RAND EUROPE

Global Mobility

Future Force Design 2040

Lucia Retter, Zudik Hernandez, Ben Caves,
Megan Hughes, Anna Knack

For more information on this publication, visit www.rand.org/t/RRA1309-1

The Global Strategic Partnership (GSP), a consortium of research, academic and industry organisations that is led by RAND Europe, provides ongoing analytical support to the UK Ministry of Defence.

About RAND Europe
RAND Europe is a not-for-profit research organisation that helps improve policy and decisionmaking through research and analysis. To learn more about RAND Europe, visit www.randeurope.org.

Research Integrity
Our mission to help improve policy and decisionmaking through research and analysis is enabled through our core values of quality and objectivity and our unwavering commitment to the highest level of integrity and ethical behaviour. To help ensure our research and analysis are rigorous, objective, and nonpartisan, we subject our research publications to a robust and exacting quality-assurance process; avoid both the appearance and reality of financial and other conflicts of interest through staff training, project screening, and a policy of mandatory disclosure; and pursue transparency in our research engagements through our commitment to the open publication of our research findings and recommendations, disclosure of the source of funding of published research, and policies to ensure intellectual independence. For more information, visit www.rand.org/about/principles.

RAND's publications do not necessarily reflect the opinions of its research clients and sponsors.

Published by the RAND Corporation, Santa Monica, Calif., and Cambridge, UK

Cover image: Adobe Stock

Preface

This is the final report for a short study commissioned by the Development, Concepts and Doctrine Centre (DCDC) of the UK Ministry of Defence (MOD) on behalf of the MOD Finance and Military Capability team (FMC) to help develop a framework for identifying future global mobility requirements for the UK, using all available means, out to 2040. The study was conducted between February and June 2021 and had three core research objectives (ROs):

- RO1: To identify, at a high level, the core military requirements for global mobility out to 2040 and any potential shortfalls vis-à-vis the current equipment plan.
- RO2: To identify a range of different options for delivery of global mobility out to 2040, including exploration of multinational cooperation models, potential business models for, and the influence of, emerging and new technologies on the delivery of global mobility.
- RO3: To identify, at a high level, the implications of these options for future force design and capability planning, considering also how the potential capability gap can be bridged.

This report will be of interest to strategy, policy and capability decision makers within UK Defence as well as wider stakeholders involved in delivering or using global mobility assets and systems now and in the future.

The study was undertaken by RAND Europe, which leads the Global Strategic Partnership (GSP) consortium providing strategic, policy and academic support to DCDC. Part of the RAND Corporation, RAND Europe is a not-for-profit research institute with a mission to help improve policy and decision making through robust research and analysis. RAND has 75 years of experience helping governments and militaries navigate complex choices in different defence domains.

For further information about the study, please contact:

Ben Caves

Senior Research Leader – Defence, Security and Infrastructure

RAND Europe

Westbrook Centre, Milton Road, Cambridge, United Kingdom

e. bcaves@randeurope.org

Summary

The *Integrated Review of UK's Security, Defence, Development and Foreign Policy* published in March 2021 presents an ambitious vision of a 'Global Britain' that has a persistent presence in different places around the world and is able to bear on a wide range of crises, operations and conflicts both close to home and further afield.

The realisation of this vision will rely on having the right force design and mix of military capabilities across all defence tasks to enable the UK Armed Forces to be 'in the right place at the right time'. Understanding how mobility requirements are likely to change between now and 2040 and what different options may need to be explored to effectively deliver mobility in a changing threat and policy environment is part of the puzzle faced by Defence decision makers looking to deliver against the UK's stated ambitions. It is likely that **the requirements for global military mobility will increase in terms of capacity, capability, survivability, assurance and speed of response, all within enduring constraints on affordability.**

A few key factors will shape the requirements for global mobility, including:

- **The nature of the threat environment**, including an increasingly contested physical (e.g. anti-access, area denial, A2AD), cyber and electromagnetic environment, climate-degraded areas, or nations refusing access, basing and overflight (ABO).
- **Developments in the information environment, cyberspace and space**, holding the potential to seamlessly integrate data between various systems (e.g. through a 'digital backbone') and achieve better situational awareness (e.g. through space-based intelligence, surveillance and reconnaissance), while at the same time magnifying security and operational risks if adversaries hack, gain access to or outright disable or destroy such capabilities.
- **Wider global trends**, including urbanisation, climate change and net zero objectives, developments in the commercial sector (e.g. automation, autonomy, advanced manufacturing), or shifting alliances and partnerships – many of which Defence cannot influence alone but will need to address.

UK Defence will continue to have to compete for finite resources with other government departments and in some ways will be required to 'do more with less' when delivering the country's global ambitions. This is exemplified by the envisaged reduction of the number of strategic airlift platforms over the next two decades. As a result, **Defence will need to think innovatively about how to design a model for delivering global mobility that is both effective and resilient.** A range of options should be considered which, in combination, could offer both effectiveness and resilience to the UK's mobility fleet and underpinning

systems. These options consider both the 'supply' side of mobility (i.e. the means of delivering mobility more effectively) and ways in which the 'demand' for mobility could be reduced and/or made more effective:

- **Multi-role platforms** – promising greater adaptability, agility and interoperability but also bringing their own risks, such as potentially being seen as expensive targets and hence too valuable to deploy to high-end threat environments, or misunderstood as a panacea for solving all mobility problems.
- **International collaboration** – opening opportunities for more cost-effective access to mobility assets through pooling and sharing and increasing interoperability, but also posing challenges in terms of availability assurance, reliability and achieving mutual benefit for all partners involved.
- **Commercial solutions** – presenting cost-effective options for permissive environments and low risk transport and logistics as well as opportunities to achieve greater environmental sustainability; but also with fewer assurances on availability than sovereign and, arguably, multilateral partnerships.
- **Uncrewed, optionally crewed, lightweight assets** – holding potential for both cost reduction and reduction of the risk to life, as well as enabling operations in challenging environments (e.g. urban, climate-degraded) but presenting regulatory challenges and changing the demand for support
- **Data-driven and/or data-enabled mobility** – presenting a necessary part of the overall digital integration of Defence systems but enhancing cyber risks and vulnerabilities, with potential for a significant impact of an adversarial attack due to the volume of data and cascading impact on military domains. Impact is foreseen both for how mobility is delivered ('supply') and also the 'demand' for mobility. This demand is likely to be shaped by enhanced situational awareness and hence an improved ability to identify where intervention is required (and hence where mobility needs to support such intervention).
- **Additive manufacturing** – building on successes in the commercial sector to provide opportunities to streamline supplies management and logistics, though applicability to the unique defence context is likely to be different across domains. Greater use of additive manufacturing can also help reduce the demand for mobility, contributing to a more self-sustaining deployed force.

To design an effective and resilient model for delivering global mobility, the UK MOD should focus on the following eight policy actions:

1. Placing **more focus on resilience and redundancy and less on efficiency** to better resource global mobility delivery, understanding the upfront costs as a necessary hedge against shocks (i.e. an insurance policy).
2. **Approaching mobility from a 'Multi-Domain Integration' perspective**[1] to increase synergies across the joint force, cutting across the traditional remit of individual Services or Top-Level Budget holders and pursuing multi-domain and multi-modal solutions to demand for mobility.
3. **Strengthening multinational collaboration arrangements** to extract greater value from them.

[1] UK MOD (2020a).

4. Working with partners and allies to **improve ABO and freedom to operate in key regions.**
5. **Investing in strategic bases and regional hubs** to allow for forward basing of mobility assets and increased use of prepositioning to reduce deployment lead times and enhance deterrence.
6. **Increasing the protection and survivability of global mobility assets** to enable their operation in a range of threat environments, given the proliferation of so-called A2AD capabilities.
7. **Mapping the vulnerabilities across Defence's global mobility assets and infrastructure** to help address potential areas of risk, including the growing challenge posed by air and missile threats, cyber-attacks and environmental degradation.
8. **Approaching global mobility from a sustainability and net carbon zero perspective** to ensure alignment with broader government sustainability goals (so far as security imperatives allow).

Table of contents

Figures, tables and boxes

Abbreviations

A2AD	Anti Access/Area Denial
AAR	Air-to-Air Refuelling
ABMS	Advanced Battle Management System
ABO	Access, Basing and Overflight
AI	Artificial Intelligence
AM	Additive Manufacturing
AMAS	Autonomous Mobility Appliqué System
ASAT	Anti-Satellite weapon systems
AT	Autonomous Truck
ATARES	Air Transport & Air-to-Air Refuelling and other Exchanges of Services
BMT	British Maritime Technology
CASEVAC	Casualty Evacuation
CONOPS	Concepts of Operations
CRAF	Civil Reserve Air Fleet
CSG	Carrier Strike Group
DCDC	Development, Concepts and Doctrine Centre
DE&S	Defence Equipment & Support
DEAD	Destruction of Enemy Defences
DEVCOM	United States Army Combat Capabilities Development Command
DFDS	Det Forenede Dampskibs-Selskab
DLODs	Defence Lines of Development
DT	Defence Task
DSCOM	Defence Support Chain Operations and Movements
DSD	Defence Strategic Direction
EATC	European Air Transport Command

EDA	European Defence Agency
EM	Electromagnetic (spectrum)
EO	Earth Observation
EU	European Union
FMC	MOD Finance and Military Capability Office
GFI	Government Furnished Information
GSP	Global Strategic Partnership
HADR	Humanitarian Assistance and Disaster Relief
HIMARS	High Mobility Artillery Rocket System
IOpC	Integrated Operating Concept
IOT	Internet of Things
ISR	Intelligence, Surveillance and Reconnaissance
IT	Information Technology
JADC2	Joint All-Domain Command and Control
KPI	Key Performance Indicator
LOGFAS	Logistics Functional Area Services
LOGFS	Logistics Functional Services
LPD	Landing Platform Dock
MACA	Military Aid to the Civil Authorities
MCCE	Movement Coordination Centre Europe
MDI	Multi-Domain Integration
ML	Machine Learning
MMF	Multinational MRTT Fleet
MMU	Multinational Multirole Tanker Transport Unit
MOD	Ministry of Defence
MOSA	Modular Open Systems Architecture
MRP	Multi-Role Platform
MRSS	Multi-Role Support Ship
MRTT	Multi-Role Tanker Transport
MRV	Multi-Role Vessel
NAO	National Audit Office

NATO	North Atlantic Treaty Organisation
NEO	Non-Combatant Evacuation Operation
NSPA	NATO Support and Procurement Agency
NSS	National Security Strategy
PESCO	Permanent Structured Cooperation
PFI	Private Financial Initiative
PJOB	Permanent Joint Operating Base
PNT	Positioning, Navigation and Timing
POE	Point of Embarkation
POGO	Proof of Good Order
RAF	Royal Air Force
RN	Royal Navy
SDSR	Strategic Defence and Security Review
SEAD	Suppression of Enemy Defences
UK	United Kingdom
US	United States
USAFRICOM	US Africa Command
USTRANSCOM	US Transportation Command

Acknowledgements

The study team is grateful to the many people who have provided their time, advice and support throughout this study. The authors would first like to thank DCDC and the FMC office of the MOD for their sponsorship of this study and constructive feedback on emerging findings and analysis.

The team are also deeply indebted to senior experts consulted during the study interviews, including: Alan Dukes, Group Captain Stuart Gregory, Wing Commander Mark Pickford, Wing Commander William Whitechurch, as well as several experts who chose to remain anonymous.

To validate and challenge emerging findings, the study team benefited greatly from contributions of senior experts from within the GSP, MOD and academia who have offered valuable insights during two expert workshops in April and May 2021 respectively, including: Ben Barry, Caron Holmes, Sean Kelly, Laura Lacey, Wing Commander Guy Lendon, Dr Martino Luis, Wing Commander Nick Maxey, Wing Commander Mark Pickford, Peter Round, Wing Commander Paul Scott, Jeremy Smith and Dr Shuya Zhong. The study team is also grateful to Professor Patrick Porter, academic advisor to DCDC, for his insightful comments on the draft report.

Finally, the team are indebted to the RAND Quality Assurance reviewers Ruth Harris and James Black for their thoughtful comments and suggestions that have improved the final document. Notwithstanding all these many varied inputs, any errors or omissions in the report are the sole responsibility of the authors.

1. Introduction

This chapter provides a brief outline of the study context, its purpose and its research approach, as well as an overview of the structure of this report.

1.1. The 2021 Integrated Review presents an ambitious vision of a 'Global Britain', requiring a fresh review of mobility requirements

In March 2021, the UK government published the long awaited *Integrated Review of Security, Defence, Development and Foreign Policy* (the 'Integrated Review' for short), setting out a strategic framework for UK policy out to 2030.[2] The Integrated Review articulates a strategic vision for the UK as a 'problem-solving and burden-sharing nation with a global perspective' operating in an increasingly competitive world. This builds on and reinforces the vision of a secure and prosperous UK with a global reach and influence as articulated in the 2015 National Security Strategy (NSS) and the Strategic Defence and Security Review (SDSR).[3,4] It also reflects the UK's track record in deploying its defence capabilities as well as its soft power capabilities to bear on a wide range of conflicts, crises and operations, both close to home and further afield, as articulated in the Integrated Operating Concept 2025.[5] The realisation of this outward-facing vision relies on a close relationship between economic security and national security and underlines the UK's current and planned investment in projecting power, influence and values globally. It advocates for the UK to more effectively and efficiently use its finite assets and relationships to project influence and protect its national interests in an era of new threats and challenges, including an increasing level of competition in the world, environmental and resource challenges, economic and information threats, and hostile efforts to undermine governance and international law.[6,7] These threats come from state as well as non-state actors and often extend beyond national borders, requiring a coordinated multilateral, if not global, response.

The Integrated Review envisages Britain's global role to be underpinned by a collaborative approach between different government departments, with the MOD and armed forces playing an important part in the ability to achieve 'global reach' and operate in many different parts of the world, alongside soft power

[2] HM Government (2021).

[3] UK Government (2015).

[4] UK Government (2018).

[5] UK MOD (2020b).

[6] UK MOD (2018).

[7] HM Government (2021).

levers of influence.[8] Indications of how these strategic ambitions are likely to play out in practice are presented in the *Defence Command Paper* released by the MOD to accompany the Integrated Review.[9] Some of the key changes include:[10]

- A strong emphasis on **'persistent engagement'** using forward-deployed units, a series of regional hubs and an expanded network of defence attachés.
- The ambition for the **Royal Navy to be a constant global presence**, with more ships, submarines, sailors and Royal Marines deployed on an enduring basis as well as episodic deployments of the Carrier Strike Group (CSG) to the Indo-Pacific.
- The creation of a **'digital backbone'** to share data across defence assets globally.
- An increased focus on **cyber and electromagnetic capabilities and space-based Intelligence, Surveillance and Reconnaissance (ISR).**
- A **modernisation and restructuring of the Army**, to include longer-range artillery, more precision fires and a 'Deep Recce Strike' Brigade Combat Team, balanced by cuts to overall troop numbers.
- Reforms to the Royal Marines to create a **Future Commando Force.**
- Creation of a new **Army Special Operations Brigade** (comprising four 'Ranger' regiments') to help conventional forces take on some of the overseas security assistance and capacity-building tasks that have hitherto been the responsibility of UK Special Forces, freeing up the latter to focus more on high-end warfighting and on countering hostile state activity below the threshold of armed conflict.

While the UK Armed Forces retain an enduring focus on the Euro-Atlantic area, in support of the North Atlantic Treaty Organization (NATO), and on countering the threats posed by Russia, they will also need to adapt their plans and posture to reflect the UK's 'tilt to the Indo-Pacific' in response to the challenges related to increasing competition in the region and the rise of China. These changes are likely to shape the force design and military capabilities required across all defence tasks, with direct implications for mobility requirements. Indeed, **global mobility – i.e. the ability to deploy people and materiel to remote locations and then support and recover them from the theatre of operations – will be a key enabler for the realisation of the strategic vision articulated in the Integrated Review by 2030 and beyond**.[11] Therefore, understanding how demand for mobility is likely to change into the future and what different options the UK may need to explore to effectively deliver mobility in this changing threat and strategic environment are fundamental building blocks towards delivering the UK's stated ambitions.

---

[8] Ibid.

[9] MOD (2021a).

[10] Ibid.

[11] MOD (2021a).

1.2. This study draws on literature and wide stakeholder consultation to identify mobility requirements and options for meeting them

This study was delivered by the Global Strategic Partnership (GSP), led by RAND Europe and had three core research objectives, each of which is broken down into specific research questions as summarised in Table 1.1. This research is intended to complement, not duplicate, the more detailed analyses of future requirements for air and space and air lift that cannot be cited due to their classification level, and the various studies and analyses conducted internally by the Defence Science and Technology Laboratory (Dstl) and others within the MOD on current and future operational challenges and capabilities relevant for operations in permissive and non-permissive environments.

Table 1.1. Research objectives and research questions

Research objective	Subordinate research questions
RO1: Identifying the core military requirements for global mobility out to 2040 and any potential shortfalls vis-à-vis the current Equipment Plan	RQ1: What are the core military requirements for global mobility in the mid to long-term future (out to 2040) and which are likely to be the most influential on the mobility force structure? RQ2: What are the likely impacts on global mobility of developments in the Space and cyber domains? What are the related threats and opportunities? RQ3: What are the likely capability gaps/risks based on the current equipment plan?
RO2: Identifying a range of different options for delivery of global mobility out to 2040	RQ4: What plausible options might be designed for a global mobility out to 2040 and what are the characteristics of each option? (e.g. What assumptions are made for the delivery of the concept? Are collaborative partnerships included? How would different Services be involved in the concept?). RQ5: What are the case studies of deployments using different global mobility opportunities and how do they link with potential deployment requirements for all Services (Land/Air/Navy)? These will be drawn from international partners, allies and adversaries to provide a broad set of perspectives.
RO3: Identifying the high-level implications of these options for future force design and capability planning	RQ6: What are the high-level implications of each of the different options for relevant force design and capability planning? RQ7: What are the high-level implications for specific sub-areas of interest (e.g. efficiency, spectrum, sustainment, climate change, interoperability)?

Source: DCDC study requirement.

