronin (2017).

[295] Bailey & Pitinanondha (2016).

[296] Taherdoost & Madanchian (2023).

C.8. Design Thinking

Related to the surge in activity around complexity and systems thinking over the last few decades, there has also been a proliferation of academic literature and practical initiatives under the auspices of Design Thinking. While there is no single authoritative definition, design is often understood to mean the act of imagining or creating that which is needed but does not yet exist.[297] Beaulieu-B and Dufort offer a definition in the military context which explicitly ties design thinking to grappling with complexity[298]:

> Military design thinking means the capability to understand a current conflict environment from a holistic perspective, to imagine a desired post-conflict environment and to realize it with counterintuitive military and non-military means. In short… [it] is an umbrella term for a more or less consistent assemblage of reflexive approaches including complexity theory (e.g. John Holland, Yaneer Bar-Yam, Robert Axelrod), systems thinking (e.g. Peter Checkland, Fritjof Capra, Humberto Maturana) and postmodern social theory (e.g. Michel Foucault, Gilles Deleuze & Felix Guattari, Jacques Ranciere) to name a few.

Since its emergence in the 1960s and 1970s, design thinking has been applied in a range of civilian sectors grappling with complex systems. Examples include computing, urban planning and consumer product design. Design thinkers often emphasise and practice multidisciplinary approaches, drawing from many of the diverse fields discussed in Chapter 2. Over the decades, various sub-fields have emerged, such as service design, with a more recent trend towards human-centric or social systems design.

Military design thinking started in Israel, where the Israeli Defence Force (IDF) coined the Systemic Operational Design (SOD) method in the 1990s. This drew on 'a diverse interdisciplinary approach that included foremost an analysis of Soviet operational art using general systems theory, informed by a critical reading of military history' as well as cybernetics, psychology and post-modernism.[299] Though the IDF later turned away from SOD in the years before the 2006 Hezbollah War, having found it hard to replace more traditional joint operational planning processes, its military design thinking soon influenced other militaries. In 2010, the United States outlined its own Army Design Methodology, while the US Marine Corps followed with its own in 2017.[300] The IDF introduced a successor to SOD in 2013, with its Systemic Inquiry in Operational Mediation methodology,[301] while the Australian Defence Force folded elements of this thinking into its Joint Military Appreciation Process.[302] Design thinking has subsequently been incorporated into professional military education courses on both sides of the Atlantic, and the notion of 'operational design' introduced into NATO doctrine.[303] For its part, the UK MOD has 'provided doctrine to their military that expresses many design concepts while avoiding the word "design" entirely'.[304]

While each national or service-level methodology for operational design has its own nuances, common themes include a strong focus on environment and problem framing, critical thinking and iterative cycles of exploration, prototyping and refinement of possible solutions.[305] This links more classical approaches to

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[297] Nelson & Stolterman (2003); Jackson (2019); Wrigley et al. (2021).

[298] Beaulieu-B & Dufort (2017, 2).

[299] Naveh (1997), cit. in Jackson (2019).

[300] US Department of the Army (2015); US Marine Corps (2017).

[301] Zweibelson (2017).

[302] ADF (2016).

[303] De Spiegeleire et al. (2014); van der Veer (2015).

[304] Zweibelson (2018), quot. in Jackson (2019).

[305] Wrigley et al. (2021).

planning and operational art (e.g. identification of desired end states, centre of gravity analysis, etc.) to complex adaptive systems theory.[306] Military design thinking methods also tend to be more community or civilian-centred and thus aligned to concepts of human security.[307] Outside of strategy making and joint planning, design methods have also been applied to other Defence problems in recent years, including force design and transformation of approaches to capability development. Examples of specific methods include horizon scanning, scenario analysis, systems mapping, wind tunnelling, prototyping, empathy mapping, GIGA-mapping, paradoxical reasoning, and substantive play.[308] While each has its own strengths and limitations, there is a recurring focus on encouraging creativity and lateral and divergent thinking.[309]

Importantly, proponents emphasise the need to apply design thinking not only to a given strategy or plan, but also to the meta-strategy, i.e. the architecture, system or process through which those strategies and plans are developed, and the metrics framework by which the success or failure of implementation is then monitored. This calls for a continuous effort to co-adapt the UK's C2 systems in light of both the prototyping and design of plans and an evolving understanding of the external environment (including hostile actors' own C2). This is illustrated in Figure 5.1 in Chapter 5. This self-reflexive design approach also bears some similarities to uncertainty-sensitive planning techniques outlined in Annex D.

