Technology Scanning for Combat Service Support (CSS) Modernization: An Investigation Study for the Canadian Army

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1. INTRODUCTION

This document provides an overview of the existing Canadian defence policy, concepts about the Army of Tomorrow, Future Army, concepts presented by allies, in order to evaluate of how emerging technology can be useful for Combat Service Support (CSS) for the Future Army. This report is based on official documents, where possible, with the remainder of the research based on open source material.

1.1 Purpose

The purpose of this research is to discuss and assess potential novel technologies which could improve CSS to the Canadian Army, specifically to enable modernization and provide an improved tactical sustainment capacity.

1.2 Structure

The document is structured as follows:

- **Section 1:** Introduction
- **Section 2:** summary of the existing doctrinal concepts for CSS;
- **Section 3:** summary of the current defence policy, and of the concepts about the Army of Tomorrow, the Future Army, and concepts from allies;
- **Section 4**: this section provides gaps in current technologies, based on official documents. Identifying each of these gaps in more detail is outside the scope of this work. The gaps presented in official documents are presented as official observations;
- **Section 5**: this section provides an overview of emerging technologies, and a summary of the strengths and limits of each technology, and specific observations about how they may be integrated into the future Army concepts (where the linkages are plausible);
- **Section 6**: Emerging Technologies – this section will summarise the challenges to implementing future technologies;
- **Section 7**: Discussion – this section will provide a discussion on the relationships between the assumptions about the Future Army, the role of technology, and those technologies that can provide maximum value for CSS; and
- **Section 8**: Conclusions and Recommendations – this section will provide conclusions on the viability of emerging technologies for CSS concepts, and recommendations for future research and work.

2. ARMY LOGISTICS: DOCTRINE AND CONCEPTS FOR CSS

This section will provide a brief overview of the concepts included in army logistics doctrinal documents. The intent is not to generate a detailed analysis of logistics doctrine, but to communicate the concepts of the supply chain (*From Warehouse to Field Employment)* that currently guide logistics employment. The purpose of this overview is to articulate each step in the supply chain in order to focus future recommendations.

2.1 Definitions of Logistics and Combat Service Support

The terms 'Logistics" and 'Combat Service Support' (CSS) are sometimes used interchangeably to mean all support operations. While both are critical to the sustainment function, CSS has a much narrower meaning than Logistics. According to *Sustain: The Operational Function (Army Doctrine)* [1]:

- **Combat Service Support:** the support provided to combat forces, primarily the fields of administration and logistics; and

- **Logistics:** the science of planning and carrying out the movement and maintenance of forces. In its most comprehensive sense, it encompasses the aspects of military operations which deal with design and development, acquisition, storage and movement, distribution, maintenance, evacuation and disposal of material, transportation of personnel, acquisition, construction, maintenance, operations and disposition of facilities, acquisition and furnishing of services; and medical and health services support.

The focus of this work is on CSS, though the report will also discuss the concepts outlined in 'logistics' that clearly support the use of combat forces. Things like computer systems that track the movement of goods; power usage in forward facilities; transporting supply to forward combat forces; scheduling and performance of maintenance.

Medical services will not be discussed in detail, beyond medical service provided directly to combat forces such as casualty evacuation (CASEVAC) and medical evacuation (MEDEVAC). Anything that is not directly related to supporting combat forces will not be included (preventative medicine, determining medical fitness of personnel etc.).

2.2 NATO Doctrine

Given Canada's emphasis on deploying on multinational missions with allies, North Atlantic Treaty Alliance (NATO) concepts of logistics will be discussed briefly. In *Allied Joint Logistic Doctrine* [2] the focus is on strategic and operational level support to multinational missions. This doctrine emphasizes that member countries will likely be supported by a mix of integrated multinational logistical support and of purely national support. Purely national support will typically be delivered for the forward-deployed units (tactical), with multinational support provided at large installations (operational) [2]. The emphasis of this document is on strategic and operational integration of logistics functions, clearly outlining that tactical support is the responsibility of the national support element. NATO does not provide doctrine on “last-mile” delivery because support to forward units is the responsibility of the member country. The *NATO Land Forces Logistic Doctrine* [3] shows the concept of operations below in Figure 1, clearly showing that national CSS Battalions are responsible for supporting land operations, not the joint theatre level support organizations.

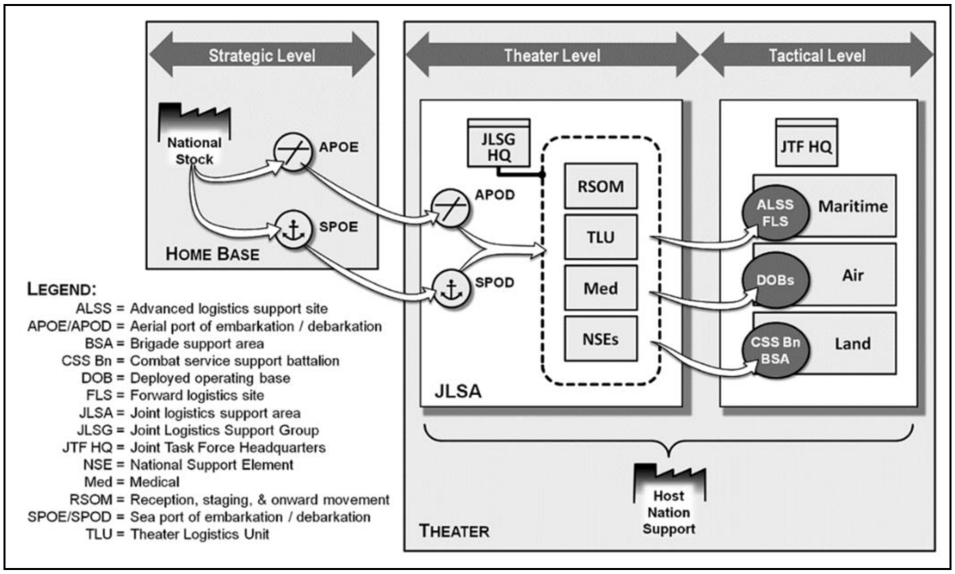


Figure 1: Outline of NATO Logistics Concept [3]

2.3 Canadian Joint Doctrine

Canada has its own joint doctrine documents for support and logistics and provides more detail on tactical level support, in addition to strategic and operational support. *Canadian Forces Joint Publication CFJP 4-0: Support, 1st Edition* [4] introduces the concept of levels of sustainment and lines of support. The three *levels* of sustainment are: tactical, concerned with services to combat forces; operational, concerned with sustaining all the combat and non-combat activities in the theatre of operations, and; strategic, concerned with readiness, force generation, projection and sustainment at a national level [4]. The four *lines* of support for the Canadian Armed Forces (CAF) are: first line support is that allocated specifically to a ship, unit, or squadron; second line support is that is organic or allocated to a formation; third line support is support to a theatre of operations and installation along the strategic lines of communications, and; fourth line support includes national depots in Canada, and contractor and industrial support [4].The intersection between those levels of sustainment and support are shown in Figure 2 below. Of note, first, second and third line sustainment operations are requirements to sustain tactical operations in a theatre.