The research for this study was conducted between February and May 2021, consisting primarily of a review of academic publications, open-source literature, Government Furnished Information (GFI), published and unpublished RAND reports, and of evidence collected via stakeholder interviews with senior MOD stakeholders and workshops with GSP experts, academics and participants from the MOD. The study team used various clustering and mapping techniques and processes, utilising a virtual whiteboard software 'Mural' to facilitate the workshop discussions.

Given the combination of a large research area and a limited timeframe for conducting the research, it is important to note a few caveats in relation to the outputs presented in this report:

- The future is **inherently uncertain** and conceptual **planning** for the 2040+ time period **is at its early stages** within the UK MOD and Armed Forces. As such, much of the analysis presented here relies on assumptions drawn from high-level UK defence policy as articulated in the Integrated Review for the period of 2030+ and wider trends out to 2030–2040 as reported in open sources (for example, in relation to the technological maturation of autonomous systems, the move towards net zero economies, or urbanisation).[12] Rather than presenting a particular version of the 2040 future, this report seeks to lay out the different factors that should be considered now when designing force and capability plans that can be resilient against multiple plausible futures.
- The analysis presented here draws primarily on **open-source data**, wide-ranging stakeholder consultation, workshop discussion and a limited number of GFI publications.
- It is **unclassified** and hence does not present detailed information on UK defence capabilities, Defence Tasks (DT) or concepts of operations, nor on those of other allies, partners, neutrals or adversaries.
- The study team **consulted stakeholders from across the Services as well as wider MOD (e.g. Dstl), the GSP partnership and wider academia, MCCE and US AFRICOM**, but more in-depth engagement with international allies and partners and with industry would be beneficial to understand concrete opportunities for collaboration in mobility.

Throughout this study, the following definitions are used.

Box 1. Definition of 'global mobility'

Mobility refers to the deployment and sustainment of military forces in support of the National Security Strategy. This considers how personnel, equipment and stores could be deployed from the UK to operational theatres in the future, out to 2040, to achieve the required effects to include use of strategic bases – points of embarkation (POE), regional hubs vs deployment direct from the UK, and the challenge of transiting through hostile and contested spaces such as A2AD environments. 'Global mobility' explicitly covers all domains, including airlift, sealift, road, rail and potentially also movement through space.

Source: DCDC (2020), Project initiation document for this study

Box 2. Definition of 'force design'

Force design is the exercise of conceiving and producing a plan for Defence capabilities to achieve the desired Defence force posture. Defence's force posture describes the national military capability and its orientation in relation to other nations. There are several elements that constitute the force design including considerations of readiness, plans, presence (locations) and force size and structure.

Source: Adapted from Ween et al. (2013)[13]

[12] See, for example, DCDC (2018).

[13] Ween et al. (2013).

1.3. This report comprises a series of core chapters, along with annexes, to provide supplementary detail on mobility options

In addition to this introduction, this report covers the following:

- **Chapter 2. Requirements for global mobility (RO1):** This chapter highlights the core military requirements for global mobility in the mid to long-term future (out to 2040) that are likely to be the most influential on the mobility force structure. This chapter also includes a high-level analysis of the reciprocal implications of space and cyber developments for mobility and a high-level overview of likely capability gaps.
- **Chapter 3. Options for delivering mobility (RO2):** This chapter identifies plausible options for delivering mobility out to 2040 and the specific characteristics of these options. Where evidence is available, this chapter also highlights specific examples of how these options could be implemented.
- **Chapter 4. Implications for future force design (RO3):** This chapter provides a structured overview of the key implications of the different options discussed in Chapter 3 for future force design 2040 and draws out specific implications of the different options for various areas of interest, including environmental sustainability, interoperability, efficiency and others, highlighting areas where options have a particularly strong impact.
- **Chapter 5. Final reflections:** This chapter draws together overarching conclusions and provides areas for reflection and high-level recommendations for next steps.

These core chapters are supported by a full bibliography, containing the references, along with **Annex A**, which provides a list of interviewees consulted during the research.

2. Requirements for global mobility

This chapter presents the core high-level requirements for global mobility out to 2040, drawing on a review of GFI and open-source literature, key informant interviews and workshop discussions. This chapter also highlights the current and planned capability picture and discusses the potential impact of developments in the 'new' domains of cyber & electromagnetic and space for mobility.

2.1. Current UK policy places increased demands on global mobility to enable the Armed Forces to be in the 'right place at the right time'

Achieving and maintaining a more persistent global presence, as foreseen by the Integrated Review, the Defence Command Paper and the associated Integrated Operating Concept (IOpC) 2025, will (logically) require the presence of UK Armed Forces in more places around the globe. In different cases, this might be on a long-term or rotational basis or just short-term deployments in response to an emerging crisis. This growing global presence comes with a related need to ensure that personnel, materiel and supplies are transported to and from the theatre of operations as well as continuously supported in the field.

Drawing on this wider policy and strategy backdrop, MOD develops the Defence Strategic Direction (DSD), setting out a series of Defence Tasks (DT) and directing how Defence needs to configure its activities to deliver these.[14] The DSD and related DT are periodically reviewed and updated, and ultimately drive the requirement for future force structure and capability development.[15]

DSD contains 25 DT, eight of which are 'permanent' tasks that Defence needs to deliver irrespective of other demands – these publicly available tasks have driven the study team's analysis of requirements. They include:[16]

- Provide nuclear deterrence.
- Deter and defend against threats to the UK.
- Deter and defend against threats to UK bases and territories overseas.

[14] UK MOD (2020c).

[15] Due to the unclassified nature of this study, the study team was unable to take into consideration the DSD and the Defence Tasks. A classified, in-depth analysis of these would be required to identify concrete requirements for global mobility as well as potential capability gaps in delivering them out to 2040.

[16] UK MOD (2020d).

- Contribute to the resilience of the UK by supporting civil contingency operations and the protection of Defence's Critical National Infrastructure and cyber space.
- Hold forces in readiness to support and conduct counter-terrorism operations in the UK.
- Contribute to understanding the global security environment.
- Resource NATO staff posts and the highest priority NATO force contribution.
- Resource core staff posts within the global Defence Network.

While in the past, UK military engagements have typically been more centralised (e.g. operating from large, well-protected and well-supplied bases during the Afghanistan and Iraq wars), the strategic vision articulated in the Integrated Review is more likely to require **a more dispersed presence but with a greater ability to converge forces and effects in one place at short notice**.[17] Much like the dispersion-convergence required to respond to crises as they unfold, the long-term sustained response will also require clear strategic planning.

New concepts will be needed, whose implications for global mobility may not be as clear. Indeed, concepts of operations (CONOPS) for the 2040 time period are in their early stages of development and most interviewees consulted for this study explicitly caveated their input by acknowledging this lack of mature thinking.[18] Yet it is also true that the speed of technological progress, accompanied by deep uncertainty around future global developments and trends, prompt the requirement for early thinking to consider potential CONOPS in terms of operating, warfighting and the underpinning enablers like mobility. At the very least, the trends that can be observed now (and are analysed in detail in later parts of this chapter) are likely to mean that **the requirements for global military mobility will increase in terms of capacity, capability, survivability, assurance and speed of response, all within enduring constraints on affordability.**

While many of these requirements may be fulfilled by the UK Armed Forces themselves (e.g. using strategic airlift, sealift, tactical resupply including support to other force elements and overseas bases), there is also a stated ambition to implement a Whole Force approach that also draws on the strengths of allies and partners, and industry providers. The military's requirements may not fully align with the platforms and services available through the civil and commercial sector, however, which may be more likely to continue on a trajectory towards greater efficiency, with cost-reduction (and profit-maximisation) paradigms as the key driving force.[19] Understanding where Defence is aligned with the commercial sector's objectives and the scale at which it is able to support mobility, or where these are divergent, is part of the challenge for thinking about options for global mobility.

[17] UK MOD (2020a); UK MOD (2020b); Interviews with RAND Europe, April–May 2021.

[18] Interviews with RAND Europe, April–May 2021.

[19] GSP workshop on the Global Mobility: Future Force Design Out to 2040, 13 May 2021.

2.2. Threat environment will shape the mobility risk calculus, prompting consideration of ways to reduce risk to life and enhance survivability

In addition, it is likely that the UK Armed Forces will be required to deploy in to a greater variety of environments, fulfilling different tasks more frequently and potentially for longer periods of time (for example if deploying into regional hubs as foreseen by the Integrated Review) than in the past. The nature of the threat environment will thus differ depending on hostile activities in the area of operations and the local geography – both physical and electromagnetic – and range from permissive to contested to denied.[20] Just as the changing **threat environment will shape force design and capability requirements** for combat forces, by extension, it will shape the demands for supporting functions such as mobility assets, logistics, infrastructure and data, all of which provide critical enablers for the deployment of combat forces in the first place.

When operating in more permissive environments, for example, the UK Armed Forces may be able to rely more on the host nation's infrastructure and logistics support and may be able to draw on collaborative partnerships for delivering mobility with allies and partners active in the same area or on commercial providers.[21] On the other end of the spectrum, hostile and non-permissive environments will present challenges for both mobility and combat forces, particularly as a result of the proliferation of so-called A2AD[22] capabilities such as integrated air defence systems, anti-ship missiles, mines, cruise missiles and ballistic missiles, and electronic warfare capabilities. Further challenges are likely to arise as a result of ABO denial, or the denial of diplomatic clearances requiring them to operate at 'greater range, reach and risk'.[23] This will require **greater survivability** (including platform protection, dispersal, deception, camouflage, use of low observability, counter-force) and/or greater support from suppression/destruction of enemy air defences (SEAD/DEAD), strike and ISR platforms or considerations of alternative options such as the use of autonomous systems if the risk of them being compromised due to adversarial cyber or electronic attack is minimised. It will also likely require the ability to re-enter theatres of operations after debilitating first strikes, against A2AD denial. To achieve mobility, more than before, may require intense and escalatory efforts to suppress an adversary's capacity to hold mobile forces at risk. These complexities will require a joined-up approach between global mobility and campaign design and strategic plans.

In other situations, the military will operate sub-threshold, creating the need for **greater ambiguity** around the purpose of its activities. For mobility, this means there may be a need for greater use of civilian mobility assets or multi-role platforms in ways that adversaries may not be able to interpret accurately.[24] In short, the nature of the threat environment will shape the **different risk calculus** when determining how mobility can be delivered to ensure operational effectiveness and efficiency, and minimise the risk to life.

---

[20] MOD (2017).

[21] Interviews with RAND Europe, April–May 2021.

[22] It should be noted that the A2AD concept tends to feature in Western military strategic literatures and does not appear in similar doctrines of Russia, China, Iran or North Korea. For an in-depth analysis of the literature on A2AD and wider implications for UK strategic thought, please see Black et al. (2021).

[23] Dstl (2021).

[24] Interviews with RAND Europe, April–May 2021.

2.3. Space and information could be enablers and means for delivering mobility but will inevitably bring risks that need to be understood

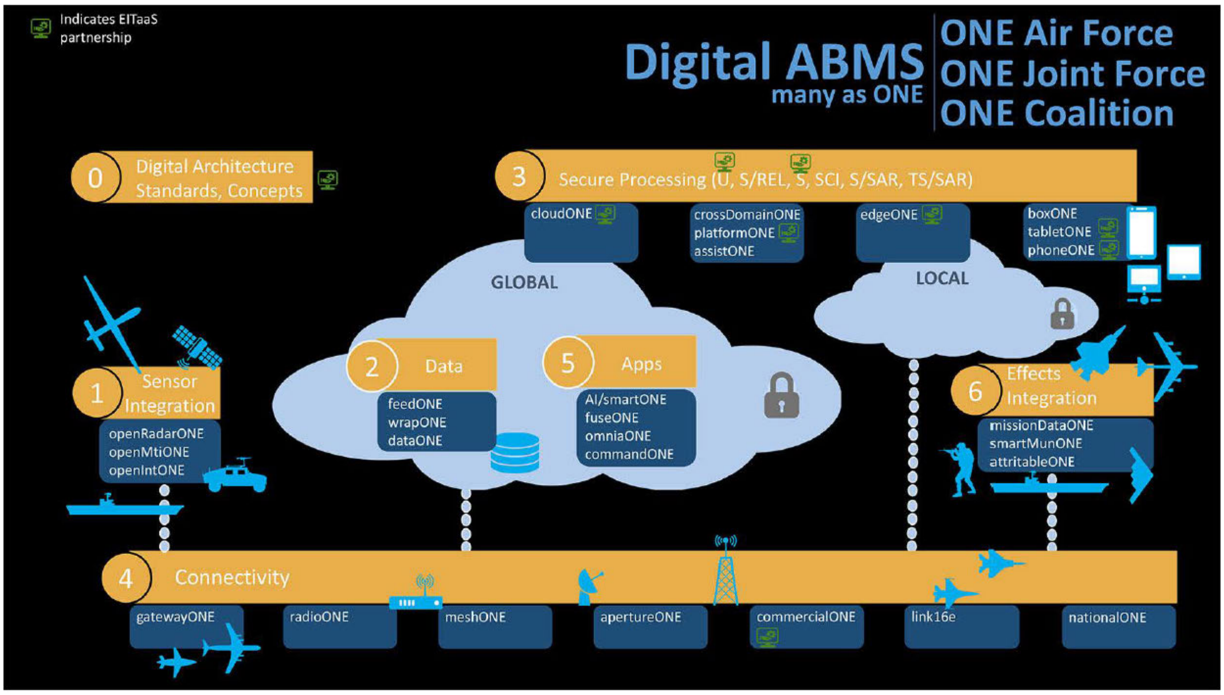
Achieving a global presence where required in the future will continue to rely on fundamentals of mobility as we know them today, including the use of strategic lift and basing.[25] However, **advances in the cyber & electromagnetic and space domains may open up new opportunities** to achieve greater situational awareness through more ubiquitous ISR and a more effective mobilisation enabled by securely shared mobility, logistics and support data between different Services (as part of a 'digital backbone' – an, as yet, aspirational system that connects military systems into a unified network, connecting sensors, effectors and decision makers).[26] Parallels with the UK aspiration for setting up a 'digital backbone' could be drawn with the US's related shift towards Joint All-Domain Command and Control (JADC2) and the creation of the Advanced Battlespace Management System (ABMS) to deliver a Military Internet of Things combining elements of both cloud and edge computing (see Figure 2.1 for a visual illustration of ABMS).

At the same time, these opportunities may be hampered by adversary activities geared towards denying or paralysing C4ISR networks. With these risks in mind, these opportunities should not take away the need for conventional effects but will enable their delivery in a more effective way, concentrating them where most appropriate given available data. They can (and should) also be complemented by strengthened diplomatic presence worldwide, as a source of early political information and intelligence. To illustrate by means of an example, it is likely that 2040 will see the UK military able to access mature space ISR capabilities (potentially from commercial providers of Earth Observation, EO, data) to enable the UK military to determine where it may need to deploy next to assist in a disaster relief operation, and what assets, supplies and support may be most appropriate for this particular mission. At the same time, however, the 2040 timeframe is also likely to see increased proliferation of anti-satellite capabilities (ASAT), posing an increased threat to space-based ISR capabilities, prompting a more balanced assessment of space-based opportunities.

[25] Interviews with RAND Europe, March–May 2021.

[26] Interviews with RAND Europe, April–May 2021.

Figure 2.1. Overview of US Advanced Battle Management System



Source: Pirolo (2020).

In addition to *enabling* mobility, space is also set to create opportunities for *delivery* of mobility, using a range of novel concepts as shown in Box 3. The US military is already considering options to add transportation of cargo (and possibly personnel) through low Earth orbit (LEO) using orbital vehicles such as Starship. While this option could significantly increase the speed of transportation, it is likely to remain significantly less cost effective than other modes of transport in the near term (see Box 3 for detail). Similarly, information is likely to have an increased role in supporting and enabling effective delivery of mobility, as shown in Box 4.

Box 3. Space-based technologies for enhancing mobility

Recent developments in both horizontal and vertical space launch technologies hold promise for achieving space-based mobility, significantly reducing costs, time, distance and extending global reach, even for transportation of heavy cargo. SpaceX's ongoing development and testing of the **Starship orbital vehicle** is seeing rapid progress after initial test failures and increasing the appetite of various actors, for using Starship to transport cargo (and possibly personnel) rapidly from point A to point B. In 2020, the US Transportation Command, which oversees global logistics of the US military, has signed a contract with SpaceX and XArc to study the use of space launch vehicles to transport supplies to any location on the globe in an emergency.[27] In the meantime, SpaceX's development of the Starship rocket is seeing successful testing, while potential interest is increasing, considering the use of Starship for various purposes from tourism to logistics and supply to, from and through orbit.[28]

The US military is looking into multiple scenarios such as the establishment of a space transportation surge capability, similar to the Civil Reserve Air Fleet (see Box 10). Delivering the equivalent of a C-17 Globemaster (top speed of around 450 knots at 8,500 metres and a maximum payload of 77,534 kg) using a Starship, which has a maximum payload to low Earth orbit of 100,000 kg and can travel anywhere around the globe in less than an hour, is considered to be a new mode in the logistics model.[29]

Reportedly, an average SpaceX Falcon 9 launch costs anywhere from $50 million to $62 million. The company expects the price to drop to around $1.5 to $2 million per launch, while the C-17's cost per flight hours varies.[30] A back of the envelope calculation using a $30,000 per hour figure and 18 hours of flight time for the C-17 would cost roughly $540,000, which is around 1/100th the current cost of a SpaceX launch; but it is somewhere between a third and a quarter of its expected cost in the future.[31] SpaceX's Chief of Operations, Gwynne Shotwell, stated that SpaceX is expected to fly large numbers of people into space as well as point-to-point transportation between locations on Earth by 2026 with the first Earth to Earth test flights already beginning in 2022.[32]

In addition to using space to transport cargo and potentially personnel, developments in space technology may indirectly contribute to improvements in mobility. The rapid progress in space engines (e.g. Reaction Engines' SABRE[33]), for example, may **contribute new engine designs** that could lead to reductions in military reaction times for cross-border operations and could also have hypersonic weapons applications, which may help overcome some of the mobility barriers imposed by non-permissive operating environments.[34] Further relevant uses of space for logistics and transportation include: providing connectivity and EO for supply-demand optimisation and just-in-time logistics; satellite-enabled indoor Positioning and Navigation; satellite-enabled smart ports and infrastructure; satellite-enabled autonomous vehicles as delivery systems; next generation connectivity and PNT for integrated logistics systems.[35]

Source: RAND Europe analysis of open source data

[27] Space News (2020).