[306] Jackson (2019).
[307] Wrigley et al. (2021).
[308] Pincombe et al. (2019); Zweibelson (2019).
[309] Furtado (2019).

Annex D. DMDU Methods

This annex provides a brief description and, where relevant, visualisation of prominent DMDU methods, building on the discussion in Chapter 5 about the intersection between tackling complexity and uncertainty:

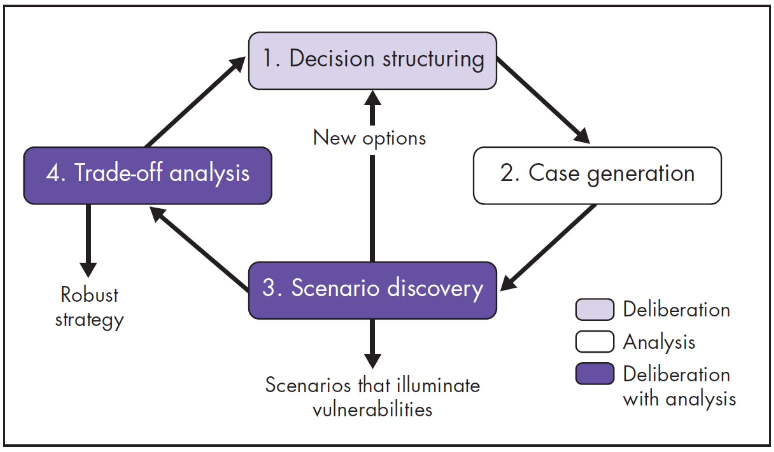
- Robust Decision Making (RDM)
- Three Horizon Foresight (3HF)
- Assumption-Based Planning (ABP)
- Dynamic Adaptive Planning (DAP)
- Strategic Portfolio Analysis (SPA)
- Dynamic Adaptive Policy Pathways (DAPP).

For a more detailed description and assessment of each, including potential applications for UK Defence and necessary enablers, see Black, Paille et al. (2021).

D.1. Robust Decision Making (RDM)

RDM is one of the most high-profile DMDU methods. It seeks to create a range of robust options (for a given strategy, policy, plan or decision) rather than to predict the optimal approach. Options can then be tested against a large number of plausible futures using computer modelling to evaluate their performance as they adapt over time and to enable an assessment of the trade-offs between them.

Figure D.1 Overview of the RDM process



Source: Lempert et al. (2013).

This involves the following steps[310]:

- Decision structuring or framing: understanding the objectives that a decision maker is seeking to frame in subsequent generation of a robust strategy or plan. This typically involves use of an XLRM framework to identify: (X) exogenous factors, i.e. those external factors that affect the success or failure of a strategy but which cannot be controlled by the decision maker; (L) levers, i.e. the possible actions available to them; (R) relationships, i.e. causal linkages between X and L; and (M) measures of performance, i.e. indicators that can be used to assess progress with a given strategy towards the agreed objectives. Figure B.2 provides an illustrative example of an XLRM framework (note: while RDM has been widely applied in defence and security studies,[311] given their sensitivities this example is instead drawn from an unclassified study on environmental management).

Figure D.2 Example of an XLRM framework

Exogenous factors (X)	Policy levers (L)
Future water demand (6)	Water management portfolios (4)
Streamflow under different climate regimes (thousands)	• Up to 40 different water management actions
• Resampled historical record	• Signposts and triggers used to specify investments
• Resampled paleoclimate record	
• Downscaled global climate model projections	
System operations (2)	

Relationships (R)	Measures of performance (M)
Colorado River Simulation System (CRSS)	10-year average streamflow at Lees Ferry (Upper Basin reliability)
	Lake Mead pool elevation (Lower Basin reliability)

Source: Marchau et al. (2019).