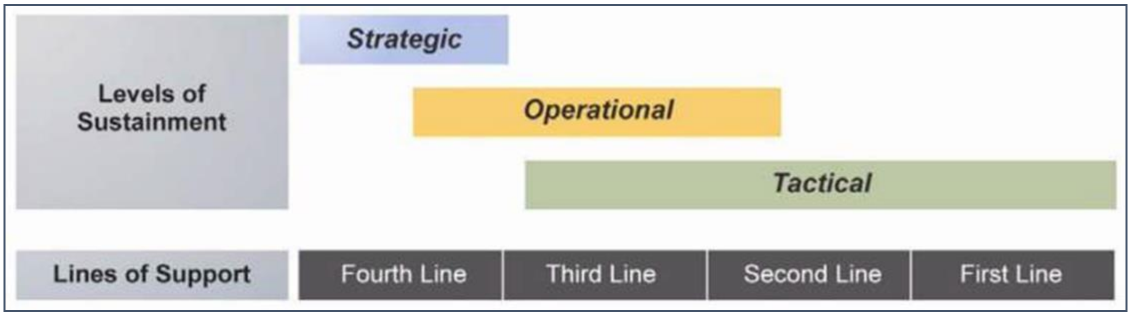


Figure 2: Relationship between Level of Sustainment and Lines of Support [4]

Canadian Forces Joint Publication CFJP 4-1: Movement. 2nd Edition [5] outlines the overall concept for sustaining operations through logistics movements, from Canada to forward areas, and the movements concepts that support the ongoing sustainment of operations in-theatre. The distinction between Theatre Support Movement, and National Movement Support is articulated in Figure 3 below, showing how organizations in Canada directly support the operational and theatre level via strategic lines of communications, and showing the reach-back capability. This applies to all elements, including the army. The purpose of illustrating this concept is to underline the distinction between the strategic and operational level of supply, and the strategic lines of communication that separate them. This will be important for discussion later in this document about suitable technologies and capability for CSS of the future; some technologies will be better suited to the strategic context, and others more relevant at the tactical and operational level.

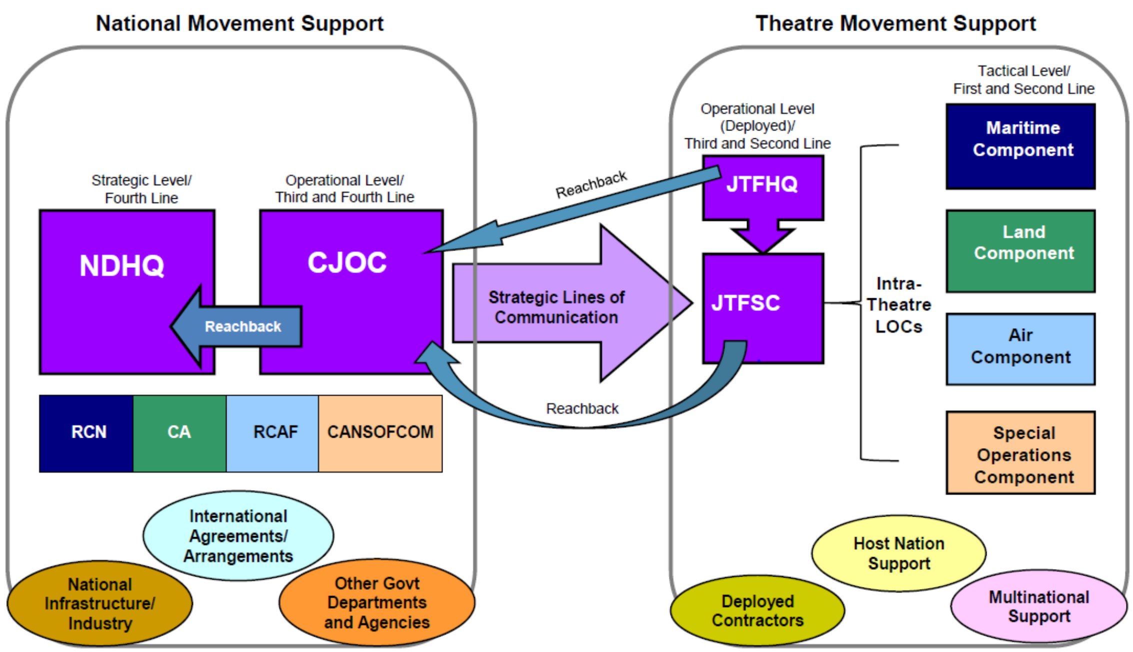


Figure 3: The CAF Movement System [5]

2.4 Canadian Army Doctrine

The lines of service described in *Combat Service Support (CSS) Units in Operations* [6] aligns to those in the Joint Publications above, showing fourth, third, second and first line support. Also contained in *CSS Units in Operations* [6] and aligning to *Movements* [5], is the definition of third line service existing in theatre, and the inclusion of support from coalition partners, the host nation, and contractors in addition to CAF units in theatre. The concept diagram is shown below in Figure 4. Note, the standard unit for Canadian doctrine is the Brigade Group (BDE GP).

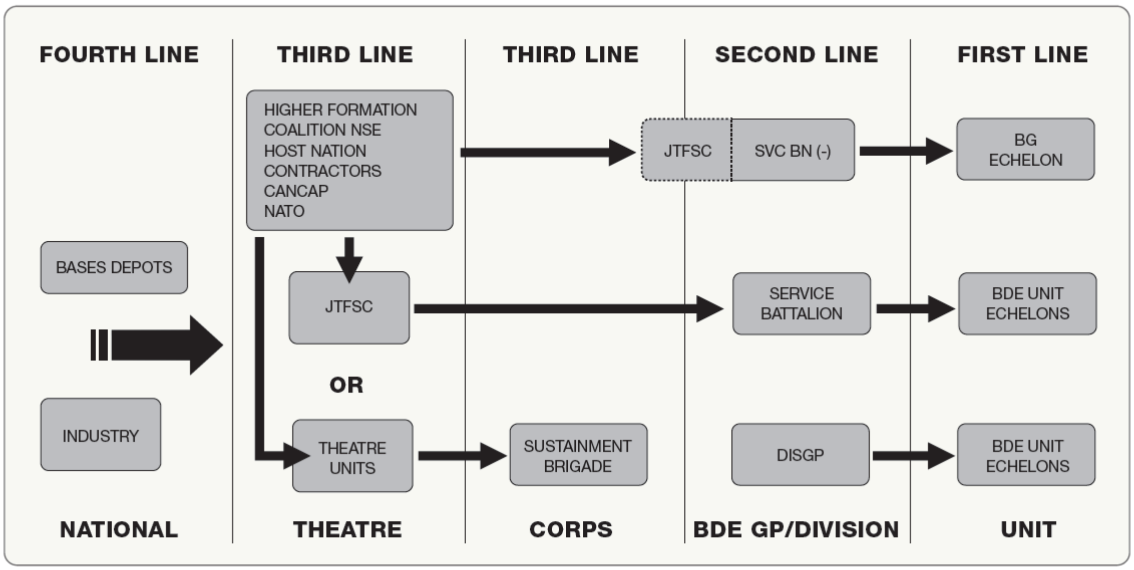


Figure 4: Lines of Support and Organizations Providing Sustainment [6]