[28] War on the Rocks (2021).

[29] Space News (2020).

[30] NDTHQ (2020).

[31] The Drive (2020).

[32] Space News (2021).

[33] Reaction Engines (2020).

[34] Interviews with RAND Europe, April–May 2021.

[35] Black et al. (2020).

Box 4. Role of information in enhancing mobility

With the increased digitalisation of Defence, all areas, including mobility, are likely to see a decrease in reliance on workforce and manual processes, offering opportunities for better **asset tracking, stockpile management, supply optimisation and support,** enabled by advances in artificial intelligence (AI) and machine learning (ML), data analytics, cloud and edge computing.

At the same time, however, logistics management systems will continue to be a target for cyber attacks or disinformation by cyber malefactors, including both state and non-state actors.[36] The resilience and integrity of the underpinning data management systems, as well as the provenance of data reported through these systems, are essential to meet successful operational outcomes and enhanced logistics efficiency.[37] This entails a growing requirement for robust cybersecurity and cyber defence, not only to protect mobility platforms or defence information technology (IT) systems and infrastructure, but also the broader supply chains and industry.

While **cyber vulnerabilities of data transfer and storage** may be better understood, there is less analysis available to understand the cyber & electromagnetic domain risks related to new 'intelligent' systems such as autonomous platforms, where the **system 'chokepoints'** lie and how these risks can be mitigated, particularly in non-permissive EM environments.[38] The physical requirements (e.g. for cooling, power generation and physical storage space) for the digital infrastructure will also need to be considered as part and parcel of the mobility requirements picture.[39]

The development of **reversionary modes** (e.g. redundancy or tactics, techniques and procedures) for when cyber-dependent systems fail need to be integrated in overall measures to enhance resilience of logistics systems.

Source: RAND Europe analysis of open source data

2.4. Several broader trends will shape global mobility and should therefore be considered as part of the mobility requirements picture

In addition to the policy drivers, the changing nature of the threat environment and the development across other domains (space and cyber & electromagnetic), the study team has also identified a number of broader trends that are likely to impact the requirements for global mobility. These include:[40]

- **Increased urbanisation** and related exposure of the UK Armed Forces to operations in complex, congested and contested environments, with implications for mobility, basing and force protection.
- **Climate change** and its implications for different areas of operations, Defence tasks and lines of development (DLODs)[41] as well as increasing **requirements for decarbonisation** and a 'green' transition towards greater environmental sustainability and resilience.[42]

---

[36] Interviews with RAND Europe, April—May 2021.

[37] Ibid.

[38] Ibid.

[39] Ibid.

[40] For a detailed analysis of key strategic trends that will influence UK Defence operations, including global mobility, please see DCDC (2018) Global Strategic Trends 6.

[41] DLODs include personnel, training and equipment to deliver Defence outputs, organisational relationships, information-handling, doctrine and concepts, infrastructure, and logistics and security and interoperability. Source: MOD (2020), *How Defence Works*.

[42] UK MOD (2021b).

- Developments and **trends in the commercial sectors** driven to increase efficiency of logistics, transport and supply (covered in greater detail in Section 3.2.3).
- **Global dynamics, alliances and partnerships** that may enable (or disable) options for mobility depending on whether they result in more 'collaborative' or more 'competitive' world orders.
- Increase in **data-driven approaches, automation and autonomy** for enabling mobility.

The following sections briefly examine the implications of each of these projected trends for global mobility.

2.4.1. Urbanisation is likely to drive demand for deploying more agile and survivable assets, including autonomous systems, helicopters and tactical transport

DCDC's own Global Strategic Trends programme foresees a significant increase in rates of urbanisation, seeing an increase of two billion more people living in urban areas between 2017 and 2050, having an impact on a vast number of factors from energy, food, water resources, criminality, violence, transport, education and many others.[43] From the perspective of mobility, such environments present unique challenges for personnel and freight transportation due to the physical constraints such as location of airfields and ports, high concentration of civilian population and broader challenges with ABO permissions and force protection related to the intense civilian activity nearby. Mobility demands will also have to account for congestion on roads, bridges and other city infrastructures like rail, as well as any potential policy or regulatory restrictions on the time or nature of transport (e.g. potential bans on transport of dangerous goods through cities). These challenges will require innovative approaches to the use of existing assets (e.g. fixed or rotary wing aircraft, ships, ground vehicles) combined with greater use of autonomous systems and/or optionally crewed assets (see Chapter 3 for further detail) as well as a sound understanding of the local environment. This could be aided by having more permanent presence of UK civil and military staff (including attachés) in regional hubs (as envisaged in the *Integrated Review*) through which such information could be gathered and shared across government.

2.4.2. Climate change and net zero objectives will present new challenges for mobility, requiring pro-active planning

Climate change is also likely to impact both the UK military operations around the globe and the internal functions of UK Defence at home, as highlighted by MOD's *Climate Change and Sustainability Strategic Approach* published in early 2021.[44] As shown in past RAND analysis for DCDC, climate change is likely to severely impact the operating environment, increasing the demand for military deployments in HADR operations and imposing a wide range of strategic, operational and tactical challenges from coordination to equipment performance and water supply.[45] At home, Defence will not be exempt from the demands to meet national net zero targets and may grow to become a target of popular discontent if it fails to move towards meeting these targets and operating in a more environmentally sustainable way (within the constraints of still addressing military requirements and affordability). Sustainability will also have to be

---

[43] DCDC (2018).

[44] UK MOD (2021b).

[45] For further detailed analysis, please see Cox et al. (2020) and Retter et al. (2021).

demonstrated when repatriating forces deployed overseas as per the requirement to demonstrate proof of good order (POGO) when leaving an overseas operation and host nation. The UK military will be required to remediate sites, clean them up and return them to the host nation in the condition that they received them in. Operating legacy mobility platforms that use fossil fuels may also become increasingly difficult when there is a high standard of remediation expected at the end of an operation and failure to do so could increase reputational risk as well financial penalties.[46]

The confluence of the growing impact of climate change and the demands for environmental sustainability are tempered by the perennial need to achieve operational effectiveness. In the transition period between now and 2040, the tensions between these drivers is likely to manifest itself quite strongly.[47] To illustrate this by means of an example: the current and planned defence equipment inventories suggest that it is unlikely that 2040 will see a full transition to renewable energy sources and it may be that some platforms (e.g. combat air) will continue to burn hydrocarbon fuels even further beyond that timeframe.[48] The delivery of adequate and timely logistics and support activity, including the supply of fuel, will have to be adapted to ensure effective supply of potentially different fuels for different equipment as well as ways to generate sufficient power supply for all the systems and sub-systems deployed. Indeed, the drive for greater digitalisation and autonomy is accompanied by an increase in energy demands (for processing power, cooling, data storage, etc.), which will need to be factored into the mobility and logistics plans.[49] Additionally, in the context of climate emergencies, mobility is likely to be reliant on energy systems that can be deployed where there is no guarantee of obtaining power sources in theatre.[50]

Potential opportunities emerge here as well, given the drive for greener technologies and move to renewable energy sources and electric vehicles/platforms in the commercial sector, holding the potential to reduce the burden on supply chains for energy as this could be generated *in situ* through wind, solar and water. Further, green technologies that aid self-sustainability of deployed operations could lead to a reduction in the amount of materiel and supplies transported through supply chains and so help reduce the demands for mobility. Similar effects could be achieved with additive manufacturing, for example, thanks to the ability to minimise the need for resupply and related frequency of supply deliveries by, instead, producing parts and materiel local to the theatre of operations and at forward operating bases.

2.4.3. Shifting alliances and partnerships will have significant impact on the ability to access mobility assets collaboratively and ensuring interoperability

As noted in Chapter 1, the Integrated Review foresees a 'tilt' towards the Indo-Pacific region, which is likely to require a finely balanced readiness of the UK to deploy both to contribute to the balance of power alignment in that region and to contribute to maintaining security within the Euro-Atlantic context. As its sovereign resources remain constrained (see Section 2.5), the UK will continue to rely on alliances and partnerships to enhance its access to both combat capabilities and enablers, including those for mobility. In

[46] Internal RAND Europe workshop, May 2021.

[47] GSP workshop on the Global Mobility: Future Force Design Out to 2040, 13 May 2021.

[48] GSP workshop on the Global Mobility: Future Force Design Out to 2040, 13 May 2021.

[49] Interviews with RAND Europe, March–May 2021.

[50] Ibid.

other words, the shift from mass to technology, combined with a global ambition, are likely to pose prohibitive constraints on the UK's ability to operate independently. To maximise the use of these constrained resources, UK Defence will need to reassess how and how effectively it is able to draw on multinational assets (e.g. through pooling and sharing initiatives such as the Movement Coordination Centre Europe (MCCE)) and how it may want to shape collaborative partnerships to derive greater benefits for its own ability to deploy effectively as well as for the overall coalition's mission effectiveness. Interoperability of assets and personnel as well as enabling systems and command and control will continue to be important, placing continued demands on common standards as well as joint training, exercises and other opportunities to build up effective partnerships (e.g. using liaison officers). Some of these are explored in more detail in Chapter 3.

2.4.4. Interconnectivity across military capabilities and the need for logistics coordination will drive demand for real-time and accurate data management

Some stakeholders expressed that data management in Defence is poor, focusing on individual components, rather than on systems across domains as a whole and with many functions carried out manually.[51] Moreover, current data management systems tend to be pushed from the bottom upwards rather than centralised as would be required if mobility were to realise its central pillar led role.[52] Big data analysis, data storage and augmented intelligence systems will be required to help tackle the vast volumes of data generated by these complex and interconnected systems.[53] If implemented effectively, these technologies could enable enhanced situational awareness and more rapid and quick predictions for logistics requirements.[54] These technologies could also enable more efficient management of stockpiles, which some stakeholders identified as one of the key challenges.[55] All platforms and systems will increasingly need to be network enabled, requiring everything to 'be on the grid [in order to] be on the battlefield' as one interviewee put it.[56] Therefore, global mobility assets will be expected to be networked and may tie in with asset and consignment tracking.

As the reliance on timely and accurate data grows, Defence will need to ensure it can keep pace with ways, means and technologies to ensure secure data generation, transfer, storage and processing and minimise the risk of data tampering or outright compromise. Understanding where and how dependent different assets and mobility systems are on data (and hence, by extension, on space and cyber capabilities) will be important to identify potential vulnerabilities. Addressing these should be a priority for UK Defence and a key enabler for streamlining delivery of mobility in a range of environments, from benign to non-permissive (which includes non-permissive EM environments as well).

---

[51] Interviews with RAND Europe, April–May 2021.

[52] Ibid.

[53] Ibid.

[54] Ibid.

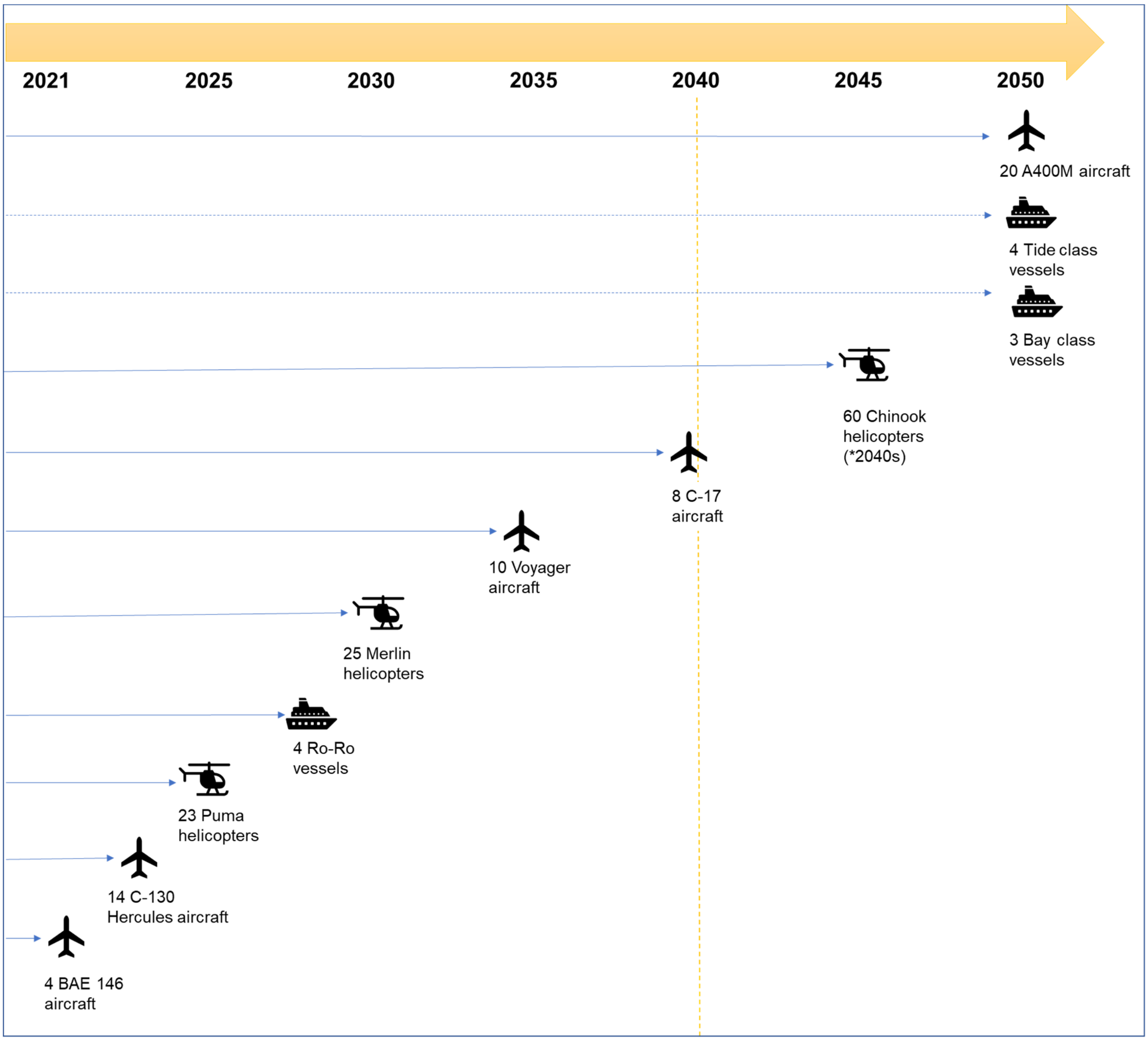
[55] Ibid.

[56] Ibid.

2.5. The increased demands on mobility emerge within a resource constrained set-up, requiring innovative approaches to meet them

To deliver the high strategic ambitions set out in the Integrated Review and Defence Command Paper, the UK Armed Forces will need to identify ways and means enabling them to utilise limited resources in the most efficient and effective way, while still being resilient and adaptable in the face of possible strategic shocks. As shown in Figure 2.2, the next 20 years will see the retirement (if not extended) of three major fixed wing mobility platforms (C-17, C-130 and Voyager), the expiration (if not renewed) of the roll-on, roll-off (Ro-Ro) contract for strategic sea-lift and its potential replacement and the retirement of Merlin and Puma helicopters. Unless additional capabilities are acquired, or existing contracts renewed, there will be a shortfall in numbers for both strategic and tactical lift assets, creating a potential risk for the UK Armed Forces' ability to deliver against the strategic ambitions previously discussed.

Figure 2.2. Out of service dates for strategic and tactical lift assets



Source: RAND Europe analysis of open source data

Contrasting the strategic vision articulated in the Integrated Review with the high-level resource map presented in Figure 2.2, it becomes clear that there is, at least in the short-to-medium term, a potential mismatch between the number and trajectory of acquiring organic mobility capabilities and the strategic ambitions. In the words of one interviewee, it seems that **UK military is expected to do 'more with less'**.[57] This conundrum presents an urgent need to identify:

- How the lift capabilities available can be used more effectively.
- How innovative solutions can help enhance the delivery of global mobility out to 2040.

Several interviewees for this study noted there is, at the moment, a siloed approach to mobility, whereby the use of strategic and tactical lift is not streamlined between the Services. One interview talked about an example where the individual services, Maritime, Land and Air, all selected different locations to build their hubs, imposing an additional logistics burden, instead of setting up a joint hub in a more integrated manner.[58]

As foreseen in the IOpC 2025, underpinning effective delivery of capabilities required by UK government ambitions should be an **integrated approach.** This approach emphasises the importance of both vertical integration through the strategic, operational and tactical levels, provides a foundation for **multi-domain integration**[59] and advocates also for horizontal integration across government and with the UK's international allies and partners, as well as industry, non-government organisations and broader society. Particularly as the demand for HADR operations is expected to grow, for example, there may be merit in considering how different government departments could better streamline both the use of mobility assets and share their through-life costs. A crucial aspect of the IOpC is the notion of promoting integration and cohesion across these different actors to enable the UK to drive the conditions and tempo of strategic activity and to maximise its competitive advantage in security and societal resilience matters, including achieving information advantage.[60] With finite resources available, accompanied by an explicit drive towards net carbon zero solutions (See Section 2.4.2), any options for achieving global mobility in the 2040 timeframe will require a careful balance between the means and the stated ambitions and ends.

---

[57] Interviews with RAND Europe, April–May 2021.

[58] Interviews with RAND Europe, April–May 2021.

[59] MOD (2020a).

[60] MOD (2020b).

3. Options for delivering mobility

This chapter presents a summary of plausible options for global mobility out to 2040 identified by the study team. The chapter describes key characteristics of each option and its relevance for military mobility.