- Case generation: using modelling and simulation to generate a wide range of plausible futures against which to test possible strategies. Here, the focus is on measuring and minimising 'regret' across these plausible futures, i.e. minimising the difference between the outcome of a possible strategy and the optimal one for a given world state. This differs from optimising a strategy for a single scenario or small set of scenarios selected according to particular criteria (e.g. likelihood); instead, the aim is to identify those strategies that minimise regret across the widest range of plausible futures. This does not necessarily mean that outcomes would be favourable, but rather that outcomes would be as good, or as least bad, as possible (which may still be unsatisfactory). Crucially, this does not mean seeking the lowest common-denominator strategy. Rather, it is about identifying those actions which help to minimise regret across a range of plausible futures so as to mitigate the risk of surprise, strategic shock or high levels of regret.

[310] Groves & Lempert (2007); Kasprzyk et al. (2013); Kalra & Groves (2017); Marchau et al. (2019).
[311] E.g. Dixon et al. (2007); Leftwich et al. (2019); Popper (2019b).

- Scenario discovery: assessing the strengths and vulnerabilities of potential strategies when applied to this wide range of plausible futures. This often involves using Scenario Discovery (SD) algorithms such as the Patient Rule Induction Method (PRIM) or Classification and Regression Tree (CART) to help identify vulnerabilities via statistical cluster analysis. These algorithms can pinpoint clusters of possible strategies that perform well for one or more values of uncertainty, and identify associated vulnerabilities or other alternative strategies for mitigating them.
- Trade-off analysis: assessing the trade-offs between the identified strategies, given the stated objectives of the decision maker (from Step 1). This can include combining elements of multiple strategies, based on analysis of levels of regret experienced over time and across the full uncertainty space in terms of plausible futures.
- Identification of robust strategies: adopting and then implementing strategies that are most robust across a wide range of plausible futures and minimise regret. Robust strategies should involve adaptive elements and monitoring of signals of changing conditions, so as to help them remain effective over time, informed by the analysis of vulnerabilities and potential shocks or surprises that could occur within the uncertainty space.

D.2. Three Horizon Foresight (3HF)

3HF focuses on the requirement for decision makers to consider multiple time frames simultaneously[312]:

- Horizon 1, representing the current state of the operating environment, as well as 'pockets of the future', i.e. immature manifestations of emergent behaviour and order, and weak signals about how the structure and dynamics of the system may evolve in the future.
- Horizon 3, representing the range of plausible alternative future states in the face of uncertainty.
- Horizon 2, representing the transition between 1 and 3, where variables and actors interact to determine which of the plausible alternative futures comes to pass, with competitors trying to steer towards their own desired futures based on their own bounded rationality and finite levers.

This technique is intended to help frame a structured conversation between analysts and decision makers in the absence of a quantitative model, focusing on understanding how best to navigate the 'triangle of conflict' that exists in Horizon 2 and to identify weak signals early on when envisaging Horizon 3.[313]

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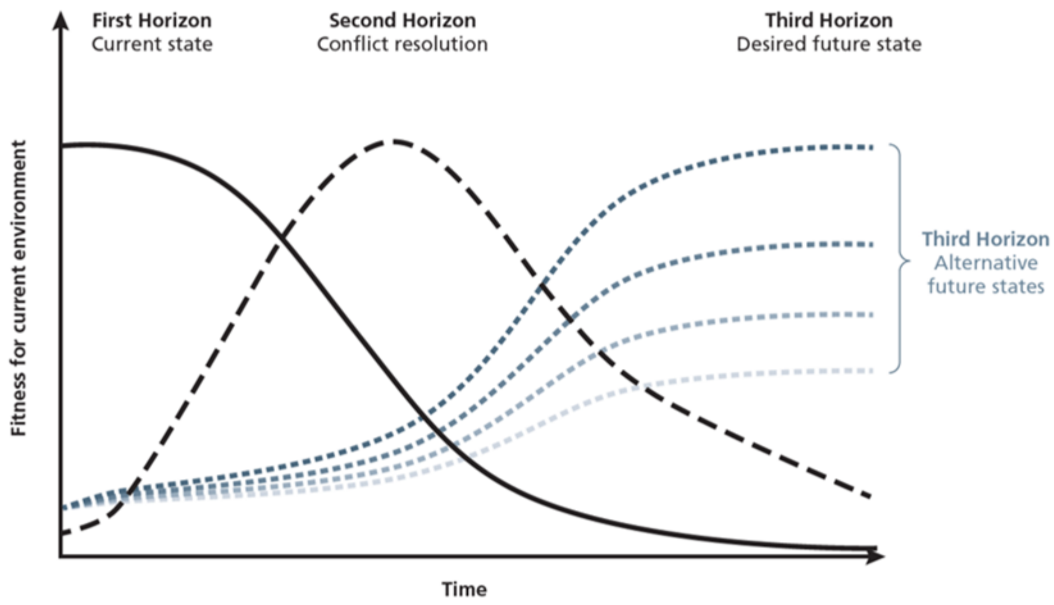
[312] Curry & Hodgson (2008).