Logistics (LOG) and Combat Service Support (CSS) Tactics, Techniques and Procedures (TTPs) [7] provides an overview for supporting land elements deployed in a theatre of operations. The focus is on operations in a single theatre and details the specifics of operational and tactical execution of CSS. In this document the focus on extending support from the Brigade Support Area (BSA) to the Forward Support Area (FSA), and then further forward to units in the field is outlined. Support to units in the field can be delivered, via road or air, or can be collected by the unit. The concepts in this document apply to managing supply, transport, maintenance, administration and medical services, with specific guidance for dispersed operations and supporting operations in built up areas. The remaining analysis will provide analysis on future technology. The concepts from this document are represented below in Figure 5 based on the material in *LOG and CSS TTPs* [7]

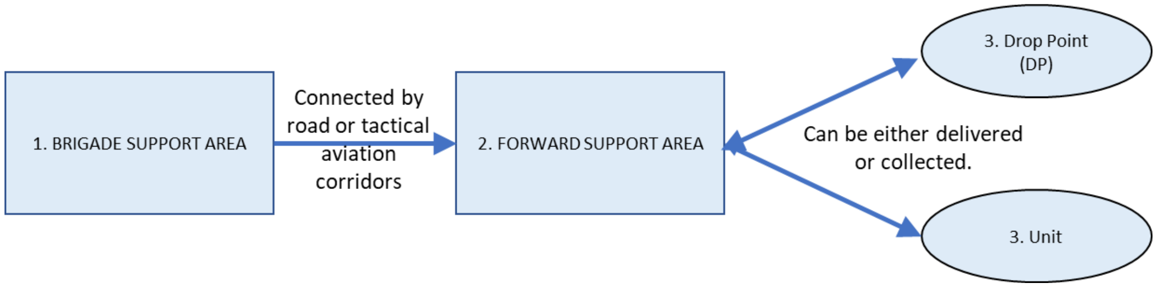


Figure 5: Tactical support chain from *LOG and CSS TTPs [based on concepts in 7]*

2.5 Observations

Consistent across all doctrinal documents mentioned above is the idea of defining logistics and CSS based on lines, from a domestic and national supply chain start point at the 4th line, an operational or theatre at the 3rd line, forward support area 2nd line, and the 1st line that is the supporting unit conduction operations. This is an important concept, because it anchors a common concept for Canada and its allies for different levels of support. This is summarized in Table 1 below.

Table 1: CSS Concepts - Summary of NATO, Joint and Canadian Doctrine

	4th Line	3rd Line	2nd Line	1st Line
NATO Allied Joint Logistic Doctrine – AJP-4(A)	Strategic Headquarters	Regional Commands / National Support Element	National Support Element / Member Countries	Member countries
NATO Army Logistics Doctrine (ALP 4.2 EDB)	Strategic Level	Theatre	Theatre / Tactical	Tactical
JP 4-0: Support	Strategic / Operational	Operational / Tactical	Tactical	Tactical
JP 4-1: Movements	Strategic & Operational Level (Domestic) / National Movements	• Operational (Domestic) Level / National Movements • Operational (Deployed) Level / Theatre Movements	Operational (Deployed) & Tactical level / Theatre Movements	Tactical Level / Theatre Movements
Logistics (LOG) and Combat Service Support	Not the focus of this document.	Joint Task Force Support Component (JTFSC)	Brigade Support Area / Forward Operating Area	Units in the Field

	4th Line	3rd Line	2nd Line	1st Line
(CSS) Tactics, Techniques and Procedures (TTPs)				
Combat Service Support (CSS) Units in Operations	National: base depots, industrial base	Higher formation, coalition national support element, host nation, contractors, NATO, Joint headquarters, theatre level units, and sustainment brigades	Service battalions	Unit echelons (BG, Bde).

To connect these lines of support, different equipment is typically used. 4th line includes Canada and the defence industrial base. Transporting materiel from 4th line to 3rd line involves large equipment, like ships, trains and strategic lift aircraft. At the 3rd line Joint Task Force Support Component (JTFSC) materiel can be transported to 2nd line Brigade Support Area / Forward Operating Area using aircraft (fixed wing or rotary wing), air drop, or land vehicles. 2nd line facilities often have only small airfield or helicopter landing zones, so fixed wing aircraft may not always be capable of moving materiel to 2nd line facilities. To move material from 2nd to 1st line – to units deployed on operations – land vehicles, rotary wing aircraft or air drops can be used, as there is no expectation of prepared airfields for fixed wing aircraft to land. The concepts included below in Figure 6 provide a summary of the means used to sustain Logistics and CSS at each level. This concept is important, but only shows the means of delivery (i.e.: pushing supplies forward).

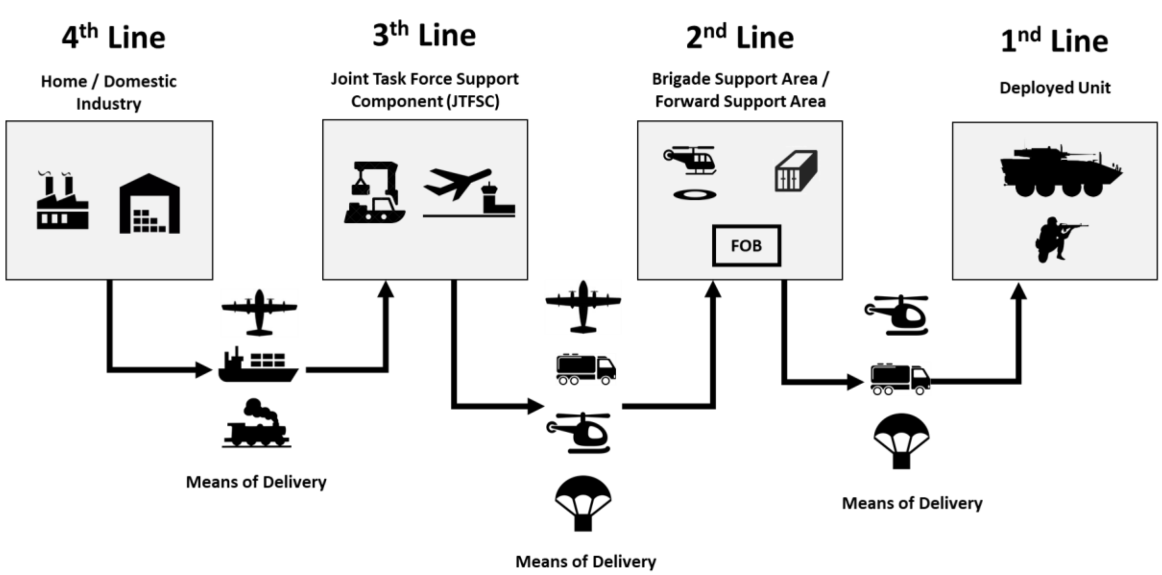


Figure 6: Logistics and CSS – Means of Delivery

There are also requirements for medical evacuation, and maintenance and repair of equipment. While some limited daily maintenance is performed by the deployed unit, typically maintenance and repair refer to the need to pull equipment out of daily service to perform diagnostics, replace or repair parts, and other tasks typically beyond the scope of the daily maintenance done by those using the equipment. In the case of both medical evacuation and repair and maintenance of equipment, both personnel and equipment are eventually transported back to deployed units if they can be cleared for service. For this reason, in Figure 7, medical and maintenance arrows point in both directions, compared to supply which points only toward the deployed unit where it is consumed.