3.1. The study team has identified six broad options for enhancing delivery of global mobility to meet requirements out to 2040

Determining *how* personnel, equipment and supplies can be transported from point A to point B depends on knowing exactly *what* it is that needs to be moved (i.e. the size, weight and nature of the payload), *why* (i.e. the level of prioritisation given the mission in question), *when* (i.e. the level of urgency) and *where* (in terms of both the start and end point but also how permissive – or not – the environment will be through which the payload will transit). Chapter 2 highlighted some high-level requirements stemming from current UK defence policy and official stated ambitions but there is, as yet, limited specific detail available given the early stages of thinking about the 2040 timeframe.

Table 3.1. Overview of mobility options

Global mobility options	
	Increased use of multi-role platforms
	International collaboration
	Commercial solutions
	Use of uncrewed or optionally crewed, lightweight assets and automation
	Data-driven and data-enabled mobility
	Additive manufacturing

Source: RAND Europe analysis

Without specific knowledge of the scale or nature of demand, it is not possible to provide an in-depth analysis of the concrete options for delivering mobility to ensure adequate supply. However, what can be done, is to identify a range of broader options (ways) to make mobility capabilities more agile and flexible to respond to the demand signal once it is known. The study team identified six such broad options, as shown in Table 3.1, which are discussed in this chapter.

3.2. Each option has its unique characteristics, with some already implemented by various actors, offering good practice examples

The following section presents a detailed description of each mobility option, outlining its core characteristics as well as specific use cases.

3.2.1. Increased use of multi-role platforms

Military assets can be tasked to perform different activities. Many of these assets serve specific purposes, which can limit the decisions on where and when to use them, as well as their availability.[61] The idea behind a hybrid design multi-role platform (MRP) is not new and has been adopted by armed forces around the globe. In 2013, for example, the Indian MOD issued a tender for building four Landing Platform Docks (LPDs) or Multi-Role Support Vessels (MRSVs) with the aim of filling multiple roles in the Indian Navy, including amphibious warfare operations, force projection, aviation and HADR operations. Technology advancements in propulsion systems, sensor fusion, air-to-air refuelling, mission systems and others will enable multi-role functionality across a range of platforms from maritime, fixed and rotary wing to ground vehicles, enabling a rapid reconfiguration to meet different task demands and threats (e.g. ISR, strike, advanced teaming functions, etc.).[62] Key enablers for multi-role platform design will include modularity and open systems architectures to allow seamless integration, upgrade, reconfiguration and tailoring to specific mission sets, including at short notice and in the field.

With the envisaged increase in demand for military deployments around the globe (see Chapter 2 for detail), there is a risk that appropriate equipment (especially for strategic lift) will not always be available due to concurrent commitments on other tasks or due to sheer lack of assets in the first place (see Figure 2.1). This could result in delays for deployment and force sustainment, undermining the likelihood of mission success, potentially increasing risk to life for deployed forces, and undermining the credibility of the UK's global defence posture in the eyes of both allies/partners and adversaries.[63]

The adoption of MRPs could enhance mobility options by enabling more flexible fleets. MRPs can potentially perform a multitude of operations (e.g. air-to-air refuelling and transport such as Voyager), can be retasked midway through or at the end of one mission, including down route or at regional hubs, to respond to another. This is in line with some of the planned investments set out in the Defence Command Paper, where a 'strategic and long-term investment is aimed towards increasing the capability of the Royal

[61] Interviews with RAND Europe, April–May 2021.

[62] JCN 1/21 Future Rotary Wing.

[63] Interviews with RAND Europe, April–May 2021.

Navy's surface fleet'.[64] This includes the Multi-Role Support Ships (MRSS) aimed at providing the platforms to deliver Littoral Strike, including Maritime Special Operations, in the early 2030s, on top of various other support roles. Greater use of MRPs, across various domains, could ultimately enhance Defence's resilience by having more adaptable and versatile fleets, including in the event there is a need to replenish losses in a given theatre as a result of adversary action in a warfighting at scale scenario.

The use of MRPs may not be equally feasible in all domains; for example, modifying space-based assets is costly and difficult, if not impossible with current technology, although advances in on-orbit servicing prototype technologies and close proximity missions are progressing fast. Despite possessing the option of performing multiple tasks/roles, MRPs can still only perform one of these at a time or else must accept the performance trade-offs inherent in being a 'jack of all trades, master of none'. Therefore, if there are not enough of these assets in the first place, their multi-role functionality does not add any additional benefits to delivering mobility or sufficiently offset the lack of overall capacity. Moreover, effective use of the MRP functionality requires appropriate TTPs in place to enable the crews to operate MRPs in these different functions.[65] Further considerations need to be given to the size of the crew itself; for example, deploying for HADR operations may be more challenging with a smaller crew.[66] Care must also be taken not to assume that maximising the number of MRPs is the most cost-effective solution. MRPs are often expensive as they typically involve the inclusion of more capability and redundancy than specialised single-role platforms.[67] Building in capability that is not required may be inefficient, and the optimum solution may be a force mix that blends multi-role and single role assets together, acknowledging that MRPs by themselves are not a panacea for resolving mobility challenges.[68]

Deploying MRPs into non-permissive environments could also create greater risk to potentially valuable platforms as they could be seen as high-value targets precisely due to their multi-purpose functionality. Illustrative examples of multi-role platforms are presented below. Finally, considerations need to be given to the potential risks that could emerge from deploying MRPs in terms of their impact on strategic stability and crisis escalation: while ambiguity of task may be an objective sought by the UK when operating such assets in certain parts of the world, this may also be interpreted as potentially hostile activity, with knock-on impact for escalation with adversaries or for ABO and diplomatic clearances with friendly nations.[69] In some situations, therefore, it may be more expedient to use 'single purpose' platforms with unambiguous roles to mitigate this risk, rather than sending a transport asset that a foreign actor might wrongly interpret as being configured for an ISR or strike mission.[70]

---

[64] MOD (2021).

[65] Interviews with RAND Europe, April–May 2021.

[66] Interviews with RAND Europe, April–May 2021.

[67] Interviews with RAND Europe, April–May 2021.

[68] Interviews with RAND Europe, April -May 2021.

[69] Internal RAND workshop, May 2021.

[70] Ibid.

Box 5. UK's Multi-Role Vessel concept

Prevail Partners has designed a Multi-Role Vessel (MRV) to provide a multitude of maritime applications.

Prevail Partners have designed a concept for an MRV from the base of an FSG 4100 Roll-on Roll-off (Ro-Ro) vessel. The MRV can be adapted from existing fleets, is quicker to deliver and deploy and can be configured for an array of applications. The MRV has a flexible design that enables a wide range of capabilities such as refuelling, carrying over 600 embarked forces, a battle group worth of vehicles, performing as a hospital and carrying deployed headquarters.[71] This type of vessel can be purchased as a completed vessel or chartered with the company providing ships and crew at a fixed price.[72] This envisaged commercial partnership would deliver over 300 operational days at sea a year if the crew is provided by Prevail. The contracted crew would operate every aspect of the ship except systems under military control.[73]

Source: RAND Europe analysis of open source data

Box 6. ELLIDA multi-role support and logistics vessel concept

ELLIDA is a multi-role logistics ship, designed to provide the capabilities needed in future global operations.

British Maritime Technology (BMT) has developed the ELLIDA concept, a 195m multi-role support and logistics vessel. ELLIDA is designed to provide the capabilities needed 'for future global operations, offering the flexibility of a large hull, with internal vehicle and stowage decks, weather deck stowage and additional accommodation'.[74] This vessel has several mission capabilities that include: global strategic movement of vehicles and equipment; transportation of vehicles, troops and supplies and logistics support to amphibious operations; replenishment at sea; HADR operations; rapid extraction of civilian persons and provision of support to these civilians in onward transit to a safe port. Its characteristics make it suitable for ship-to-shore offloading as well as support to naval operations through landing craft, boat operations, multi-spot aviation and replenishment at sea.[75]

Source: RAND Europe analysis of open source data

3.2.2. International collaboration

Access to mobility assets and services in a timely fashion is key to successful military operations, especially far from the homeland.[76] With limited resources available at the national level, various multinational pooling and sharing initiatives already exist that span many of the UK's allies and partners, helping to deliver mobility more efficiently. Different types of collaborations include buying together, tasking together, operating together or trading spare capacity. At the moment, the UK is only significantly involved in the first of these (buying together) with more limited involvement in the last two.[77] Assurance of access and the associated risk appetite differ significantly based on the type of operation and type of transport that is required: transport into permissive environments in peace-time or below the threshold of armed conflict

[71] Naval Technology (2021).

[72] Ibid.

[73] Ibid.

[74] BMT (2019).

[75] UK Defence Journal (2021).

[76] Interviews with RAND Europe, April–May 2021.

[77] Interviews with RAND Europe, April–May 2021.

places less demand on assured access to assets than combat operations or operations into non-permissive environments. Availability of pooled/shared capabilities can provide flexibility when surge capacity is needed, but they may offer less assurance of availability than sovereign owned assets.[78] However, having access to additional mobility capability and capacity through such multinational arrangements does add resilience to the UK's fleets.

Effective international collaboration is predicated upon trust, information sharing and common standardisation and interoperability of platforms.[79] Projects involving partner nations like the PESCO framework for military mobility[80] aim to enable the unhindered movement of military personnel and assets within the borders of the European Union (EU); others, such as the MCCE, Heavy Airlift Wing provide an opportunity to share irreducible spare capacity in assets to its members to increase efficiency and effectiveness of their utilisation and enhance mobility options across different modes (e.g. rail, air, sea). The MCCE aims to provide access to multi-modal solutions, coordinating sealift, air transport, inland surface transport and air-to-air refuelling across its Member Nations. By offering its members the opportunity to operate their capabilities collectively,[81] the MCCE facilitates a consolidated and coordinated approach to the market when sourcing strategic lift. It should be noted that control of mobility assets is retained by the MCCE Member Nation allowing it to withdraw its offer at short notice should a higher priority national tasking emerge. However, previous RAND studies identified a number of challenges undermining the effective functioning of MCCE, including lack of information sharing, poor IT systems and difficulties organising multi-modal solutions, often due to insufficient advanced planning of member nations.[82] Other multinational collaborative arrangements, such as the European Air Transport Command (EATC), with its underpinning ATARES mechanism,[83] involve tasking of pooled assets centrally, leading to some loss of sovereignty and control by the owning nation. However, the trade-off here is more efficiency through centralised tasking. How much control the UK is willing to give up will be a critical factor in deciding which existing or new future initiatives it wants to become part of out to 2040.

Illustrative examples of collaborative programmes are presented below.

---

[78] Interviews with RAND Europe, April–May 2021.

[79] GSP workshop on the Global Mobility: Future Force Design Out to 2040, 13 May 2021.; Retter et al. (2018); Caves et al. (2020).

[80] PESCO (n.d.).

[81] MCCE (n.d.).

[82] Caves et al. (2020).

[83] The 'Air Transport & Air-to-Air Refuelling and other Exchanges of Services' (ATARES) is a cashless exchange system for air transport services. 28 European and NATO nations are part of the multinational ATARES arrangement. The exchange of services is based on the 'Equivalent Flying Hour' (EFH): this reference is the cost price of one (1) C-130/C-160 flying hour that serves as a baseline for all other calculations. Source: EATC (n.d.).

Box 7. The ARK project enabling access to mobility assets from other partnering nations

The ARK project, introduced by Denmark and later adopted by Germany, provides a heavy move sealift capability using Ro-Ros, which can be chartered to the civilian market while not needed for military purposes.

The ARK Project consists of a multinational but Danish-led (DFDS) pool of ships. This cooperation started with DFDS and the Danish Armed Forces and in 2006 the German Armed Forces joined the project. Its purpose is to ensure stable charter costs for sealift in the event of a crisis or war. The contracted capabilities for heavy sealift use Ro-Ros, which are chartered to the civilian market when not needed for military transport, thereby minimising the costs for the military.[84]

A new agreement reached in November 2020 between DFDS and the Danish Armed Forces covers a total of seven Ro-Ro vessels. The previous agreement included five Ro-Ro ships (three German and two Danish with the option of a third Danish Ro-Ro ship depending on the market situation). The agreement states that the ships will sail with goods on a daily basis on DFDS's ferry routes and will be made available to the military when and to the extent requested by the Danish Defence.[85]

This fleet has transported military equipment for several other countries including the UK, Belgium, France, The Netherlands, Germany, Norway, Poland, Spain, Italy, Denmark and Slovakia. Destinations have included Northern Norway, the Falkland Islands, Tanzania, Pakistan and Iraq.[86]

Source: RAND Europe analysis of open source data

Box 8. The Multinational MRTT Fleet (MMF)

The Multinational MRTT Fleet enables the six participating nations, which have the exclusive rights to operate the NATO-owned aircraft in a pooling and sharing arrangement, to perform a wide range of operations in multiple domains.

In 2012, the European Defence Agency (EDA) started to address the shortfall in AAR refuelling capacity across its participating member states. This led to a Multinational Multi-Role Tanker Transport (MRTT), currently managed by the NATO Support and Procurement Agency (NSPA), on behalf of the participating nations. The programme was initially launched by the Netherlands and Luxembourg with other nations (Germany, Norway, Belgium and Czech Republic) joining in the following years.[87] The Airbus A330 aircraft used is configured for in-flight refuelling, the transport of passengers and cargo, and medical evacuation operations.[88] It is also widely used by various national fleets (including in the UK as the Voyager) beyond this multinational programme.

The full multinational fleet will consist of nine aircraft (three of which have been already delivered) able to provide strategic transport, AAR refuelling and medical evacuation capabilities to its six participating nations. Five aircraft will be based in Eindhoven, and four in Cologne. MMF aircraft will be operated by the Multinational Multirole Tanker Transport Unit (MMU) comprising military personnel from the participating countries. The unit is based in two permanent operating bases, the Main Operating Base in Eindhoven (Netherlands) and the Forward Operating Base in Cologne-Wahn (Germany).

Source: RAND Europe analysis of open source data

---

[84] DFDS (2020).

[85] Ibid.

[86] Shipping Today and Yesterday (2015).

[87] NATO (2020).

[88] Airbus (2020).

3.2.3. Commercial solutions

The use of commercial logistics solutions may also enhance the suite of options available for UK Defence, particularly in operations in permissive environments and in the competition phase short of open armed conflict. As e-commerce grows at a rapid pace and many businesses continue to embrace globalisation, commercial logistics companies are constantly improving their logistic and supply chain processes to support customers around the world. This enables them to remain profitable and defend market share in an ever more competitive environment. These companies have considerable knowledge and experience relating to global and regional logistics networks, market intelligence and supply chains, as well as transportation management and warehousing systems created to improve the quality, speed and precision of their services.[89] Through deepening partnerships with commercial logistics providers, the UK military could improve its logistics processes through sharing of good practice, gain additional capacity beyond existing organic military capabilities, ease the pressure on military platforms, and even turn platforms into revenue generators.[90]

Using appropriate contractual agreements, UK Defence could turn platforms into revenue earning assets as they can have a military role as well as a commercial role when not required.[91] Establishing partnerships between commercial providers and the UK military could lead to the creation of more resilient and integrated supply chains drawing upon and utilising the best commercial technologies. This could lead to benefits in terms of more advanced fleets of vehicles and capabilities for future mobility. Understanding the fast-moving commercial marketplace and which technologies could be implemented by the military, in terms of logistics and mobility, could also bring significant benefits to the future of mobility.[92] Further, exploring the commercial sector's use of artificial intelligence (AI), connected ecosystems (e.g. cyber-physical systems and the Internet of Things), robotic and autonomous systems and green solutions, could provide opportunities to enhance UK Defence's access to the hardware and software of the future. One such example focused on developments in autonomy is presented in Box 9. Yet, these commercial offerings would need to be examined rigorously in terms of their reliability, force protection requirements and security vulnerabilities (e.g. cyber security) to establish whether they could be transferred to the military context – not only in terms of their benefits from a cost and efficiency perspective.

[89] Interviews with RAND Europe, April–May 2021.

[90] Interviews with RAND Europe, April–May 2021.

[91] Interviews with RAND Europe, April–May 2021.

[92] Interviews with RAND Europe, April–May 2021.

Box 9. Autonomous vehicles for logistics and supply and future projections

The increasing use of autonomous vehicles for logistics and supply has been driven by a number of trends, including: growing demand for rapid transport of goods, labour shortages and technical advances in AI and autonomy. Warehouses are seeing a growth in the use of **autonomous vehicles** as **automated guided vehicles** (AVGs) and **swarm robots** are increasingly being used to move goods. **Intermodal terminals**[93] are expected to see a growth in the use of automation with autonomous cranes likely to emerge in the near term.[94]

Autonomous driving is one of the leading technologies in terms of the acceleration of investments. Semi-autonomous logistic convoys have already been jointly tested by Dstl in the UK and the US Army's Combat Capabilities Development Command (DEVCOM).[95] By 2027 it is estimated that commercial driverless autonomous trucks (ATs) will be rolled out in the US.[96]

However, despite the heightened expectations around the potential of autonomy to increase efficiency of logistics, supply and transport, automotive and aerospace industries looking to manufacture autonomous vehicles face a **period of uncertainty.** There is scepticism in terms of near-term profitability, especially within a regulatory environment and test and verification protocols that have yet to adapt to emerging technologies to ensure safe operation in a variety of different environments. Further to this, companies face uncertainty when choosing the technologies in which to invest. At present, there are over 50 significant technologies currently in development that could aid in the automation of the supply chain.[97] In the aftermath of Covid-19, the development of advanced technologies could be delayed if original equipment manufacturers (OEMs) scale back innovation funding to tackle more immediate challenges.

Source: RAND Europe analysis of open source data

As noted in Chapter 2, however, commercial logistics providers may not have the same understanding and approach to risk that the military has,[98] and this has the potential to endanger operations if not managed appropriately. Indeed, while incurring delays in the commercial sector may simply have a financial impact, logistics delays in support of military operations could, at its worst, lead to mission failure or loss of human life. Also, rules and regulations for operating in non-permissive environments would need to be clearly defined as commercial providers will have a different risk appetite where platforms and crews are placed in potential danger.[99] These arrangements could compromise freedom of action as availability may not be as easy (or as cost effective) to assure via commercial contracts – though the growing use of remotely piloted and autonomous systems in future may do away with some of the policy, legal and ethical concerns associated with putting contractors in danger, making it much easier for the military to deploy commercially-owned assets in a non-permissive environment.