[313] Curry & Hodgson (2008).

Figure D.3 Three Horizon Foresight model



Source: Ecola et al. (2018).

D.3. Assumption-Based Planning (ABP)

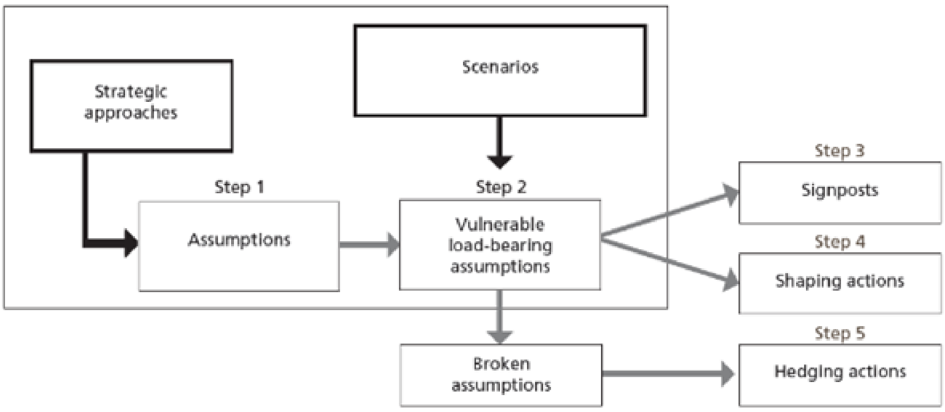
ABP is a qualitative method for developing more robust decisions in the face of an uncertain and complex situation.[314] It involves five steps:

- Identifying the assumptions underpinning a given strategy or plan.
- Identifying which of these are 'load bearing' (i.e. their negation would jeopardise success and require significant changes to the approach) and which are vulnerable (i.e. 'if a plausible event in the world would cause them to fail… within the planning time horizon'[315]).
- Identifying signals that may suggest to decision makers that these assumptions are changing and thus that the initial plan is becoming increasingly vulnerable to failure, if not adjusted. Monitoring systems can then be set up to capture these warning signs and enable adaptation.
- Identifying shaping actions, defined as proactive steps that can be taken in the short term of the planning horizon to 'control the vulnerability of an important assumption' (e.g. if a plan relies on an ally's continuing support, taking diplomatic action to shore up that support).
- Identifying hedging actions, defined as steps that can be taken in the short term of the planning horizon 'intended to better prepare an organisation for the failure of one of its important assumptions' (e.g. if a plan relies on an ally's continuing support, taking steps to diversify into other partnerships or shore up sovereign capacity to act alone if the ally withdraws support).

[314] Dewar & Levin (1992); Lempert et al. (2008).

[315] Dewar et al. (1993).

Figure D.4 Assumption-Based Planning



Source: Ecola et al. (2018).

D.4. Dynamic Adaptive Planning

DAP draws on a similar overarching philosophy to ABP, but elaborates upon it within an overall two-phase approach covering design and implementation. The design phase involves five steps[316]:

- Stage setting: defining the objectives that a plan aims to fulfil, along with known constraints and possible options available to decision makers.
- Assembling an initial plan: development of an initial plan on the basis of the outputs of the first step and gathering a variety of expert and stakeholder perspectives to identify the conditions (e.g. PESTLE-M or similar framework) necessary to achieve success (i.e. key assumptions).
- Increasing the robustness of the initial plan: taking action to increase robustness and the scope for the plan to endure and adapt over time in response to feedback. This includes identifying opportunities and vulnerabilities, i.e. elements that will reduce or increase the success of the plan as initially envisaged. This can be done via a range of methods depending on data, time and resource, including exploratory modelling for a more quantitative approach, or a more qualitative SWOT analysis or Delphi process.[317] Five types of near-term actions can then be taken to address these opportunities and vulnerabilities:
    - Mitigating actions: these address the initial plan's likely vulnerabilities.
    - Hedging actions: these address uncertain vulnerabilities and the associated risks.
    - Seizing actions: these are those likely to improve the plan based on likely opportunities.
    - Exploiting actions: these exploit uncertain opportunities for the plan's benefit or success.
    - Shaping actions: these seek to influence the external environment of the plan (e.g. the international system) to limit its likelihood of failure and increase its likelihood of success.