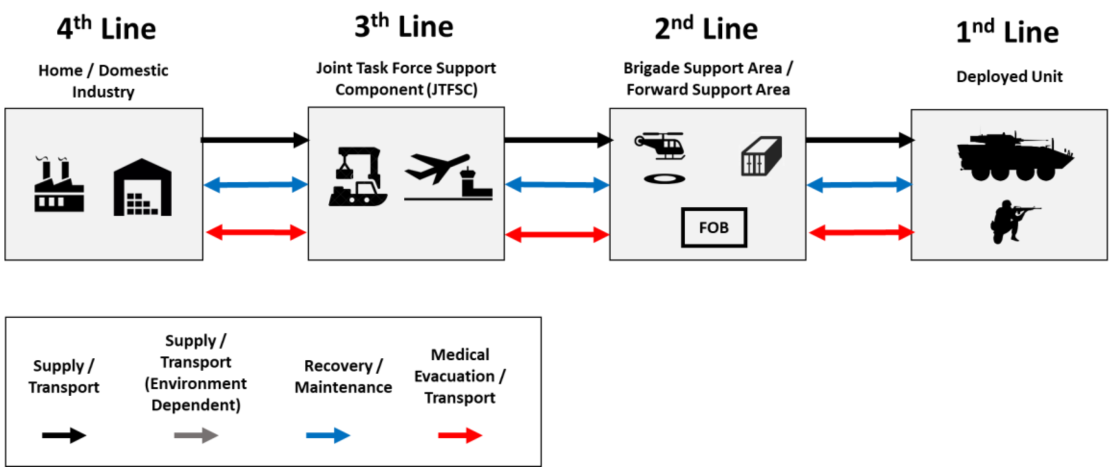


Figure 7: Direction of Flow - CSS Delivery, Recovery and Medical Evacuation

3. CURRENT DEFENCE POLICY AND FUTURE CONCEPTS FOR ARMY LOGISTICS

This section provides a brief overview of *Strong, Secure, Engaged* [8] (SSE) defence policy to articulate the overall mission and purpose of the CAF. It also lists the main points of *Designing Canada's Army for Tomorrow* [9], *Close Engagement* [10] and all three volumes of *Canada's Future Army* [11] [12] [13] to provide a view of the expected future operating environment and the role for the CAF.

The documents referred to in this section reflect the "Three Army Model" [11]. This model identifies three different armies, measured in time. The army of today is represented as the army that currently exists and will exist 5 years into the future; the Army of Tomorrow (AoT) is the army of 5 to 15 years into the future, and the Future Army is the army 15 plus years into the future. The review of SSE is intended to frame the understanding of the army of today, *Close Engagement* [10] is intended to provide an overview of the AoT, and *Canada's Future Army* [11] [12] [13] provide a view of the Future Army.

This section will focus on the future security environment and the implications for logistics. The technology observations from these documents will be discussed in more detail in Section 4 and Section 5.

3.1 Strong, Secure, Engaged: Canada's Defence Policy

Strong, Secure, Engaged: Canada's Defence Policy [8] was introduced as government policy in 2017 by the Minister of National Defence. It outlines the personnel, procurement and mission priorities for the CAF, and articulates expectations of the security environment and the types of missions the CAF will be called upon to perform. It is this document that will guide all strategic level decision making until it is superseded by a future policy.

In terms of army specific investments that will modernize the CSS capability, SSE includes modernized logistics vehicles, improved communications and sustainment equipment. It also outlines a requirement to improve the army's ability to operate in remote environments by investing in modernized communications, shelters, power generation, advanced water purification systems and other equipment needed for austere environments [8].

SSE identifies the evolving balance of power in international relations and global political economy. The impacts of globalization, competition between states, climate change, the rise of non-state actors, and the shifting dynamics of global governance institutions all have the ability to shift the balance of power in international relations [8], and therefore influence ongoing armed conflict and the potential for future conflict. We can observe the manifestations of this evolving balance of power in the actions of Syria in their use of chemical weapons and the use of indiscriminate force against civilians, and North Korea's ongoing testing of nuclear weapons and the missile systems to deliver them.

The nature of contemporary conflict itself is changing from the previously understood and accepted models of conflict between states. Where the CAF once prepared for operations against the known and well-defined forces of other state, we now see growing ambiguity and variation in the types of forces the CAF is facing, the rise of non-state actors, and increased complexity to drivers to conflict [8]. The line between states and non-state groups are blurring with the rise of so-called hybrid warfare. The blurring of lines between intra and inter-state warfare makes it more difficult to distinguish who is acting alone and who is acting with support from a state. Simultaneously the threat of global terrorism and weapons proliferation is real and presents challenges to Canada and its allies. The strategic implications for Canada are the reduced significance of national borders, at home and abroad; increasing complexity in all operational considerations; increasingly interrelated components of security challenges; and, the need for Canada to maintain its international commitments to its traditional allies, to NATO, and to continue monitoring higher risk regions and ungoverned spaces [8].

SSE also acknowledges that technology is evolving in a way that enhances global connectivity. Cyber and space technology provides the means to do banking, order material online, communicate in near-real time around the world, enhance navigation, and the use of telecommunications. This has the potential to accelerate the exchange of information for business, governments, and for military operations. However, with enhanced connectivity comes increased potential of threats from intelligence and security services of hostile powers and by skilled individuals working for non-state groups [8] that seek to exploit connectivity for nefarious purposes. The most sophisticated cyber threats come from the military services of foreign states, and typically target government, militaries and industries that rely heavily on technology, seeking to exploit vulnerabilities for the purposes of disrupting operations. The use of cyberspace is crucial to all day-to-day operations, such that Canada must work with its allies to ensure the continued use of cyberspace.

Without the ability to network the systems and platforms of the Canadian Army the speed and agility of the force will fall behind relative to those competitors that can more effectively connect their deployed units to command and control nodes. This also applies to the CSS function, where the ability to anticipate future requirements is mandatory for effective demand-driven logistics. Without the connectivity envisioned in SSE, modernization of CSS concepts will be limited.