With these considerations in mind, commercial partnerships are more likely to be suitable for low priority, low risk deliveries in permissive environments. Assuring availability from commercial providers when Defence needs it, also comes at a cost. Ordinarily, Defence could wait until there is a requirement for

[93] Intermodal terminals are nodes within transport infrastructures which act as the interface between different modes of transport. The basic function of intermodal terminals is the loading of units from one transport mode to another.

[94] McKinsey (2019).

[95] McKinsey (2018).

[96] Ibid.

[97] McKinsey (2019).

[98] GSP workshop on the Global Mobility: Future Force Design Out to 2040, 13 May 2021.

[99] GSP workshop on the Global Mobility: Future Force Design Out to 2040, 13 May 2021.

commercial support and then go to the marketplace to find the best price. However, this is risky in that there may not be spare capacity when it is needed, particularly if this coincides with a surge in demand from elsewhere such as around Christmas (when demand from the retail sector is highest in Western countries). Entering into enabling contracts could allow Defence to contract for availability at additional cost so Defence would need to calculate how much it would be willing pay to guarantee this in different circumstances, given such terms will determine the price.

Additionally, the UK does not currently have a reliable and large scale 'prime' commercial logistics provider based on sovereign soil, i.e. a prime contractor that has developed a strong commercial relationship with the UK military, understands its business, and from which it could work to improve efficiency and the costs of contracting for Defence. Other European countries provide examples of good practice here as the basis for a strong contracting platform from which sub-contracts with other providers can be launched: Germany has Deutsche Bahn, while Luxembourg has Cargolux – all providing market intelligence and knowledge in logistics at the national level as well as pre-existing networks that can facilitate military mobility in various environments as required.[100]

In addition to the use of commercial logistics companies, commercial contracts could be set up to enable UK Defence to have direct access to mobility assets at the time of need in a pre-agreed arrangement. Indeed, the Air Tanker contract for the provision of the Voyager in both an Air Transport (AT) and AAR capability is one such example, centred around a core fleet of eight aircraft, with the option of surging capacity to access an additional fleet of five aircraft at short notice.[101] The five aircraft, when not required by Defence, are operated in the civil market to generate additional revenue.[102] The ability and speed of converting aircraft 'back' into the military operation mode are regularly tested to ensure that the model achieves desired levels of readiness.[103] A similar principle is used in the operation of the US Civil Reserve Fleet (as shown below) although at a much larger scale.

[100] Interviews with RAND Europe, April–May 2021.

[101] RAF (n.d.).

[102] Ibid.

[103] Interviews with RAND Europe, April–May 2021.

Box 10. US Civil Reserve Fleet

The US Civil Reserve Air Fleet (CRAF), is a unique and voluntary programme that represents a significant part of the American air mobility resources.

The CRAF is a cooperative agreement ready for activation when needed, in which selected aircraft from US airlines, augment the US Air Force's own aircraft fleets during a national defence related crisis. This contractual commitment to CRAF through the US Transportation Command (USTRANSCOM), provides the selected aircraft carriers with certain benefits that include carrying commercial cargo during peacetime as well as passenger traffic for the DoD.[104]

This agreement has a national segment that satisfies domestic requirements and an international segment divided into short-range and long-range sections, where the former is made up of medium-sized passenger and cargo aircraft that provide support near offshore and selected intra-theatre airlift requirements.[105] The latter consists of passenger and cargo aircraft capable of transoceanic operations.[106] Additionally, the contractors will need to provide all personnel, training, supervision, fully operational equipment, facilities, supplies and any items and services necessary to perform international long-range and short-range airlift services during peacetime and both international and domestic airlift services during CRAF activation in support of the DoD. Airlines such as American Air Lines, Delta Air Lines and United Air Lines are all part of the CRAF.[107]

Source: RAND Europe analysis of open source data

3.2.4. Use of uncrewed, optionally crewed, lightweight assets and automation

The development of uncrewed, optionally crewed, lightweight assets and autonomous systems may bring about a transformation in how military mobility is delivered. Options that reduce the risk to human life when delivering mobility, logistics and resupply are likely to become increasingly attractive.[108] Such systems have particular tactical advantages for the final mile delivery and especially in non-permissive environments, where uncrewed and lightweight delivery options could become much more appealing for deployment, data gathering and sustainment of troops.[109] These options not only reduce the risk to life, but they can also reduce the associated costs and crewing challenges (e.g. reduced need to conduct physical training with assets, thereby increasing their operational life and reducing acquisition and through-life costs). Optionally-manned systems may also offer flexibility, if with the trade-off of losing many of the design and cost advantages (e.g. removing the cockpit and life support systems) associated with a fully uncrewed platform. The use of rotary wing platforms for mobility, for example, could see demanding tasks within complex (e.g. urban) environments requiring crew members on board, while routine movements in the maritime domains, in particular, could become unmanned.[110]

Additionally, the adoption of automation and related technologies throughout the enabling functions and tasks underpinning mobility (e.g. the use of autonomous vehicles and robots or exoskeletons for loading and unloading platforms) should be considered as further options for increasing efficiency and reducing the

104 US Air Force (2014).

105 Ibid.

106 Ibid.

107 Ibid.

108 Interviews with RAND Europe, April–May 2021.

109 Interviews with RAND Europe, April–May 2021.

110 JCN 1/21 Future Rotary Wing.

burden on humans. As technologies mature, more options will become available for implementing these in the field. When fully matured, unmanned aerial vehicles (UAVs) could potentially deliver the AAR task and other roles in operations, therefore removing one of the key requirements for manned aircraft. Box 11 illustrates another example of using autonomy in ensuring safety of military truck drivers in convoys of vehicles.

Box 11. Lockheed Martin's Autonomous Mobility Appliqué System (AMAS)

Lockheed Martin's AMAS brings autonomous capability to trucks in convoys; they have the capability to lighten soldiers' physical loads and increase their mobility and effectiveness as well as helping to reduce driver fatigue, something that would normally occur during long missions.

On long missions, drivers in convoys of military vehicles tend to get fatigued. This can result in accidents causing loss of human life, loss of cargo and materiel. The AMAS system is an efficient man-machine interface that allows the machine to do the driving. This is a low-cost/low-risk technology, it is a kit-based solution that can be retrofitted safety, and it enables a semi-autonomous and autonomous capability to be installed onto any vehicle in the military's logistics fleet. The system provides a Driver Warning/Driver Assist functionality, which assists a driver in an array of tasks such as avoiding obstacles and collisions, maintaining a safe distance from the vehicle ahead and maintaining position within a driving lane. Another functionality is the Leader-Follower mode, which provides the capability to link a large number of vehicles together as a cohesive convoy packet, allowing follower vehicles to operate without a driver, reducing risk to life in the event of an attack.[111]

This technology improves soldier safety and battlefield survivability. By using these autonomous and semi-autonomous systems, the cognition and situational awareness of the crew is increased while reducing vehicle collisions and driver fatigue, an occupational hazard in this type of role.[112]

Source: RAND Europe analysis of open source data

In the transition period to full autonomy, however, the possibility of adversaries disrupting the behaviour of unmanned assets can place the operation as well as the equipment in danger. Ensuring secure connectivity to such unmanned systems – together with advances in explainable AI, validation and verification processes, improved human-machine interfaces and build-up of skilled personnel to design and operate such systems – will be essential to instilling the necessary confidence in them. Only then can these technologies be adopted widely. When operating in contested EM environments, reversionary modes will be required to assure operation of these assets. Additionally, autonomous systems may have ramifications in different areas such as fleet organisation, the physical attributes of high-mobility military systems, the individual behaviours of autonomous assets, the interactions between humans and autonomous systems, and the operation and teaming strategies, which should be analysed and understood widely before extending their use into these areas.[113] Deploying UAVs to deliver supplies onto naval ships, including aircraft carriers, for example, has so far been hampered by regulation that complicates such use of UAVs due to the moving landing platform and potential risks that this may pose in open airspace.[114] Overall, however, the use of autonomous and optionally crewed systems for mobility and logistics are likely to see a faster uptake than

---

[111] Lockheed Martin (2021).

[112] Lockheed Martin (2021).

[113] See Bayrak et al. (2020).

[114] Interviews with RAND Europe, April–May 2021.

systems that employ lethal force (e.g. for strike missions) due to the technical, policy, legal and ethical challenges associated with lethal autonomous weapons systems.[115]

3.2.5. Data-driven and/or data-enabled mobility

Data collection, management and sharing also needs to be aligned with current available technology. Currently, the UK military does not have a centralised data management system from which analysis can be done to provide the most efficient route or to select the right mechanisms to provide mobility.[116] Data analysis is a powerful tool, especially when it comes to logistics and supply chain management. Poor data quality on decision support systems, data management and data collection, can lead to delays in transportation, the wrong provision of assets, and inventory management problems that can result in high financial and operational costs. Access to more reliable data could accelerate decision making and improve operational tempo. Commercial operators have invested heavily in digitalisation, primarily focused on cutting costs and expanding efficiency (see Box 12).

Box 12. Digitalisation of the supply chain and future projections

The digitalisation of the supply chain holds significant value-creation potential. In the aerospace and defence industry, it is estimated that digitalisation could produce value of up to $9 billion a year.[117] In the shipping industry, shippers and carriers using data and analytics to forecast demand have reduced inventories by up to 75 per cent and cut warehousing cost by up to 30 per cent.[118]

However, there are obstacles to be overcome. Data is often disparately organised across organisations and the supply chain. This **data would need to be consolidated** – often manually – to provide better opportunities for collaboration between OEMs and suppliers. Several companies have had success with digitalisation. Volkswagen is a notable example, having built an 'industrial cloud' to link 30,000 locations and 1,500 suppliers through a common platform. This platform gathers and analyses real-time data from sources such as component trackers to improve logistics.[119] Several other companies have deployed digital procurement methods to improve processes such as the automation of sourcing. **Internet of Things (IOT) sensors can also be used connected to products alongside advanced analytical methods to forecast real-time inventory requirements** and to determine where inventory should be held.[120]

A future trend expected to emerge is **real-time data exchange between all elements within the supply chain**.[121] This could reap multiple benefits such as the ability to track the flow of materials using geolocation tags, to optimise inventory levels and to rapidly build knowledge on supply-chain issues.

Source: RAND Europe analysis of open source data

---

[115] For a detailed analysis please see Retter et al. (2019).

[116] Interviews with RAND Europe, April–May 2021.

[117] Ibid.

[118] McKinsey (2018).

[119] McKinsey (2021).

[120] Ibid.

[121] Ibid.

Exploiting space and cyber capabilities could provide new ways of gathering and managing good quality data to enhance efficiency of mobility capabilities (e.g. a centralised database of available assets, data-driven approaches to warehousing, resupply and maintenance) as well as enabling better anticipation of future deployment requirements and better prediction and forecasting of the mobility needs – as illustrated in more detail in Chapter 2.[122] The creation of a digital backbone underpinned by space and cyber capabilities would be a significant enabler for connectivity between platforms and systems operated by Defence as a whole and a key practical enabler of multi-domain integration.[123] Effectively, every platform 'becomes a sensor' that is capable of exchanging data with other platforms and systems integrated via a secure network to enable delivery of effects (including mobility) across the different domains.[124] Naturally, there will be a requirement to integrate not only new platforms but also legacy platforms, which may pose initial challenges due to legacy systems in place.[125]

Good quality data can facilitate the understanding of needs and requirements, but is not a perfect solution. The need to implement advanced technological tools that can provide real-time data to inform planning and execution of mobility tasks will increase in importance but will expose cyber and space vulnerabilities and present additional security risks. While data-driven approaches geared to optimise warehousing and supply are widely used in the commercial sector (e.g. 'just in time logistics' as shown in Box 13), their adoption within the military context has to be tempered with considerations around mission effectiveness and assurance of supply; these may demand a balanced approach that combines stockpiling with agile delivery models.[126] Examples from the commercial sector may be useful to consider, e.g. DHL's development of Big Data Analytics, where it is an essential part of their de facto operating model for their logistics operations, as illustrated in Box 14, or Google Cloud data-driven supply chain platform.[127]

---

[122] Interviews with RAND Europe, April-May 2021.

[123] Interviews with RAND Europe, April–May 2021.

[124] JCN 1/21 Future Rotary Wing

[125] GSP workshop on the Global Mobility: Future Force Design Out to 2040, 13 May 2021.

[126] Interviews with RAND Europe, April–May 2021.

[127] Interviews with RAND Europe, April–May 2021. Google Cloud (n.d.).

Box 13. AI applications in predictive logistics

The use of predictive logistics is currently AI's most powerful and important application for the logistics industry and supply chain technologies.

The use of AI to create predictive logistics is made possible by the abundance of supply chain data from which to draw predictive insights. This has become a priority for large established logistics companies such as DHL or FedEx as well as more recently emerged e-commerce players such as Amazon in the US or Ocado in the UK. As more information is made available and accessible to companies, AI will progress towards creating a dynamic route optimisation, managing numerous variables such as delivery time windows, ad hoc pickups and traffic patterns to generate accurate time-window predictions for customers. With AIs evolving and becoming more sophisticated, their predictions and forecasts could take logistics players into new territory including anticipatory delivery models. This envisages supplying goods to customers before they even realise what is needed.[128]

The emerging field of supply chain data science has the potential to change the way logistic operations work. Transforming from reactive to proactive operations, and ultimately predictive operating models, is the natural next step as a result of new information tools – data mining, pattern by recognition, business analytics and business intelligence – all powered by processing vast amounts of high-quality and real-time data.[129]

Source: RAND Europe analysis of open source data

3.2.6. Additive manufacturing

Historically, military platforms have spent many decades in service and often the original equipment manufacturers (OEMs) that supply replacement parts disappear before the platforms are decommissioned. A lack of providers for replacement parts could render systems unusable until a replacement is delivered. This can occur on the frontline and in forward operating bases, where not only platforms but other items such as rifles or radios have the potential to break. Waiting for a replacement spare to make its way through the supply chain before they can be repaired poses a real challenge. The lack of spare parts in more remote areas where the military is deployed places significant burden on military supply chains and potentially on combat operations. As shown in Box 14, additive manufacturing, also commonly known as 3D printing, has been trialled by the commercial sector for several years with new technological developments in this area enabling the production of replacement parts *in situ* quicker and with increasing varieties of materials, including titanium, carbon fibre, concrete and many others.

[128] DHL (2021a).

[129] DHL (2021b).

Box 14. 3D printing and future projections

The use of additive manufacturing (AM) to print spare parts and supplies is growing across multiple industries. Leading this trend are the aerospace, automotive and logistics & transportation sectors.[130] In 2019, the global additive manufacturing (including 3D printing) market grew to over $10.4 billion[131] and the number of organisations using in-house 3D printing systems measured 40 per cent – a 31 per cent increase from 2016.[132]

AM is also penetrating mass-markets, with small parts for smartphones being produced using 3D printers. Whilst the Covid-19 pandemic has slowed the growth of some 3D printing companies as revenue declined (in line with declines in the shipment of goods and the airline industry) other companies saw growth as businesses. Hospitals, for example, used AM to produce emergency parts for medical supplies on-demand.[133]

Despite the pandemic, **companies are continuing to attract capital and the 3D printing market is set to double in size every three years**.[134] There is a large number of companies who utilise additive manufacturing. Moog (along with Microsoft, ST Engineering and Air New Zealand) demonstrated the benefits of on-demand 3D printing on a Boeing 777-300ER.[135] Whirlpool has committed to digitising its parts catalogue and use 3D printing to produce spare parts.[136] Both UPS and Deutsche Bahn have well-established systems in place to manufacture spare parts and supplies. UPS have a base for industrial-strength orders in Kentucky, and a network of smaller 3D printers in 60 locations around the US.[137]

Looking ahead, there is an **expectation that companies' uses of 3D printing for the production of parts or goods will double in the next 4 years.**[138] In terms of what this could look like: fully automated high-rack warehouses with 3D printers producing spare parts could be operational by 2030.[139]

Source: RAND Europe analysis of open source data

Having the ability to quickly produce replacement parts for ageing military aircraft, vessels and ground vehicles, as well as structures, will help in reducing lost time in getting these machines back up into action as soon as possible or transporting the spare parts and structures.[140] AM could also reduce the environmental footprint and burden on logistics by replacing the requirement to transport replacement parts with the raw material used by 3D printers instead.[141] This could make accessing specialist spare parts far easier. Different 3D printing techniques enable an array of opportunities for military applications. Recently, the US Air Force was able to 3D print a new titanium piece for the F22 Raptor Stealth fighter. The US Army and the

[130] McKinsey (2021).

[131] AMFG (2020a).

[132] AMFG (2020b).

[133] AMFG (2020a).

[134] AMFG (2020b).

[135] Aerospace Technology (2019).

[136] AMFG (2018).

[137] UPS (2016).

[138] AMFG (2020b).

[139] McKinsey (2021).

[140] Interviews with RAND Europe, April–May 2021.

[141] Interviews with RAND Europe, April–May 2021.

Dutch military also both use Markforged 3D printers that create essential components such as jigs, fixtures, tools or spare parts that can be easily printed directly on site within a very short time.[142]

The maturity of this technology permits experimentation on different techniques and approaches for military use. Considerations regarding power and energy usage, quality of the finished products, space required within vessels and safety measures should be fully understood before implementing this technology on a large scale as they will inevitably shape the trade-offs between benefits, costs and risks.[143] Additionally, 3D printing may pose new challenges for industries whose business model relies on significant revenues from maintenance, repair and overhaul, which could see declines due to the use of 3D printing *in situ*. Crucially, data encryption for design information and other protective measures should be a priority to minimise the risk of backward engineering of 3D printed items by adversaries and potential leaks of intellectual property.[144]

Box 15. US Marines use additive manufacturing to print a rocket launcher shelter

The introduction of additive manufacturing in the military provides a myriad of applications such as manufacturing a rocket launcher shelter with quick-drying concrete using the ICON's Vulcan 3D printer.