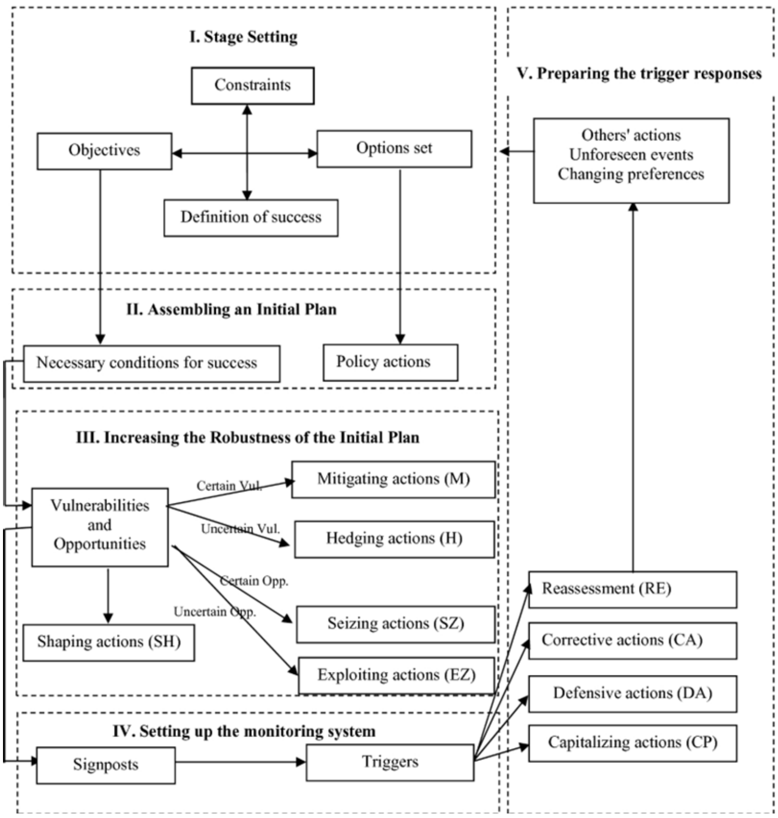
[316] Marchau et al. (2019).

[317] SWOT = Strengths, weaknesses, opportunities, and threats. Delphi is a workshop-based expert elicitation technique involving multiple rounds of assessment and scoring, with deliberation in between, so as to identify the reasons for divergence of expert opinions and move towards a common position.

- Setting up a monitoring system: developing a monitoring system to capture signals that decision makers can use to evolve and adapt the plan over time during the implementation phase, based on feedback on the environment. This involves identification of indicators that could feasibly be tracked and, where relevant, thresholds that indicate a change to the plan needs to occur.
- Preparing the trigger responses: identifying four types of contingent actions that can be taken if needed due to signals picked up by the monitoring system set up in the previous step:
    - Defensive actions: taken in response to triggers identified in Step 4 but which do not alter the nature of the plan.
    - Corrective actions: taken to change the plan in light of the triggers.
    - Capitalising actions: taken to exploit emerging opportunities to increase the performance of the plan after it is implemented.
    - Reassessment: stepping back to the beginning of the planning cycle when it becomes clear that the plan can no longer be successful (e.g. due to changing conditions or goals).

Having addressed these issues in the design phase, it is then possible to implement the initial plan and then monitor signals and learn and adapt over time as needed, increasing robustness in the face of uncertainty.

Figure D.5 Dynamic Adaptive Planning: the design phase



Source: Marchau et al. (2019).