Other technologies include new information technologies like data analytics, deep learning, autonomous systems, and emerging transformative technologies like quantum computing and synthetic biology [8]. Canada must position itself to take maximum advantage of emerging technologies and must do so in a way that rigorously respects all applicable domestic and international laws, is subjected to proven and effective checks and balances and with maximum oversight and accountability for all applications [8]. The top priorities for taking advantage of new technologies includes cyber, space and remotely piloted systems while respecting establishing international norms with our partners and allies [8].

3.2 Designing Canada’s Army for Tomorrow (AoT - 2011)

The growing complexity and ambiguity in conflict and operating environment was recognized by National Defence in 2011, when *Designing Canada’s Army for Tomorrow* [9] was published. This document identifies an uncertain future, marked by volatility, a wide range of possible threats (including so-called hybrid warfare), and a continued focus on small wars, where direct conflict with rising powers is still possible. The operating environment will likely operate in both urban and rural settings – often simultaneously as part of a single operation – with a diversity of terrain, with even greater challenges posed by operations in the littoral or arctic.

There is also a specific focus on the “adaptive dispersed operating concept” (ADO), a concept initially introduced in 2007 in *Land Operations 2021 – Adaptive Dispersed Operations: The Force Employment Concept for Canada’s Army of Tomorrow* [14]. This concept emphasizes the complexity of the operating environment, a non-contiguous operational framework, geographically distributed operations, and the acceleration and convergence of communications, robotics, nano, and biologics technologies. The fundamental requirements for operating successfully in this environment are [14]:

- Developing situations prior to contact, or rapidly regaining the initiative upon contact;
- Manoeuvring to positions of advantage;
- Influencing the adversary beyond his ability to influence the situation with fires and other capabilities;
- Destroying the enemy’s cohesion, will and support with lethal and non-lethal precision and area fires;
- Conducting close combat and close engagement at the time and place of our own choosing, and;
- Transitioning between operations without loss of focus or momentum.

Making matters more complex, the army of the future expects to be comprised of “modular and interchangeable structures that are based on the smallest effective building blocks of capability in order to provide a force generation and force employment flexibility” [9]. This also means simplifying the core elements of force employment to the greatest extent possible, with the:

> “fewest number of fleets with the greatest practicable commonality between them. It needs the fewest types of platforms that support the required number of functional configurations. The basic equipment platforms should all share the maximum number of common attributes (e.g.: the layout of driver stations, interchangeable parts) have a high degree of modularity (e.g. fitted-for-but-not-with) and be readily modifiable (e.g.: open architecture) to quickly mitigate new weakness while increasing flexibility and platform lifespan” [9].

These fundamentals and expectations present significant challenges for the CSS function: distributed manoeuvre elements will rely on speed and agility to menace the adversary, and to maintain momentum while doing so. The CSS challenges for supply, recovery & maintenance, and medical will be significant given the likely demand for consumables, non-consumables, maintenance, recovery and casualty evacuation this pace of conflict will produce. This document does not envision a change in the core purpose of CSS as the enabler of combat and manoeuvre elements; however, the expected pace of operations, distributed nature of operations, and requirements for greater precision in the delivery of goods, specifically from the air, clearly shows that a dedicated effort is required to better understand the role technology can play in realizing the sustainment vision for the AoT, and therefore the army of the future.

3.3 Close Engagement (Draft 2017)

This document, currently still in draft review, will be the capstone operating concept for the AoT [10], meaning it will provide the view of the army's capabilities and operating concepts 5-15 years into the future. It is intended to provide a single vision to ensure coherence and consistency in army capability development into the future. In this vision of the future, the brigade group remains the basic formation concept, operating in a world that is complex, dynamic, volatile and highly uncertain, with threats emanating from increasingly capable states and non-state actors with increasingly sophisticated and lethal technologies [10]. The operating environment is not geographically specified because the model is threat-driven. The anticipated threat spans the range of state and non-state actors, acting independently or together to achieve their objectives in an increasingly digital operating environment. Non-state actors include potential insurgents and guerillas and can also include transnational criminal gangs working with states or non-state groups to generate income and/or launder money through the global financial system.

The rise of the internet and social media means groups with a political agenda can organize and get their message out much easier and more effectively than in years past. This applies to political and special interest groups, and also to potential adversaries, regardless of whether it is for the purposes of political activism, organizing violence, or both. Techniques and approaches of concern for the CAF and the army include spreading false news on traditional and social media, hacking of databases, cyber-attacks, the employment of 'troll armies', or other means to generate a false narrative to undermine public support for CAF and for the Government of Canada more broadly [10].

To address these challenges, the AoT is envisioned to have [10]:

- core combat skills, as the bedrock capability to enable the army to carry out a wide range of tasks in hostile environments;
- adaptability and versatility of the organization, including personnel, equipment, processes to adjust to changing conditions faster than potential adversaries;
- scalability and self-sufficiency across the full spectrum of potential operations;
- resiliency to deal with shock and uncertainty;
- the ability to disperse as a matter of force protection, to cover a wide operating environment, respond to humanitarian crises, and providing stability during domestic operations; and
- the ability to concentrate at a decisive point and time to provide stabilization, confront aggressors, and achieve decisive victory in close combat.

The AoT is expected to emphasize agility of the force and the ability to conduct high-tempo operations, connectivity between combat units and with reach-back sustainment organizations, modularity of task forces to meet mission requirements, adaptive dispersion to achieve a broad range of effects, and integration of the force in the joint, inter-agency, multi-national and public (JIMP) space [10].

In the *Close Engagement* [10] vision of the future, the brigade group is still the expected formation size, with integral CSS units providing support for all brigade operations, and it is also the element that will coordinate sustainment from higher formations, such as multi-national divisions and support from the home front. Units within the brigade will each have the sub-units, which for CSS means supply, transport, maintenance, medical and administration, that provide support to the overall mission of the brigade. The customization of capabilities within the empowered combat arms team (ECAT) comprises many different capabilities (infantry, armour, transport platoon, engineers, electronic warfare (EW) units, civil-military-cooperation (CIMIC) units) that will drive unique challenges for CSS units and will require them to organize CSS sub-units to meet the sustainment requirements of the ECATs.

To sustain this force, *Close Engagement* [10] envisions a real-time common logistics operating picture and use of predictive planning tools to allow for coordination and prioritization of CSS resources and tasks. An improved land equipment management system (LEMS) will enable predictive repair and maintenance scheduling, to allow spare parts to be ordered before the original parts reach the end of their useable life, and for preventative maintenance to be scheduled to extend the useful life of all equipment [10] Autonomous delivery systems are envisioned to reduce the exposure to casualties on supply missions, and mobile repair and recovery teams will be network-enabled to increase efficiency. Relying on LEMS will give commanders visibility on how many vehicles are ready at any given time, upcoming maintenance, and visibility on anticipated resupply and materials in transit. Total asset visibility will provide much needed clarity for commanders to integrate maintenance and supply schedules into existing operational plans. Land Equipment Engineering (LEE) capability will provide commanders with just-in-time engineering, allowing for the design and test of field customizations to equipment, with forensic level evaluations.