In 2020, the US Marine Corps tested its ICON's Vulcan 3D printer and created a concrete rocket launcher shelter in under 36 hours.[145] The shelter can hold a HIMARS truck-mounted multiple rocket launcher system. This structure can shelter personnel, vehicles and supplies from the weather. The Vulcan 3D printer is designed to spray layers of proprietary Lavacrete, which is a fast-curing polymer concrete that can be ready for use as soon as 12 to 24 hours after printing. This concrete-like material has a strength rating of 6,000 pounds per square inch (psi) and can block radiation. The US Marines used the Vulcan printer by spraying down layers of the Lavacrete that harden into horizontal cross-sections of the building. Engineers can then lift the cross-sections upright and assemble them into a complete building.[146]

Being able to print different structures using the Vulcan 3D printer reduces the need for transporting these structures into the deployment area. Several designs can be used to create fortifications, including aircraft shelters, bunkers and revetments to store ordnance, supplies and to protect weapons systems.[147]

Source: RAND Europe analysis of open source data

3.3. Implementing these mobility options will not take place in siloes; rather, it is their integration that is likely to bring the greatest benefits

The previous sections have examined six options that could present opportunities for UK Defence to enhance the effectiveness of delivering global mobility as it looks to meet its strategic ambitions for 2030 and beyond. While these have been described as separate 'options' to ease clarity of presentation, they are in fact interconnected and will inevitably be combined to deliver benefits for global mobility. Many of the

[142] Mark 3D (2018).

[143] GSP workshop on the Global Mobility: Future Force Design Out to 2040, 13 May 2021.

[144] Internal workshop, RAND Europe, May 2021.

[145] Popular Mechanics (2020).

[146] Ibid.

[147] Ibid.

examples mentioned throughout this chapter already illustrate this: the RAF's operation of the Voyager platform, for example, illustrates both the use of multi-role assets (here for transport and AAR capability) and a specific commercial model that seeks to maximise the cost-effectiveness of delivering mobility while also assuring that this capability is provided on time and in a fit state when needed in an emergency. Similarly, international collaboration as a model for developing or accessing mobility capabilities often draws on multi-role mobility assets (as is the case with the MRTT and the Ark project) to maximise the use of spare capacity on such platforms and to enable access to a wider range of stakeholders who may not be able to afford to develop and operate organic capabilities alone. Finally, the increased use of uncrewed and autonomous systems is impossible to imagine without an effective underpinning framework for data generation, transfer and storage that is secure, reliable and timely. Indeed, secure transfer of data is fundamental to enable all the other options, whether it is to ensure secure communication between different actors to signal demand for mobility assets (e.g. within a commercial-military set-up or an international partnership) or 3D printing of various designs.

The next chapter explores how the different options examined here affect considerations around force design and capability planning for the future.

4. Implications for future force design

This chapter revisits the six options identified through research and described in more detail in Chapter 3 to identify their potential implications for UK future force design, considering in particular the opportunities and challenges they might bring for capability planning out to 2040.

4.1. Each option offers opportunities and challenges, requiring an 'eyes open' approach to identify where benefits outweigh costs and risks

As discussed in Chapters 1 and 2, the art of delivering global mobility within the Defence context relies on a complex interaction between different actors and covers a wide range of activities, from large air and sealift of personnel and equipment to commercial delivery of packages to deployed personnel around the globe. The modes for delivering mobility are equally varied, as shown in the previous two chapters, ranging from large military platforms to commercially operated ships, aircraft, trucks and, where appropriate, rail. Looking into the 2040 timeframe, this variety is likely to increase even further, with the 'sunrise' of mature autonomous and uncrewed or optionally crewed platforms in all settings from sea (above and below sea level), land, air and possibly the use of space-based mobility assets as well. Technological advancements and maturity of modular designs and open systems architectures are likely to increase the drive for MRPs (as already seen in ships), and the broader impetus within UK Defence towards multi-domain integration will encourage a focused development of a digital backbone that connects different systems into an overarching system-of-systems and information architecture to enable a truly integrated management of operations.

As noted in Chapter 3, the high-level options identified by this study are interlinked, and their merits and drawbacks will therefore combine into a complex mix of considerations when determining their benefits. This complexity demands a robust approach to identifying:

- The contexts within which each option is likely to bring more opportunities than challenges.
- The ways in which challenges can be mitigated to reduce risk to mission success.

In short, identifying the right mix of capabilities and options for 2040 will require an 'eyes open' approach that is conscious of the different trade-offs each option imposes on future force design and capability development. Table 3.1 provides an overview of some of these trade-offs as identified through literature review, interviews and workshop discussions with GSP partners and other external experts.

Table 4.1. Opportunities and challenges of the identified global mobility options

Global mobility options		Opportunities	Challenges
	Increased use of multi-role platforms	• Can perform a multitude of roles (e.g. passenger, freight, air-to-air refuelling) • Increased interoperability between platforms • Platforms could become revenue earning assets with both a military role and a civilian role • Can be retasked after each operation without delays, including at regional hubs • Greater ability to respond to a variety of tasks (e.g. combat, HADR, medical assistance) • Greater agility and adaptability, helps improve the overall resilience of mobility as a capability	• Increased demand for these platforms leading to less availability • Can often only perform one task at a time • Could become a more attractive target for adversaries if perceived as more valuable due to multi-role function • Training and size of the crews could present challenges and needs to be factored in • Greater feasibility in some domains (e.g. naval) than others (e.g. space, land) in the near term • Multi-role platforms are typically more expensive so finding right balance is essential
	International collaboration	• Timely access to mobility assets • Shortening border crossing times • Cost reduction for participating nations • Collaboration can provide flexibility when surge capacity is needed • Greater availability of assets • Enables better understanding of local relationships and networks • Contributes to fostering of broader strategic relationships with key allies and partners	• Collaboration not possible or difficult in some areas (e.g. due to complexity and regulation of munition supplies and food supply chains) • Less freedom of action and aversion to command dilution • Conflicts of interest may constrain operations • Less assurance of availability of assets than sovereign owned assets • Merging of supply chains could be complex • Lack of interoperability (technical systems, culture, etc.) could hinder seamless operation

Global mobility options	Opportunities	Challenges
Commercial solutions	• Exploiting market intelligence, knowledge in logistics networks and supply chain know-how of commercial partners • Platforms could become revenue earning assets • Could ease the pressure on military platforms • More resilient and integrated supply chains • Can provide technological advantages for mobility and logistics (e.g. SpaceX Starship) • Opportunities to tap into innovative 'green' solutions adopted in the commercial sector	• Could compromise freedom of action as availability may not be as easily assured via commercial contracts • Different risk perception (life threatening vs non-life threatening) and understanding of military vs civilian needs • Merging of supply chains could be complex • Different payload for commercial assets and military assets • Lack of reliable 'prime' commercial logistics provider on domestic soil in the UK
Use of uncrewed, optionally crewed, lightweight assets and automation	• Could help reduce the loss of human life (reduces exposure) • Flexibility, cost reductions and reliability • Facilitates last mile resupply and operations in non-permissive environments without endangering human lives • Greater support availability (less dependent on operating crew, e.g. swarm drones) • Reduces configuration and crewing challenges (training, duty times) and boosts mass • Reduction of loading/unloading times via automated systems (vehicles or robots) or human enhancements (exoskeletons)	• Loss of uncrewed assets could put in danger troops in theatre (lines of supply broken) • Data-flows vulnerabilities leading to tainted (possibly controlled by an adversary) information and algorithms • Poor connectivity could cause system disruption • Adversaries could take advantage of cyber and electronic vulnerabilities • Creates the need for resilient autonomous systems in a contested environment • Energy and power requirements need to be considered • Policy, legal and ethical barriers

Global mobility options		Opportunities	Challenges
	Data-driven and/or data-enabled mobility	• Instant access to data analysis and supply chain data management • Access to more reliable data could accelerate decision making and operational tempo • Just-in-time logistics that reduces unnecessary supplies and material to store • Improves understanding of the requirements and needs for mobility (warehousing, stock resupply, maintenance of assets) • Exploiting space and cyber capabilities and shift to Internet of Things and cyber-physical systems could provide new ways of gathering and managing data to enhance efficiency	• Vulnerabilities of data, communication and analytics leading to tainted (possibly controlled by an adversary) information • Just-in-time requires perfect understanding of demand and communications and also may undermine resilience by reducing redundancies • Network vulnerabilities could enable adversaries to obtain or subvert information • Increased contestability of space and cyber could pose a threat to the way data are collected • Increased demands on energy supply
	Additive manufacturing	• On-site manufacturing (shorter supply chains) • Efficiency (e.g. energy, waste, stock) • Reduction of transportation costs and less dependency on host nation • Shorter lead and transportation times • Reduction of warehouse space requirement • Wide variety of materials available, including polymers, ceramics, metals and composite materials • Access to a wide variety of items that could not be readily available for shipping	• Increased demand on energy supply • Safety measures need to be implemented • Training and expertise could pose a problem • The quality of the items could hinder the use of this technology • Transportation or sourcing of raw materials will need to be introduced in the logistics operations • Intellectual properties and design availability • Stability and balance factors of the manufacturing site (e.g. printing inside vessels) • Physical space required (specific for vessels)

Source: RAND Europe analysis

4.2. When assessing different options, UK Defence should systematically consider trade-offs between organic and shared capabilities

Identifying which options are most suitable for which future defence task – including tasks that may be conducted in collaboration with other government departments – requires both an understanding of key trade-offs each option brings (see previous section) and a systematic process to assess them. To do so, defence planners need to understand the following:

- **What is already available and likely to be available in the 2040 timeframe**: what mobility assets does UK Defence have at its disposal (whether organic or shared with partners/allies or accessed commercially)? If these cannot meet the requirements of the operational scenarios envisaged for the 2040 timeframe, are there opportunities to retask from lower priority missions, rerole (for multi-role platforms), adapt or upgrade? For global mobility assets, this might include assets already deployed to regional hubs that are closest to the requirement and can be retasked from the location.
- **What is essential for strategic imperatives and operational independence[148]:** which parts of the mobility requirement must be delivered in an assured way? How can assured access be provided using organic (sovereign) capability and/or shared assets? Is the capability critical to other government departments and agencies (e.g. in support of intelligence operations)?
- **What is feasible**: does UK Defence have sufficient time to use a particular option? Is there time to consider multi-modal options? Is the use of commercial mobility services feasible (e.g. with time, money, assurance risks)? Short notice high-priority requirements tend to revert to the use of organic military solutions as the quickest means to meet the requirement, closing off wider options that could be more cost effective and/or environmentally sustainable.
- **Which mobility requirements offer flexibility of choice**: which parts of the mobility requirement present scope for a broader set of options due to either decreased risk to mission success, or potential for increased effectiveness and efficiency, or both?
- **Which options are desirable for the UK nationally and UK Defence specifically:** which specific options provide the most attractive proposition in terms of the benefits, costs and risk across a range of relevant factors (including, for example, performance metrics such as time, speed as well as a range of broader appraisal metrics such as value for money, industrial benefits, social value, impact on environmental sustainability, impact on partnerships, etc.).

It is beyond the scope of this short study to design a comprehensive decision tool mapping out the different steps; rather, this section highlights the principal considerations that should inform the decision making as UK Defence moves to identifying how best to combine legacy and new systems to meet its evolving global mobility requirements out to 2040.

[148] MOD (2021c).

4.3. Implementing an effective model for delivering global mobility could draw on known good practices and UK Defence's levers of influence

To enable an effective adoption of these different options, it is useful for UK Defence to consider how it may set up arrangements (with the commercial sector or allies and partners) for enhancing its mobility capabilities. Previous RAND research has identified several transferable lessons from collaborative arrangements on various multinational defence programmes, including for global mobility, as well as from public-private partnerships and contracts for delivery of large public finance projects, including those in defence. Additionally, there is a wealth of past government reports, National Audit Office (NAO) reports as well as published and unpublished RAND research on good practices in defence acquisition and support, from which lessons can be identified to enhance capability development in mobility.

Highlighted good practices are presented in this section.

Multinational partnerships

Previous RAND studies have identified strategic factors that are important when designing collaborative programmes. These emphasise the importance of behaviours, culture and relationships between partners, more than simply the design of formal governance structures. Relevant factors include[149]:

- Genuine interest and support from a military service on each side.
- Clearly stated and limited objectives of the programme.
- Similar national requirements and schedules (not subject to constant revision and rescoping).
- Complementary and mutually reinforcing technology, data or R&D capabilities.
- Complementary, rather than duplicative, technical strengths present in industrial partners.
- Compatible corporate cultures.
- Workshare allocation that takes advantage of the partners' relative economic and technological strengths, rather than top-down political considerations.
- Avoidance of duplication of tasks in design, development and production.
- Clear lines of authority in programme management on both government and industry levels.
- Utilising standardised multinational planning systems such as NATO's Logistics Functional Area Services (LOGFAS), or its replacement Logistics Functional Services (LOG FS) programme.
- Utilisation of appropriate exchange mechanisms (e.g. ATARES).
- Proactive considerations of multi-modal options for delivering logistics and transport.

In addition, a RAND Europe's review of collaborative programmes identified a set of key enablers for a successful programme delivery. These can be grouped under: 1) structural enablers; and 2) practical enablers, and encompass governance arrangements and processes, as well as behaviours and incentives (see Table 4.2).

[149] Lorell (1995).

Table 4.2. Multinational collaboration enablers

Structural enablers	Practical enablers
Shared understanding of motivations and approach to cooperation • Shared strategic priorities, levels of ambition and threat perceptions. • Identifying areas with clear operational, rather than political, logic for cooperation.	**Creating clear, coherent and transparent institutional structures** • Clear allocation of roles and responsibilities. • Definition of clear national points of contact and coherent relationship management. • Effective oversight and performance monitoring.
Balance within any partnership, while retaining agility • Ability to match partners' capability provisions and requirements. • Cognisance of differing advantages of big-with-small or of equal partnerships. • Portfolio approach to manage 'quid pro quo' across multiple cooperative programmes (e.g. different national primes act as lead industries in different programmes).	**Defining clear and equitable mechanisms for sufficient resourcing** • Long-term commitment of requisite financial and human resources. • Balanced and mutually supported mechanism for burden sharing.
Balancing national industry interests with political and military imperatives • Using flexible operating principles to address national concerns. • Political willingness to prioritise cooperation benefits over national industry interests.	**Establishing clear and transparent parameters for programme delivery** • Agreement and clarity on budgetary thresholds. • Agreement and clarity on development trajectories. • Risk identification and management.
Easing legal and regulatory barriers to cooperation • Flexible framework for cross-border movement of parts, systems, expertise. • Acceptance of non-national standards and certification.	**Improving information sharing** • Promoting greater sharing and transparency of information on national taskings • Enabling increased interoperability through use of common information technology platforms.
Providing political leadership and promoting trust • Bonds of mutual trust at political, institutional and individual levels. • Clear and consistent political direction. • Lobbying from existing partners to bring new countries to the programme. • Leveraging member nations' relationships with host nations to benefit other partners.	

Source: Retter et al. (2017) and Caves et al. (2020).

In addition, the study identified a need for better **evaluation mechanisms** to enable identification of best practice. Such evaluation mechanisms would involve regular collection of data (e.g. on cost, schedule, savings, technology spillovers, etc.) as well as collection, analysis and communication of lessons identified to relevant stakeholders and potential future partners.

Public–private partnerships

RAND's internally funded research on public–private partnerships to deliver large capital investment projects offers an overview of good practices that are likely to be of relevance to Defence partnerships with large commercial actors for provision of mobility assets and services. These are summarised in Table 4.3.

Table 4.3. Core good practices for effective public–private partnerships

Partnership	
Main risk: An unequal relationship, with agreements, formal or informal in favour of one partner, resulting in a lack of trust and miscommunication	
Defining requirements: Identifying strategy, objectives and service outcomes	Continuous improvement of performance, processes and people to drive better value for money as a common goal of the partnership Contractual agreements on use of resources within the partnership, clear and unambiguous escalation routes to resolve conflicts
Selecting the partner with expertise and adopting best practice in tendering	Select the provider with a view to minimising total public costs Full reputational assessment (incl. previous successful experience of delivering something similar) Avoiding specific partnership models that reduce incentives to minimise costs on both sides – promoting flexibility within the partnership
Communication and information sharing between partners	Joint teams with fully aligned goals Clarity (clear alignment of objectives across the partners, and an ambivalent statement of what success looks like, and how these objectives are to be achieved and measured)
Trust and openness	Aligned values and work ethics/culture Relationship survey to monitor cultural and process related aspects of the relationship to ensure effective relationship Open book accounting
Ending the partnership (managing the transition)	Lessons identified and robust mechanisms for collecting and learning from feedback to address barriers and improve performance over time

Performance
Main risk: Poor (or non-existent) performance management processes that contribute to failure in delivering contract objectives, and do not make use of monitoring tools and data to manage risk

Performance targets, objectives and Key Performance Indicators (KPIs)	Specific KPI tailored to the outcome goals of the partnership. Wider categories of KPI covering not only the service but also items such as equity, knowledge transfer and improvement Independent evaluation and assurance of performance targets to enable the evaluation of biased opinions and emerging unintended consequences
Flexibility and innovation	Adaptive contracts enabling renegotiation of terms to deliver innovation and continuous improvement Performance delivery linked explicitly to outcomes and having flexibility to changes in customer demand or requirements
Monitoring and measurement	Evaluation of performance not limited to output of the partnership Effective measurement of partnership health, staff performance and linked to more mature KPI categories Independent or regulatory audit bodies can access the same information as is used to evaluate performance within the partnership

Skills and expertise	
Main risk: Insufficient competencies within the partnership as a result of undertrained and/or under skilled individuals who lack awareness of technical and contextual requirements	
Market expertise	Long-term modelling of prices and market conditions, evaluation of impact of partnering dynamics on the external market. Understanding and utilisation of arbitrage mechanisms
Contracting expertise	Public sector engages collectively to leverage economies of scale where possible. Pooling of commercial resources to enable improvement
Managerial & Technical Performance expertise. Effective data analysis and intelligence leading to improved performance	Joint teams with fully aligned goals Clarity (clear alignment of objectives across the partners, and an ambivalent statement of what success looks like, and how these objectives are to be achieved and measured)
Effective management of staff across the partnership	Skills transferred/acquired through synergies between partner organisations and core team members (i.e. knowledge transferred from each organisation on process & practices, skills in management & communication)
Ending the partnership (managing the transition)	Understanding and continuous tracking/evaluation of risks, use of resources and key skill requirements across the partnership