D.5. Strategic Portfolio Analysis

Portfolio analysis focuses on how to balance between multiple objectives, as opposed merely to increasing the robustness of a plan to deliver on one goal. It can be defined as an 'analysis that assesses alternative investment options by diverse qualitative or quantitative objectives, including risk mitigation. The analysis aids in "balancing" investment to address all objectives and mitigate all risks but to different degrees, depending on priorities, budgets, and feasibilities.'[318]

SPA encourages a strategic, top-down but layered view of how alternative futures might affect performance against multiple goals, helping to identify not only the mitigations and hedging actions that can be taken but also the trade-offs between goals. Various evaluation tools exist to support this sort of activity.[319]

D.6. Dynamic Adaptive Policy Pathways

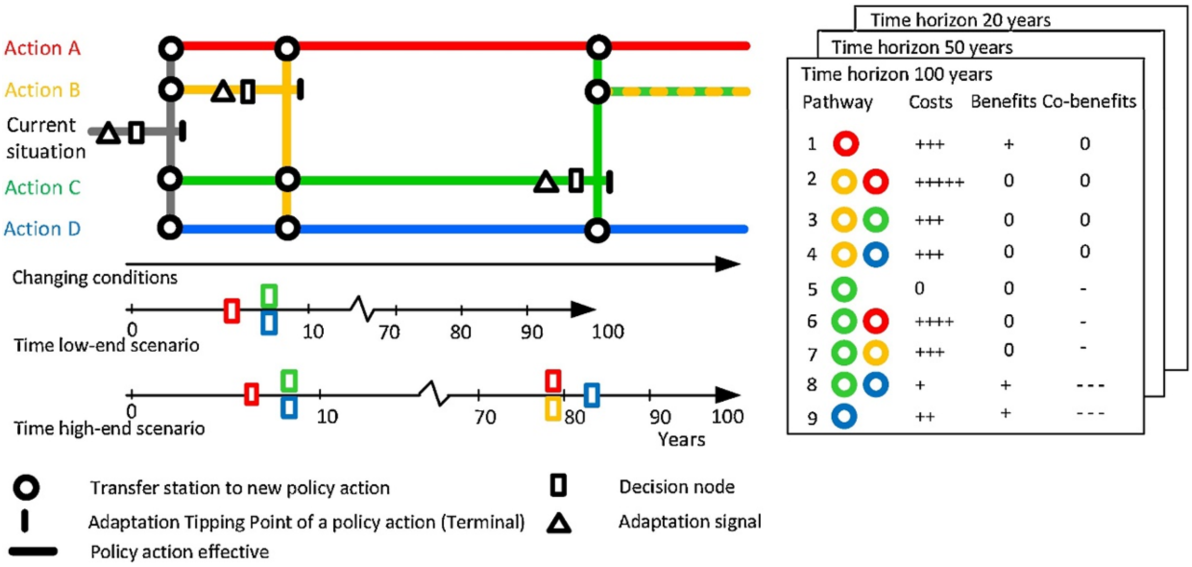
Bearing some similarity to DAP, DAPP integrates flexibility and adaptive pathways into the design and implementation of a given strategy, policy or plan. This involves seven main steps:

- Problem framing: defining the current state of a system, i.e. whether it is complex, its structure, characteristics and objectives if applicable (e.g. if looking at an organisation), as well as the constraints which bound it. The aim here is to understand the uncertainties and measures, indicators or targets that can be used later in the process to monitor and evaluate whether the plan has been successful or not.
- Assessment of vulnerability and opportunities: identifying the conditions under which the plan is likely to fail (using various methods, e.g. by assessing the plan against future scenarios), so as to clarify the 'adaptation tipping point' (ATP) conditions that signpost the need for change.
- Contingent actions: identifying possible contingent actions (akin to DAP's Step 5) and assessing these against the ATPs to determine which are most promising (e.g. efficient).
- Pathways design and execution: developing pathways (i.e. individual or groups of actions in pursuit of the plan's objectives) that can evolve over time in response to ATPs and their signals. These can then be evaluated against relevant criteria (e.g. urgency, impact, uncertainty) using a variety of quantitative tools (e.g. agent-based, or multi-objective optimisation models) or qualitative methods (e.g. deliberative mechanisms) to identify trade-offs between them. The aim is to enable transfer between possible actions based on monitoring changing conditions and ATPs.

[318] Davis et al. (2008).

[319] Davis et al. (1996); Davis & Dreyer (2009); Davis (2014).