Beyond the integration of technology, providing CSS to the future force is expected to involve longer distances than the army of today. While adaptive, dispersed operations (ADO) already assume a geographically dispersed force, the AoT is expected to be easily transportable by airlift or sealift to the theatre of operations, and then capable of moving long distances, at speed. Once in theatre, the force is envisioned to be capable of operating in austere conditions, with soldiers living out of vehicles, using existing buildings, and buying material from local markets, where possible. The speed and agility anticipated of the future force will require the ability to provide CSS to a force that is widely dispersed, creating delivery challenges due to the distance (and therefore time) separation of deployed elements from CSS hubs. Air dropping or air delivery will be increasingly required to sustain a force with this anticipated level of agility and dispersion.

For deployment of this force the *shield* and *sustain* functions will be especially important from the perspective of CSS [10]. For *command,* CSS units will be responsive to the commander's intent and requirements; for *act,* a dispersed environment with units requiring support; for *sense,* CSS units will have access to the necessary briefings before planning their own operations is anticipated.

For *sustain* the CSS force of the future is envisioned to maintain centralized control at the formation level while also being dispersed along with the supported combat force.

This is consistent with the previous ADO concepts, and of sub-units operating independently, physically separated from other units. The dispersed force brings with it increased potential of units and sub-units fighting alone, with limited support. This creates two challenges for CSS: the need for increased survivability of the CSS force in order to maintain lines of communication with supported units, and also the need to provide enhanced casualty care and casualty evacuation capability for all personnel within the force. The increased distances from a JTFSC and Brigade Support Areas means longer distance to evacuate casualties, and increased time required to transport casualties to hospital facilities. The “golden hour” in which most casualties can be saved may be threatened with a more widely dispersed force, and further distances to travel for CSS elements supporting them.

For *shield* the impacts on CSS are two-fold: physical security of CSS vehicles and equipment, and electro-magnetic (EM) protection of CSS vehicles and equipment, especially with the anticipation of digital, networked systems as the backbone of predictive capabilities and the networking of the force. In the dispersed environment CSS sub-units will be expected to conduct missions in hazardous areas, often without other units providing supporting fires. Threats from enemy action (direct attack, improvised explosive devices (IEDs), etc.) are anticipated in any combat theatre, and this applies to CSS units and combat units. When CSS units come into contact, they will take the necessary immediate actions in response. If the CSS unit is required to turn back due to heavy resistance, or sustains significant casualties, the support that a forward unit is expecting will take longer to arrive, which could impact operational plans of combat units.

In terms of EM protection, this will be significant for all vehicles and systems that rely on data and connectivity. The necessary precautions should be taken to shield critical CSS and combat systems against EM vulnerabilities. Situational awareness systems rely on presenting accurate data, and on the consumers trusting the data they are being given. Situational awareness data includes the location of friendly units, asset visibility, communicating CSS requirements to CSS units, and CSS units communicating time of arrival for support.

Close Engagement [10] also embraces the joint environment concept, and clearly states where it will rely on the Royal Canadian Navy (RCN) and Royal Canadian Air Force (RCAF) to support its operations. For sustainment, the RCN is expected to contribute the army sustainment through sea-basing of medical and logistics elements in support of land operations. This will be most useful for the army in the context of littoral operations. The RCAF will be responsible for maintaining the strategic communications infrastructure (SATCOM including secure voice, radio rebroadcast capability), and providing the air elements to support army operations, including sustainment. The RCAF will also provide jamming-resistant navigation and timing equipment, and tactical aerial resupply support from fixed and rotary wing platforms, precision air delivery, and low altitude air drop, all in austere environments. Space will be a key element of support for CSS, as space-based systems are expected to enable communications and the visibility on the location of units and assets.

3.4 Canada's Future Army (2016)

The *Canada's Future Army* series of documents (*Volume 1* [11], *Volume 2* [12] and *Volume 3* [13]) provides a comprehensive view of what Canada and the rest of the world are expected to look like in 2040, and the kind of future operating environments and scenarios the Canadian Army should consider to anchor its capability development and future force generation. Each volume of *Canada's Future Army* is discussed below.

3.4.1 Volume 1: Methodology, Perspectives and Approaches

Volume 1 [11] provides the methodology, perspectives and approaches that were used to develop visions of the future. Four 'alternate worlds', or visions of the future, were developed using a matrix with two axes: availability of energy supplies, and the reactive or proactive approach used by global powers in managing global energy supplies.

Each alternate world was developed considering [11] the environment (in general terms – not region-specific terms), the international political system, international legal norms, the global economy, and domestic considerations. Accelerated globalization has the potential to drive the displacement of large groups of people, whether seeking new economic opportunities, moving away from actual or threatened environmental degradation, or fleeing violence perpetrated either by weak or corrupt states or by non-state actors. A large migration of people, as we have seen across Africa and as a result of war in Syria and Iraq, stresses the resources of the countries receiving them. This can have significant negative consequences when those countries receiving them lack the institutions and/or resources to handle the crisis.

Consistent across all these alternate worlds is the expectation [11] of the globalization of science and technology, enabling governments, civil society and private citizen's access to technologies connecting them to the rest of the world. Information, communications and computing technologies are expected to be ubiquitous, with continued expansion of social networks. In terms of new and emerging technologies, autonomous systems, additive manufacturing, human performance modification through nanotechnology and biotechnology, metamaterials, printed electronics, and synthetic biology are all expected to move beyond their current conceptual and experimental stage and into reality.

The four alternate worlds are [11]:

- **High-Octane "Green World":** a world in which energy supply exceeds demand (i.e. sustainable), and the world is taking a proactive approach to the environment. This is a world characterized by less aggregate inequality, slower population growth than previously forecasted (with corresponding reductions in aggregate demand for goods, services and energy), and growth in technology, specifically in the cyber and space domains. The threat of inter-state wars (systemic and regional) is low, with medium threats from organized crime, state and industrial espionage, humanitarian crises and radicalization. This represents a best-case view of the future;
- **Global Quagmire**: a world in which energy supply is increasingly scarce (i.e., not sustainable) and the world is taking a reactive approach to energy. In this future, energy supplies are in steady decline, and environmental ruin is accelerating.

Innovations are slowing down, markets are unstable, and the global population is rapidly aging. The international system is stressed and countries seek self-preservation by retaining power and influence above all else. The threat of interstate war is increasingly likely, specifically in certain regions; intra-state war is likely, and the threat of terrorism, organized crime, espionage, humanitarian crises and radicalization are all high. This represents a worst-case view of the future;

- **Materialism Gone Mad:** a world in which energy supply exceeds demand (i.e. sustainable) but in which the world continues to take a reactive stance on the environment. This is a world permeated by a functioning international system, continued economic prosperity, wealth concentrated in the hands of the powerful few, and an aging population and therefore a shrinking work-force. Population growth continues, migration continues, and the global competition for power continues with state and non-state actors all vying for advantage. The primary threats in this world stem from those left behind by globalization, including radicalization, humanitarian crises, terrorism, espionage to gain commercial advantage, with low risk for systemic inter-state war and medium risk of regional inter-state war; and
- **Recyclable Society:** a world in which energy is scarce (i.e. not sustainable) but one in which global actors are taking proactive approaches to the environment. A history of wastefulness has prompted global actors to take proactive approaches to reducing energy consumption and recycling commodities as best possible. Governments and industries are spending as little as possible, attitudes about commercialism and consumerism are falling, and mistrust of corporations rises. Global markets are unstable, living standards decline in some parts of the world, global population growth shrinks, and international politics fragments into multiple poles of power and influence. The threat of systemic interstate war remains low, though regional interstate wars are possible. The greatest threats come from radicalization, humanitarian crises, and terrorism and organized criminal activity, though these threats are less severe than those in the *Global Quagmire* scenario above.