Governance and accountability
Main risk: Poor (or non-existent) performance management processes that contribute to failure in delivering contract objectives, and do not make use of monitoring tools and data

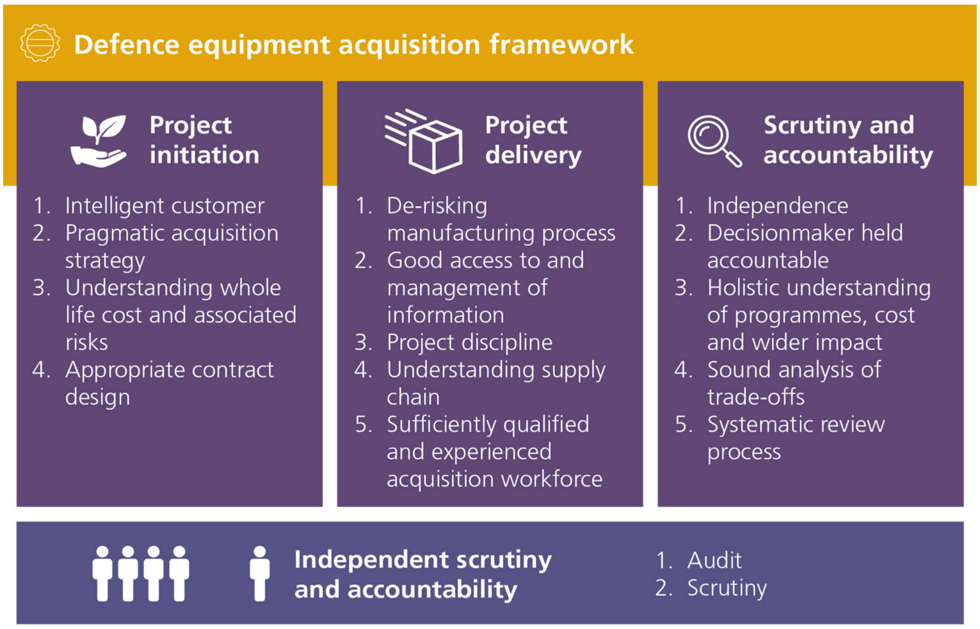
Plan for effective governance structures and accountability mechanisms internally and beyond the partnership	An effective improvement planning response process is in place. To react to both internal governance decisions and/or external regulatory recommendations or mandates Understanding of the need to have adaptable project delivery teams
Risk allocation and management	Accurate estimations within a Whole Life Cost model of the levels of risk provision required to mitigate uncertainty in demand, improvement activity and market behaviour Mechanisms allowing the rewards (for example for innovation) to be distributed according to the risk that each party has assumed
Information	Mechanisms for instantaneous and transparent information delivery across the partnership, full open book accounting mechanisms
Public accountability	Publication of the achievement of partnership outcome performance. Involving feedback from local communities or wider public stakeholders Effective improvement in the delivery of both public value for money or private sector shareholder value
Payment mechanisms	Consider an availability contract for services not financed by user fees

Source: Penny et al. (2012).

Defence acquisition models, strategy and relationships

Relying on decades of research on defence acquisition as well as government and NAO reviews of past and current defence acquisition practices has resulted in the generation of 'gold standard' principles for sound acquisition practices. These are summarised in Figure 4.1.

Figure 4.1. 'Gold standard' – principles for successful defence acquisition



Source: RAND Europe analysis

In addition to these broad principles, UK Defence has opportunities to pursue fresh approaches to capability development that are likely to be better suited to novel technologies and the need to tap into the latest innovation (e.g. in autonomy, space systems, etc.). These approaches include, but are not limited to[150]:

- **Spiral development,** which emphasises incremental development and quick reactions to changes in capability needs based on end user feedback.[151]
- **Creation of digital twins and use of digital engineering** (as is a priority for the US Space Force).[152]
- **Rapid prototyping,** which is a set of design and development activities conducted in the early stages of acquisition to reduce technical uncertainty and to inform subsequent acquisition decision making, towards fielding capabilities faster than traditional acquisition programmes.[153]
- **Modular open systems architecture (MOSA),** which makes use of a modular design philosophy with plug-and-play system modules connected via consensus-based interface standards, which allow for interoperability and technology reuse across the organisation.[154]
- **DevSecOps and iterative models of software development,** which focus on optimising workflow to generate faster times to market, improved overall productivity, while prioritising security throughout all stages of development.[155]

When deciding which agile acquisition approach to select for a given programme, Defence should build on the lessons provided by other domains, including previous MOD successes, and the experiences of allies, partners and commercial organisations.

[150] Kim et al. (2020).

[151] Ibid.

[152] Armstrong. (2020).

[153] Kim et al. (2020).

[154] Ibid.

[155] Plutora (2021).

5. Conclusions and recommendations

This chapter draws together conclusions from the previous chapters and offers recommendations for UK Defence to help it more systematically approach the selection of different options for delivering global mobility out to 2040 as it goes about further refining its understanding of future requirements.

5.1. Addressing the mismatch between resources and ambition will require creative approaches to selecting mobility options

UK Defence is facing a difficult conundrum. In line with the revitalised approach set out in the Integrated Review, it is being asked to do more and be in more places than ever before. This has implications across the different defence tasks, along with the personnel and equipment deployed to support them, including those for achieving global mobility. Yet the accompanying policy documents (notably the Defence Command Paper) provide little detailed guidance on the resource that will be made available to meet the increased demand. Despite a recent uplift in defence spending, as fiscal constraints continue into the recovery period beyond the COVID-19 pandemic, it is likely that Defence will be **required to do 'more with less', balancing finite resources with the requirement to remain operationally effective, while more resilient and environmentally sustainable.** Robust and innovative approaches that consider different options in a systematic way with 'eyes wide' open to the risks and trade-offs they bring will be increasingly necessary to achieve such balance.

Historically, the **default option has often involved sovereign ownership and operation** (government-owned, government-operated) models, with enlarged organic military fleets. Arguably, this may quickly become cost prohibitive and could be expending taxpayers' money on capabilities that might never be needed. It is often more cost effective to outsource requirements for additional surge capacity for lower threat requirements, paying for it as required during these periods.[156] Indeed, UK Defence has already been doing this for many years, with examples including: contracting in additional commercial lift during high demand periods, such as in the initial deployment phase of an operation or during redeployment towards the end. However, arguably, this has been done less than effectively, and in a haphazard and ad hoc way.[157]

To navigate this complex decision space, it may be more appropriate to take a **holistic approach to the entire mobility fleet** (drawn from assets and systems from across the different Services), one that is based on risk and cost. This means making an informed assessment on how much mobility capability should be owned

[156] Interviews with RAND Europe, April–May 2021.

[157] Interviews with RAND Europe, April–May 2021.

by Defence, collaborated on with allies and partners (as with the A400M programme) or with industry, such as through private finance initiatives like the Air Tanker contract, or simply accessed when required either through the market place or multinational pooling and sharing agreements. The optimum blend depends on a number of factors relating to risk appetite, changing threats, assurance of availability and cost, and this calculation needs to be better understood collectively across Defence's entire global mobility capability to understand where the synergies or risks exist across the portfolio.

5.2. As in other domains, managing capability demands for mobility will require a robust approach to 'own-collaborate-access' choices

The 2012 *National Security Through Technology* outlined an approach to prioritising between sovereign and collaborative programmes based on Technological Advantage. This white paper has been supplanted by the 'own-collaborate-access' model introduced in the *Integrated Review* and *Defence and Security Industrial Strategy* (2021).[158] Drawing on the high-level descriptions provided in the public IR document, these options can be understood as follows:

- '**Own**': where the UK has leadership and ownership of capability from concept to development and manufacture; notably, this may refer to full capabilities or sub-systems within these.
- '**Collaborate**': where the UK can provide unique contributions that allow us to collaborate with others to achieve our goals.
- '**Access**': where the UK will seek to acquire access to capabilities/services from elsewhere through options, deals and relationships.

To maximise the use of constrained resources, UK MOD should **consider sovereign ownership when necessary, collaboration where possible and access to existing commercial or multinational solutions where prudent**, given the levels of risk as discussed in previous chapters. Defence could consider retaining a military fleet capable of operating in high threat environments, or to allow the UK government full freedom and sovereignty of action in certain operations, while

embracing alternative and cost-efficient ways and means of delivering mobility for more permissive environments and discretionary operations. Beyond this, the benefits of entering into collaborative partnerships through commercial contracts will still allow a degree of autonomy in how those assets are used and assured availability, while enabling less financial cost to be committed up front and also opening opportunities for greater resilience given access to a larger fleet of assets in times of need.

Finally, accessing additional capability on an ad hoc basis as part of looser multinational pooling and sharing arrangements or through additional commercial capacity from the marketplace provides the least amount of assured access, but arguably lower cost still in terms of being locked into enduring contracts. Given the fast progress in commercial sector innovation towards environmental sustainability, there may also be benefits for Defence in tapping into some of these solutions to minimise its carbon footprint. UK Defence would need to investigate this calculation to decide how it wants to hold its global mobility capabilities in

[158] MOD (2021a), MOD (2021c).

future **across the 'own, collaborate and access' spectrum, balancing cost and risk to come up with the optimum blend**. Considerations around what is available, what is essential, what is feasible, what is flexible and what is desirable can help navigate some of these complex decisions when selecting either 'own-collaborate or access' options (see Section 4.2 for more detail).

5.3. Several policy actions and recommendations should be considered when designing new models for global mobility

The following sections outline several recommendations that have been identified both in terms of high-level approach and policy actions. These have been identified through interviews with stakeholders as well as in consultation with external and RAND subject matter experts.

5.3.1. More focus on resilience and less on efficiency to better resource global mobility delivery

As discussed in this report, recent trends in and outside of Defence have tended to focus on efficiencies and lean methodology with business processes aimed at eliminating waste and increasing value across the system. This has arguably led to underinvestment and reduced resilience across various capabilities. The same logistics enablers, such as global mobility capabilities, are required to support deployments during various contingent operations and are often over committed. Whilst Defence plans for a suite of concurrent operations, a degree of risk is taken that these will not all happen at once. This risk has steadily grown since the UK's withdrawal from large scale enduring operations in Iraq and Afghanistan that were well established and predictable. Indeed, fewer large-scale missions have been replaced with a greater number of smaller and more unpredictable contingent operations, many of these occurring suddenly. Arguably, some of the agility and flexibility to respond to these types of operation has been lost over the last couple of decades, not least due to cuts in overall mobility assets since the end of the Cold War.

A brief look at the variety of missions that the UK's global mobility assets have been required to support recently is all that is needed to recognise that more investment in resilience is required. These have included enduring commitments to supporting air strikes in Iraq and Syria, annual HADR operations in the Caribbean, and contingency preparations surrounding Brexit and the COVID-19 pandemic. UK Defence faces a difficult choice. It can either invest more in its global mobility capabilities to grow its capacity and match the ambitions set out in the Integrated Review, or face spending even more in a crisis (or accept a loss of freedom of action and heightened risk of mission failure) in the event it has to grow this capability at short notice in an emergency. This will inevitably cost more and will not provide the assurance of availability that prior planning can provide. If global mobility capabilities are seen as an insurance policy, with the increase in the risk of multiple events happening at once, the associated premium should increase likewise, in the form of diversified access to different mobility options that can be drawn upon – be it commercial partnerships or bilateral or multilateral solutions.

5.3.2. Approaching mobility from a Multi-Domain Integration (MDI) perspective rather than at the individual domain level to increase synergies

Global mobility as a capability must be seen increasingly from an MDI perspective across the five domains[159] if limited assets and capability are to be used as efficiently and effectively as possible. This includes vertical integration across the levels of warfare (strategic, operational and tactical) and horizontal integration across other government departments, wider allies and partners, the commercial sector and industry. Making sure that mobility assets are fully network-enabled and interoperable with wider Defence capabilities will ensure better and more timely information sharing on logistics requirements allowing mobility assets to be utilised as efficiently as possible and minimising irreducible spare capacity.

As information and data becomes more widely available, the ability to share and analyse large quantities in real time through Big Data Analytics, AI and machine learning, can help to drive efficiencies across the supply chain, as discussed in Chapters 2 and 3. Likewise, with an increase in HADR and MACA type missions in response to natural disasters, UK Defence will increasingly find itself in a supporting role to other government departments, or as the lead, and better integration across government will help ensure better information sharing when deploying its limited mobility assets. This also extends to working with the commercial sector and industry, as well as allies and partners. In terms of multi-modal tasking across the domains, this is already happening to some extent through the MOD's joint tasking agency, the Defence Support Chain Operations and Movements (DSCOM); matching tasking requests to the most cost effective and efficient transport solution to meet the requirement. This means, for instance, not defaulting to faster, more expensive airlift outlets when delivery times do not require this. Embracing MDI principles further offers ways to improve this and with the advent of space and cyber, the impact of these domains needs to be taken into account. Defence should examine its global mobility requirements in relation to MDI and ongoing investments in related areas such as a 'digital backbone' or multi-domain command and control – including the lessons learned through related modernisation and transformation efforts in other countries, such as the US military's ongoing shift to Joint All Domain Operations – to identify where further improvements are possible.

5.3.3. Strengthening multinational collaboration arrangements to extract greater value from pooling and sharing initiatives

In line with earlier discussion on defining the right mix of ownership, collaboration and access to global mobility capabilities, an important aspect of Defence's future force design should be greater collaboration with allies and partners through multinational pooling and sharing arrangements, including to enable access to multi-modal tasking. Although the UK is already a member of several of these, such as the MCCE and the ATARES mechanism that underpins it, anecdotally it does not make as much use of it as other member nations and is often a net contributor rather than user of services. The MCCE in essence is just a clearing house to enable nations to share irreducible spare capacity on particular journey legs that would otherwise go unutilised. Nations are free to cancel at short notice for higher priority national taskings and they retain full control and sovereignty of their assets. Other multinational sharing organisations, such as the EATC,

[159] Land, maritime, air, cyber & electromagnetic and space.

involve greater surrender of control but allow multinational tasking to be better coordinated centrally, arguably making it much more efficient.

Traditionally, problems with efficient and effective sharing in the MCCE, stem from imperfect information sharing mechanisms, due in part to lack of trust from national governments and therefore lack of timely information sharing on national deployment planning. It also stems from problems with the national information architecture systems that sit beneath these, making it more difficult to share information when it is needed. This leads to an inability to maximise use of the full range of multimodal options due to late notification of asset availability or tasking requirements. All nations will be facing similar pressures in future on national defence budgets and so will be looking for opportunities to innovate and share capability. There is an opportunity for the UK to examine more closely its role and commitment to these initiatives to see if further benefits can be derived. For instance, the UK does not currently include its commercial lift contracts but other countries successfully share these as part of their offer.

5.3.4. Working with partners and allies to improve access, basing and freedom to operate in key regions around the world

Improving the UK's freedom to operate in key areas of interest around the world will provide more options for using global mobility to meet Defence's objectives. The UK already accesses a number of diplomatic channels and processes for gaining clearances in advance across the domains. Strong relationships here help to smooth the granting of permissions, for instance for ABO, and the UK is able to achieve more influence for instance with nations it may have a long-standing relationship with, such as former colonies. As airspace and the other domains become more contested and competition extends beyond the kinetic battlespace, the UK will need to use all the levers of influence it has at its disposal to allow its mobility capabilities to continue to operate. Here, it could leverage other allies and partners who have their own longstanding relationships with particular regions and countries where the UK holds less influence to help maintain that freedom of action. Using existing collaborative partnerships may help provide the catalyst for this.

5.3.5. Invest in strategic bases and regional hubs to allow for forward basing of mobility assets; offering greater flexibility to match the UK's global ambitions

Increasing and maintaining a persistent global presence will place more demands for global mobility requiring greater reach, speed, survivability and ubiquity; more than ever, assets will almost need the ability to be in several places at once and the ability to be retasked down route. Mounting deployments direct from the UK each time will become increasingly inefficient. Options to improve efficiency here may include greater use of hub and spoke, using regional hubs or forward basing of assets more permanently with the associated requirement for logistics, engineering and other support to achieve this. All this points to greater requirement for investment in regional bases. This could include older more established overseas bases, such as the UK's Permanent Joint Operating Bases (PJOBs) in the Falkland Islands, Ascension Island, Cyprus, Gibraltar and Diego Garcia, and newer bases, particularly those towards the Indo Asia-Pacific such as the UK's Joint Logistics Support Base in Duqm, Oman and the British Defence Singapore Support Unit in Sembawang, Singapore. While regional hubs and forward bases offer a number of opportunities, these will have to be considered vis-à-vis broader considerations for support and adequate resourcing in terms of personnel in all functions: warfighting as well as support and maintenance. There is also a growing need to ensure sufficient active and passive defences at these crucial hubs and POE/PODs, in the face of increasing threats from manned and unmanned aircraft, cruise, ballistic and hypersonic missiles, cyber-attack and various other proliferating technologies.[160]

5.3.6. Global mobility assets will require increasing protection from an array of threats that range from kinetic to non-kinetic

Competition no longer exists only in the kinetic battle space but includes sub-threshold activity in seemingly permissive environments. The threat environment is expanding, and this trend is likely to continue for the foreseeable future, necessitating a recalculation of what constitutes acceptable levels of risk. As discussed in this report, this is as a result of several factors. Firstly, to fulfil the aspiration for a 'Global Britain', UK forces will need to be more agile, reaching a greater range of places at distance and more quickly. This will bring them into more and more diverse threat environments. Likewise, competition has been steadily expanding out from traditional physical environments far away, encroaching upon friendly and seemingly permissive environments in sub-threshold operations as well as on space and the Cyber & Electromagnetic domain and the broader information environment. The proliferation of relevant technologies has increased the access to a greater number of actors meaning that less well-developed nations and non-state actors have entered the stage. Global mobility assets that will be required to enable deployments or transit through a greater number of now non-permissive environments will need to be better protected – not just physically but also through various counter measures. All this comes at a cost and needs to be factored in when determining how much capability is required.