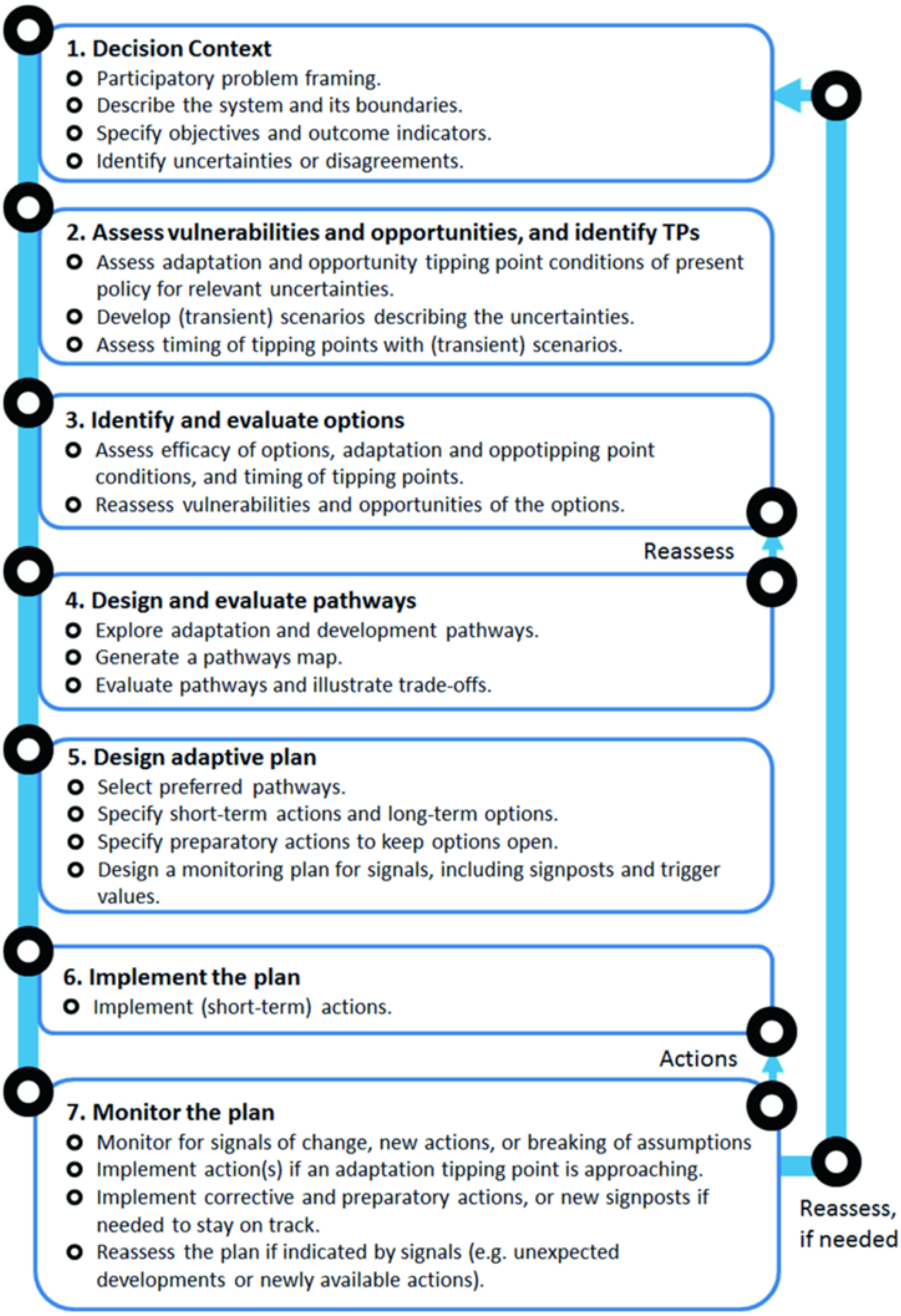
Figure D.6 DAPP Pathways development process



Source: Marchau et al. (2019).

- Adaptive strategy design: identifying the preferred pathway(s) based on this evaluation of trade-offs. At the same time, short- and long-term options and preparatory actions (e.g. defensive, corrective, capitalising, etc.) are identified and a monitoring system established to identify reliable signals and triggers for a change in pathway. (Note: whereas ATPs relate to the plan's objectives, these broader signals and triggers relate to wider changes in conditions that could affect the system.)
- Strategy implementation: implementation of the plan, starting with short-term actions.
- Strategy monitoring: rolling usage of the monitoring system established in the previous steps to capture signals that may then trigger decisions to change pathway.

Figure D.7 The seven steps of DAPP



Source: Marchau et al. (2019).