These alternate worlds are important concepts, because they provide a structure that links the potential future consequences of current trends, depending on the trends toward energy supplies and the actions of government in response to those trends. Each alternate world above is traceable from the challenges of today, extrapolated into the future using a matrix. A common ranked threat profile allows the reader to identify the relative severity of threats depending on the alternate world of the future.

The impact for future operations and CSS rests on the mission types that are more or less likely in each alternate world of the future. For example, in all the scenarios except *Global Quagmire* the threat of intra-state armed conflict, humanitarian crises, terrorism and radicalization, organized crime, espionage is higher than the threat of interstate war. Of note, in *Global Quagmire,* the alternate world in which inter-state war is most likely, the other threats are just as likely or more likely. Based on these alternate worlds the lessons for CSS are clear: ADO concepts as defined in other documents [9] [10] such as non-contiguous operating environments, displacement of combat forces, and greater distances separating brigade headquarters from combat teams are still envisioned in the majority of potential future operations in all alternate worlds presented in *volume 1* [11]. *Canada's Future Army* does not discount the threat of inter-state war – either regional or systemic – but it is only a significant threat in one alternate world. This means that CSS concepts and technology development should be developed with a focus on ADO concepts as the baseline assumption, while still being compatible with the idea of more traditional, linear inter-state conflict.

3.4.2 Volume 2: Force Employment Implications

Volume 2 [12] provides an evaluation of the implications for the Future Army, based on the assessment of the future security environment provided in *Volume 1* [11]. *Volume 2* discusses what the future force employment will look like for the army predicated on global energy supplies and the reactions of world governments. Using wargaming, missions and tasks were assigned to each alternate world according the perceived likelihood of those missions and tasks in the future, and the impact. Table 2 below provides a summary of most likely missions envision is represented in *Volume 2* [12].

Table 2: Most Likely Missions and Tasks - Canada's Future Army (Volume 2)

Alternate World	Domestic Mission	Expeditionary Mission	Both
High Octane Green	• Sovereignty Operations	N/A	N/A
Global Quagmire	• Arctic Sovereignty Operations • Border Security • Vital Resource and Infrastructure Security • Support to Other Government Departments (OGD) • Humanitarian Relief Operations (HRO)	• Warfighting • Expeditionary Intelligence Gathering, Surveillance (HUMINT, etc.)	N/A
Materialism Gone Mad	• Humanitarian Relief Operations (HRO) • Defend Canadian Sovereignty • Cooperation with CSEC, CSIS, RCMP, PSC	• Non-Combatant Evacuation Operations	• Response to Cyber Attack • Counter-terrorism
Recyclable Society	• Exercise Sovereignty • Assist Law Enforcement • Aid to Civil Power	N/A	• Intelligence, Surveillance and reconnaissance (ISR) Operations

To rank the likelihood of these mission types [12], four groups of individuals from diverse backgrounds (joint, allied, defence science and academic backgrounds with variable levels of expertise with army doctrine) participated in wargaming sessions to discuss likely operations for each alternate world. The most notable observation was that the number of domestic missions was deemed more likely than expeditionary operations. In fact, in the two more optimistic scenarios (high octane green, and recyclable society) expeditionary missions were not among the most likely at all. Even in the two more pessimistic scenarios (global quagmire, and materialism gone mad), domestic type mission still outnumbered expeditionary operations.

For the Future Army cyber and space are new operating environments, affecting both domestic and expeditionary operations; space is naturally infinite, and the cyber domain is enabled by technology created through engineering [12], connecting traditional platforms, equipment and personnel in ways that was not possible before. Though cyber and space are relatively new concepts as operating environments, they will exist simultaneously within traditional operating environment and terrain: desert, mountain, jungle, woodland, grassland, the arctic and urban or rural settings.

The human dimension provides another layer of complexity to consider in the land environments. The need to understand the relationship between the physical terrain and the human terrain, to discriminate targets, limit collateral damage, and to operate in dense urban, possibly littoral, possibly polluted environment [12] will represent a major challenge for future operations. The confluence of cyber and space, the human terrain, and traditional operating environments will add to the complexity of delivering any mission effect for the Future Army.

In light of this complexity, it is anticipated that the Future Army will be required to conduct multiple operations, simultaneously, across multiple domains against a variety of threats, and in the case of some missions for an extended duration [12]**.** The force required to meet this challenge will require that Canada maintains a diverse set of capabilities across the full continuum of conflict, from humanitarian assistance to war-fighting. To make that force adaptable to novel and emerging threats across the full continuum of conflict, the Future Army will need to master its understanding of the terrain and also the human terrain of its operating environments, will need to embrace a broader role in conflict include the use of violent and non-violent means of achieving mission objectives, and will need to maintain a comprehensive approach to operations, relying on cooperation from other government departments and those of Canada’s allies.

For CSS employment, this means the ability to provide something akin to the improved land equipment management system (LEMS) mentioned in *Close Engagement* [10] to satisfy the *sense* requirements of collecting data on emerging and current CSS requirements and operations, and present that data in a way that is meaningful to support decisions in the *command* function and at the brigade level. A LEMS-type system will also be vital to inform *command* decisions made by CSS unit and sub-unit commanders to meet the requirements of supported units. CSS operations will be vital in the *act* functional area, by conducting their own operations in a complex environment to support offensive and defensive operations to meet higher-level objectives. These operations will rely increasingly on unmanned or autonomous systems. In the *shield* function area, the need for data connectivity and integrity requires protection against cyber-attacks and outages. The LEMS that supports command decisions, and therefore operational initiative, will require effective shielding against space-based and cyber-based system to enable effective navigation – likely of automated systems – while also allowing for a reliable logistics common operating picture. As mentioned above [12], the reliance on cyber and space systems applies to all missions, domestic and expeditionary. The dependability and integrity of cyber and space systems is essential for the Future Army, and for the role of CSS in it.

In the *Sustain* function the Future Army envisions a more self-sustaining model for deployed units, tapping into domestic and existing infrastructure, adopting water recovery and purification technologies, using alternate energy sources in order to reduce vulnerability, and reducing resource consumption and the volume of support required [12]. Tactical and strategic lift – air, sea and land – will remain essential for force employment in the domestic and expeditionary context for the Future Army. Projecting into the urban littoral may require amphibious or air delivery capabilities that do not currently exist, in addition to vertical and horizontal construction and re-construction for providing essential services once forces are established in their operating environment [12]. Accelerating procurement cycles, including the use of off-the-shelf technologies, will likely be required to meet unforeseen requirements during active operations.