5.3.7. Mapping key vulnerabilities across Defence's global mobility capabilities and infrastructure to help address potential areas of risk

As Defence becomes more dependent on global networks, with many interconnected and overlapping dependencies across the domains, this creates both opportunities but also vulnerabilities to attack from various malign actors including state and non-state. The advent of MDI and the ongoing shift towards networked platforms and systems offers huge benefits but also introduces significant risk. This includes global supply chains and the mobility assets that facilitate them. Risks in isolation may not be fully appreciated as part of wider aggregated risks across logistics systems unless mapped collectively. Likewise, Defence infrastructure has historically suffered from a chronic lack of investment leading to limited resilience and failure of systems or closure of bases on cost-saving grounds, without fully understanding what the knock-on effect is to supply chains and global mobility capabilities. Future global mobility platforms will be even more interlinked, connected to more systems and rely on more data sharing to make them function seamlessly. It is therefore important that Defence's mobility capabilities and the infrastructure that supports them are treated as one system-of-systems and that their dependencies and vulnerabilities are mapped together so that these can be mitigated and resources targeted to best effect.

[160] Gordon et al. (2019); Shlapak & Johnson (2016).

5.3.8. Approaching global mobility from a sustainability and net carbon zero perspective to ensure Defence is doing all it can to support government goals

In procuring and maintaining existing and future mobility capabilities, either through organic military fleets or as part of commercial arrangements and multinational sharing, a key consideration will be their impact on the environment. The UK government has signed up to increasingly challenging carbon reduction initiatives to achieve its net carbon zero targets by 2050 and will expect all government departments to contribute their share to reduction targets. This will create a growing challenge for Defence in trying to move away from high carbon emitting platforms, while having to retain many of these due to the considerable time they still have left in service. Looking out to 2040, Defence will need to get used to operating mixed fleets of both legacy and more advanced capabilities. New capabilities can be procured with this in mind such as autonomous vehicles that are battery powered and can be charged from renewable energy sources. However, Defence can also investigate how legacy fleets can be made more sustainable through the introduction of synthetic fuels, for instance.

Other considerations include understanding what impact sustainability has on diplomatic permissions and ABO. Some nations may impose strict requirements on countries transiting through their territory related to how sustainable their mobility assets are. In the future, sustainability may become a strict prerequisite for access, at least in times and situations below the threshold of open armed conflict. Similarly, the UK may choose in future to actively avoid certain nations *en route* to destinations, which have a poor track record in sustainability and environmental policy. Working with the commercial sector may also be influenced by this too and Defence may choose to only work with commercial providers of lift that have demonstrated their sustainability credentials. In the same light, sustainability may become a factor on multinational pooling and sharing initiatives with future membership conditional on nations meeting their sustainability targets.

These are all issues that UK Defence will need to take into account as it builds on the high level and unclassified analysis provided in this short report to develop a more detailed understanding of its requirements for global mobility out to 2040.

References

Aerospace Technology. 2019. 'Air New Zealand Forms Partnership for 3D Printed Aircraft Parts.' As of 21 June 2021: https://www.aerospace-technology.com/news/air-new-zealand-forms-partnership-for-3d-printed-aircraft-parts/

Airbus. 2020. 'Airbus Delivers First A330 MRTT to NATO Multinational Multi Role Tanker Transport Fleet.' As of 21 June 2021: https://www.airbus.com/newsroom/press-releases/en/2020/06/airbus-delivers-first-a330-mrtt-to-nato-multinational-multi-role-tanker-transport-fleet.html

AMFG. 2018. 'How 3D Printing is Transforming the Spare Parts Industry [2021 Update].' As of 21 June 2021: https://amfg.ai/2018/05/29/3d-printing-transforming-spare-parts-industry/

______. 2020a. 'The Fall and Rise of 3D Printing: How the Pandemic Has Impacted the Industry.' As of 21 June 2021: https://amfg.ai/2020/09/16/the-fall-and-rise-of-3d-printing-how-the-pandemic-has-impacted-the-industry/

______. 2020b. '40+ 3D Printing Industry Stats You Should Know [2021].' As of 21 June 2021: https://amfg.ai/2020/01/14/40-3d-printing-industry-stats-you-should-know-2020-redirect/

Armstrong, M. 2020. 'Cheat Sheet: What is Digital Twin?'. IBM. As of 21 June 2021: https://www.ibm.com/blogs/internet-of-things/iot-cheat-sheet-digital-twin/

Black, James, Rebecca Lucas, Sam Stockwell & Paola Fusaro. 2021. Warfighting at Reach. Conceptual Approaches to Power Projection and the Delivery of Military Effects from Standoff.

Black, James, Linda Slapakova & Kevin Martin. 2020. Future Uses of Space out to 2050. Emerging Threats and Opportunities for the UK National Space Strategy. Forthcoming publication.

BMT. 2019. 'ELLIDA-200 Multi-Role Logistics Ship.' As of 21 June 2021: https://www.bmt.org/media/4197/bmt-das-uk-ellida-200-multi-role-logistics-ship-a4-210x297mm.pdf

Caves, Ben, Pauline Paille & James Black. 2020. Strategic Airlift in Africa. Understanding Challenges and Opportunities for the Movement Coordination Centre Europe.

Cox, Kate, Anna Knack, Martin Robson, Neil Adger, Pauline Paille, Jon Freeman, James Black & Ruth Harris. 2020. *A Changing Climate: Exploring the Implications of Climate Change for UK Defence and*

Security. Santa Monica, Calif.: RAND Corporation. RR-A487-1. As of 21 June 2021: https://www.rand.org/pubs/research_reports/RRA487-1.html

DFDS. 2020. 'New Contract with Danish Defence.' As of 21 June 2021: https://www.dfds.com/en/about/media/news/new-contract-with-armed-forces

DHL. 2021a. 'Artificial Intelligence.' As of 21 June 2021: https://www.dhl.com/global-en/home/insights-and-innovation/insights/artificial-intelligence.html

______. 2021b. 'The Predictive Enterprise.' As of 21 June 2021: https://www.dhl.com/gb-en/home/our-divisions/supply-chain/thought-leadership/videos/unlocking-potential-predictive-analytics.html

The Drive. 2020. 'The Military's Puzzling Plan To Have SpaceX Deliver A C-17's Worth Of Cargo Anywhere In An Hour.' As of 21 June 2021: https://www.thedrive.com/the-war-zone/37020/the-militarys-puzzling-plan-to-have-spacex-deliver-a-c-17s-worth-of-cargo-anywhere-in-an-hour

Dryad Global. 2020. 'The Strategic Case for the UK's Multi-Role Vessel in Humanitarian Application.' As of 21 June 2021: https://channel16.dryadglobal.com/the-strategic-case-for-the-uks-multi-role-vessel-in-humanitarian-application

Dstl. 2021. *RAF Future Air and Space Study (FASS) and Dstl 2035 Cross Capability Study combined sprint on roles of Air and Space Power*. Workshop Report, 2021.

EATC (n.d.). ATARES. As 21 June 2021: https://eatc-mil.com/en/what-we-do/atares

Google Cloud (n.d.). Supply Chain Logistics. As of 21 June 2021: https://cloud.google.com/solutions/supply-chain-logistics

Gordon, John, Igor Mikolic-Torreira, D. Sean Barnett, Katharina Ley Best, Scott Boston, Dan Madden, Danielle C. Tarraf & Jordan Willcox. 2019. *Army Fires Capabilities for 2025 and Beyond*. Santa Monica, Calif.: RAND Corporation. RR-2124-A. As of 21 June 2021: https://www.rand.org/pubs/research_reports/RR2124.html

Jenkins, Dan, Lucia Retter, James Black, Louise Taggart, Lucia Retter, Alex Hall, S. Patel & J. Downes. *Industrial Implications of the UK Future Combat Air System (FCAS)*. Santa Monica: RAND Corporation, 2015 (not publicly available).

Kim, Y. et al. 2020. *Improving Acquisition to Support the Space Enterprise Vision*. RAND Corporation. RR-2626-AF. As of 21 June 2021: https://www.rand.org/pubs/research_reports/RR2626.html

Lockheed Martin. 2021. 'Autonomous Mobility Applique System (AMAS).' As of 21 June 2021: https://www.lockheedmartin.com/en-us/products/autonomous-mobility-applique-system-amas.html

Lorrel, Mark & Julia Lowell. 1995. *Pros and Cons of International Weapons Procurement Collaboration*. Santa Monica, CA: RAND Corporation (1995).

Mark3D. 2018. '3D Printing in the Military.' As of 21 June 2021: https://www.mark3d.com/en/3d-printing-in-the-military/

McKinsey Global Institute. 2018. 'Distraction or Disruption? Autonomous Trucks Gain Ground in US Logistics.' As of 21 June 2021: https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/distraction-or-disruption-autonomous-trucks-gain-ground-in-us-logistics

______. 2019. 'Automation in Logistics: Big Opportunity, Bigger Uncertainty.' As of 21 June 2021: https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/automation-in-logistics-big-opportunity-bigger-uncertainty

______. 2020. 'Coronavirus: Industrial IoT in Challenging Times.' As of 21 June 2021: https://www.mckinsey.com/industries/advanced-electronics/our-insights/coronavirus-industrial-iot-in-challenging-times

______. 2021. 'Digital: the Next Horizon for Global Aerospace and Defense.' As of 21 June 2021: https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/digital-the-next-horizon-for-global-aerospace-and-defense

MOD. 2017. *Joint Doctrine Note 1/17.* As of 21 June 2021: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/668722/doctrine_uk_joint_theatre_entry_jdn_1_17.pdf

______. 2018. 'Global Strategic Trends.' As of 21 June 2021: https://www.gov.uk/government/publications/global-strategic-trends

______. 2020a. 'Multi-Domain Integration (JCN 1/20).' As of 21 June 2021: https://www.gov.uk/government/publications/multi-domain-integration-jcn-120

______. 2020b. 'The Integrated Operating Concept 2025.' As of 21 June 2021: https://www.gov.uk/government/publications/the-integrated-operating-concept-2025

______. 2020c. 'How Defence Works.' As of 21 June 2021: https://www.gov.uk/government/publications/how-defence-works-the-defence-operating-model

______. 2020d. 'MOD Appraisal Report.' As of 21 June 2021: https://www.gov.uk/government/publications/ministry-of-defence-records-appraisal-report-2020/mod-appraisal-report-2020-accessible-version

______. 2021a. 'Defence in a Competitive Age.' As of 21 June 2021: https://www.gov.uk/government/publications/defence-in-a-competitive-age

______. 2021b. 'Ministry of Defence Climate Change and Sustainability Strategic Approach.' As of 21 June 2021: https://www.gov.uk/government/publications/ministry-of-defence-climate-change-and-sustainability-strategic-approach

______. 2021c. 'Defence and Security Industrial Strategy.' As of 21 June 2021: https://www.gov.uk/government/publications/defence-and-security-industrial-strategy

Movement Coordination Centre Europe (MCCE). MCCE COVID-19 Response. As of 21 June 2021: https://www.mcce-mil.org/

Naval Technology. 2021. 'Littoral Strike Ship: Prevail Partners Refines Multi-Role Vessel.' As of 21 June 2021:

https://www.naval-technology.com/features/littoral-strike-ship-prevail-partners-refines-multi-role-vessel/

NDTAHQ. 2020. 'Spacelift: USTRANSCOM, Space Force, and the Irresistible Rise of True Rapid Mobility.' As of 21 June 2021: https://www.ndtahq.com/spacelift-ustranscom-space-force-and-the-irresistible-rise-of-true-rapid-mobility/

NSPA. 2020. 'Multinational MRTT Fleet (MMF): Third Aircraft Arrives at Eindhoven Main Operating Base.' As of 21 June 2021: https://www.nspa.nato.int/news/2020/multinational-mrtt-fleet-mmf-third-aircraft-arrives-at-eindhoven

Penny, Maryse, Dan Jenkins, Celine Miani, Benoit Guerin & Saba Hinrichs. 2012. *Minimising the Risk Within Public-Private Partnerships (PPPs)*. RAND-initiated research (not publicly available).

Plutora. 2021. *DevSecOps: A Complete Guide to What, Why, and How*. As of 21 June 2021: https://www.plutora.com/blog/devsecops-guide

Popular Mechanics. 2020. 'The Marines 3D-Printed a Rocket Launcher Shelter in 36 Hours.' As of 21 June 2021: https://www.popularmechanics.com/military/a33500541/marines-3d-print-rocket-launch-shelter/

PESCO. n.d. 'Military Mobility (MM).' As of 21 June 2021: https://pesco.europa.eu/project/military-mobility/

Pirolo, Bradley M. 2020. 'Information Warfare and Joint All-Domain Operations: A Primer for Integrating and Prioritizing Data Requirements'. *Air & Space Power Journal.* Winter. As of 21 June 2021: https://www.airuniversity.af.edu/Portals/10/ASPJ/journals/Volume-34_Issue-4/V-Pirolo.pdf?source=GovD

Reaction Engines. 2020. 'SABRE: The Engine that Changes Everything.' As of 21 June: https://www.reactionengines.co.uk/beyond-possible/sabre

Retter, Lucia, Erik Silfversten & Dan Jenkins. 2017. *Response Strategies to the Cost Escalation of Defence Equipment*. RAND Europe. As of 21 June 2021: https://www.rand.org/pubs/external_publications/EP67014.html

Retter, Lucia, Sarah Grand-Clement, Alex Hall, James Black, Jerry Uren & Richard Farry. 2019. Fully Autonomous Weapon Systems (FAWS)- Capability Gap Evaluation. ASC Task 0176.

Retter, Lucia, Anna Knack, Zudik Hernandez, Ruth Harris, Ben Caves, Martin Robson & Neil Adger. 2021. *Crisis Response in a Changing Climate: Implications of Climate Change for UK Defence Logistics in HADR and MACA Operations.* Santa Monica, CA: RAND. As of 21 June 2021: https://www.rand.org/pubs/research_reports/RRA1024-1.html

SAE International. 2019. 'Future of Autonomous High-Mobility Military Systems.' As of 21 June 2021: https://www.sae.org/publications/technical-papers/content/12-03-03-0016/

Shipping Today and Yesterday. 2015. 'ARK Germania & ARK Dania.' As of 21 June 2021: https://www.shippingtandy.com/features/ark-germania-ark-dania/

Shlapak, David A. & Michael Johnson. 2016. *Reinforcing Deterrence on NATO's Eastern Flank: Wargaming the Defense of the Baltics*. Santa Monica, Calif.: RAND Corporation. RR-1253-A. As of 21 June 2021: https://doi.org/10.7249/RR1253

Space News. 2020. 'U.S. Transportation Command to Study Use of SpaceX Rockets to Move Cargo Around the World.' As of 21 June 2021: https://spacenews.com/u-s-transportation-command-to-study-use-of-spacex-rockets-to-move-cargo-around-the-world/

______. 2021. 'SpaceX Adds to Latest Funding Round.' As of 21 June 2021: https://spacenews.com/spacex-adds-to-latest-funding-round/

War on the Rocks. 2021. 'A Starcruiser for Space Force: Thinking Through the Imminent Transformation of Spacepower.' As of 21 June 2021: https://warontherocks.com/2021/05/a-starcruiser-for-space-force-thinking-through-the-imminent-transformation-of-spacepower/

Ween, Anthony, Thitima Pitinanondha, Ivan L. Garanovich & Nitin Thakur. 2013. *Analysis of whole-of-force design planning*. As of 21 June 2021: http://ismor.cds.cranfield.ac.uk/30th-symposium-2013/analysis-of-whole-of-force-design-and-planning/@@download/paper/30ismor_ween_paper.pdf

UK Defence Journal. 2021. 'Ellida – The Future Multi Role Support Ship?'. As of 21 June 2021: https://ukdefencejournal.org.uk/ellida-the-future-multi-role-support-ship/

UK Government. 2015. 'National Security Strategy and Strategic Defence and Security Review 2015.' As of 21 June 2021: https://www.gov.uk/government/publications/national-security-strategy-and-strategic-defence-and-security-review-2015

______. 2018. 'Global Britain: Delivering on our International Ambition.' As of 21 June 2021: https://www.gov.uk/government/collections/global-britain-delivering-on-our-international-ambition

______. 2019. 'Coalition Autonomous Systems – the Future of Military Logistics.' As of 21 June 2021: https://www.gov.uk/government/news/coalition-autonomous-systems-the-future-of-military-logistics

______. 2021. 'The Integrated Review 2021.' As of 21 June 2021: https://www.gov.uk/government/collections/the-integrated-review-2021

UPS. 2016. *How 3D Printing Can Help Optimize Distributor Operations*. As of 21 June 2021: https://www.ups.com/assets/resources/media/knowledge-center/How_3D_Printing_Can_Help_Optimize_Distributor_Operations.pdf

US Army. 2017. *Robotic and Autonomous Systems Strategy*. As of 21 June 2021: https://mronline.org/wp-content/uploads/2018/02/RAS_Strategy.pdf

Annex A. Interviewees

This annex contains the list of interviewees consulted during the course of this study.

Table A.1 List of interviewees

Interviewee	Role	Organisation
Anonymous	Anonymous	Cyber Partnership Force Development
Alan Dukes	Voyager DE&S Team Leader	DE&S
Gp Capt. Stuart Gregory	Director MCCE	MCCE
Anonymous	Anonymous	MOD
Anonymous	Anonymous	RAF
Anonymous	UK StratCom DefSp PolFD StCpRI 1	MOD
Wg Cdr Mark Pickford	FMC Capability Strategy SO1 Force Development 4	FMC
Anonymous	Anonymous	Voyager DT
Anonymous	Anonymous	RAF
Wg Cdr William Whitechurch	Air Staff – Strategy 1	RAF
Anonymous	FD/SO1 Concepts and Experimentation	MOD
Anonymous	Anonymous	Directorate for Logistics, AFRICOM
Anonymous	Anonymous	Directorate for Logistics, AFRICOM
Anonymous	Anonymous	DSTL
Anonymous	Anonymous	RN
Anonymous	Anonymous	RN
Anonymous	SO1 Future Force	RN
Anonymous	Anonymous	UK Army