For all operations, specifically those that are dirty, dull, dangerous or denied, the use of autonomous systems and robotics are envisioned as a key future capability, with emphasis on those that are smaller and cheaper than a manned solution and reduce the physical and cognitive burden for soldiers [12]. Speed, cost, physical and cognitive effort are important metrics, as current robots for tasks like IEDs tend to be more time consuming than having a human do the job. However, IED robots remain preferable for those tasks because they reduce the risk of casualties when dealing with explosive devices. A roadmap for the development of army robotic and unmanned systems is required, considering both internal army development, and for integration with other CAF environments, allies and partners.

This volume of the Future Army envisions more domestic operations and a greater emphasis on *close engagement* as opposed to only *close combat* [12]; though close engagement does not preclude combat, as required by the mission and operating environment. For the future of CSS, this does not fundamentally change the need to bring supply, medical support, maintenance and administration services to the level of close engagement. In a future world the systems that provide CSS may rely on fewer humans, be networked into a synthetic environment of sensor data, provide real-time updates, and support enhanced sense-making. However, the core function of sustaining deployed forces has not fundamentally changed in this alternate world.

3.4.3 Volume 3: Alternate World and Implications

The alternate worlds described in *Volume 2* [12] are continued in *Volume 3* [13] *and* provide some guidance on how to track the realization of alternate worlds against current events, and a brief list of the capabilities the Future Army will require to realize that vision.

The concepts for tracking the realization of the alternate worlds includes signposts, signals and trends [13]. Trends are discernable patterns of change that are observed over time, including societal or technological developments. Signposts are discrete events or thresholds between the present and the trend toward realizing the alternate world, and signals are local innovations or disruptions that have the potential to identify shifts in trends. It is important to note that signals are everywhere and distinguishing them from the ‘noise’ of everything else that is happening in science, technology, social movements, etc., is a persistent challenge [13]. Each alternate world is evaluated in Volume 3 for the most likely missions and tasks that will be assigned, and then a capability matrix is assigned that shows the capabilities that will be most important for the Future Army for each alternate world. Table 3 below is a collection of all the capabilities that pertain specifically to CSS for each of the alternate worlds. Because capability development is required to prepare for the full spectrum of conflict, all the CSS-applicable capabilities are included in a single table to provide a view of the full spectrum of CSS-tasks envisioned for the Future Army. The clear bias we can observe for technology is toward enterprise level decision-making systems to enable more efficient and effective CSS operations, and reliance on autonomous systems where applicable.

Table 3: Full Spectrum of CSS Capabilities for the Future Army (all four alternate worlds)

High-Impact, Low Likelihood	High Impact, High Likelihood
• Support independent operations, including permissive and non-permissive entry operations	• Rapid analytics and decision support, suing massive amounts of data from different feeds. • Logistics System (self-sustainment, tapping into domestic infrastructure, water recovery / purification, alternative energy sources, and other measures to reduce consumption and size of logistical tail). • Create understanding using analytics, diagnostic and fusion. • Interoperability with traditional and non-traditional allies (international force) • JIMP / interoperability with key OGDs at regional / provincial / federal levels. • Rapid procurement of material requirements during operations and capability development • Network capable of supporting static and deployed operations, to include secure communications. • Ability to operate in network degraded environment.
Low Impact, Low Likelihood	**Low Impact, High Likelihood**
• Automated systems that reduce physical and cognitive loads on humans. • Ability to project into the urban / littoral using amphibious / airborne means. • Reliance on local resources and shared services.	• Conduct forward deployment • Cyber-sense capabilities • Operational prototyping (additive manufacturing, in-theatre) • Engineering for domestic construction / re-construction

3.5 Technology Development - Army of Tomorrow & Future Army

DRDC produced a Scientific Letter evaluating disruptive technologies that are emerging and identifying how these technologies will impact the Army of Tomorrow (AoT) and the Future Army when involved in deployed theatre-level operations [15]. This document is written in the context of the future envisioned in the AoT and Future Army and seeks to provide a view of the impact on technology development for the next 25 years, and to contextualize the maturity of some key technologies out to 2040 to identify how they can be harnessed for army CSS. The three technologies identified for the AoT and the Future Army in this document are logistics decision support (LDS), the internet of things, additive manufacturing, and autonomous systems.

Logistical decision support systems link all layers of the logistical support system, in-theatre, from brigade, to battalion, to company, and right down to platoon, for mission planning, predictive analytics, asset visibility, visualization, and enhance situational awareness [15]. The expected applications of a logistical decision support system include tracking of assets, a recognized logistics picture / asset visibility, inventory management, and managing the supply chain through the system [15]. The objective of these systems is to provide material managers, logisticians, and supported units in the field with near-real time information on where assets are located – whether in storage, in transit, or in the field – in order to make better decisions, and to enable better coordination. When implemented, such a system is expected to enhance the command and control of assets, increase responsiveness to changing situations, enable more timely decision making, reduce the cognitive load on human operators, and to optimize the distribution of goods. A series of NATO and US systems are under development, with the integration of health usage monitoring systems, automated identification technology, and map-based planning services.

The challenges to any near-real time logistical system is maintaining network connectivity, the complexity of developing such a system and integrating all of the necessary sensors into it, the interoperability of the system with our allies, and maintaining cyber and information security of the system [15]. Information technology projects are well known for being late, over-budget and not delivering all of what was initially promised. A study of over 5400 projects revealed that large IT projects are over budget 45% of the time, late 7% of the time, and 56% of them deliver less value than was initially envisioned and expected [16], with the increased likelihood of budget overruns the longer the project runs. It is safe to assume that a project integrating operational units, the CSS units that support them in the field, and the BSA and FSA level storage and distribution centres would be a multi-year project running in the hundreds of millions of dollars. The added requirements for interoperability and the omnipresent need for cyber security to the greatest extent possible will increase the risk on a project of this magnitude further still.

Internet of things (IoT) is the concept of connecting physical things, digitally, into a larger network making them actionable information sources that, once connected, are able to communicate and collaborate with one another [15]. For example, one thing can collect sensor data that serves as an input to another thing, via the internet and wireless means. In the context of CSS this means facilitating a near-real time visibility of the supply chain in terms of who has requested CSS, and how far away that support is from being delivered. The IoT will enable asset visibility, tracking, situational awareness on supply, predictive analytics, predictive maintenance, demand forecasting, facility management, distributed and collaborative planning, and support identifying implications for optimizing military healthcare [15]. When implemented, IoT systems are expected to reduce asset loss, optimize transport and power usage, reduce transport risk, provide more timely information and therefore enable more timely decision making, allow for multiple assets to be simultaneously coordinated, and improve overall system-level efficiency in all domains. The current emerging technologies are the use of embedded sensors and actuators that communicate automatically, radio frequency identification (RFID) and bar code readers, near-field communications (NFC), S-beam, Bluetooth, guidance through GPS or Ultrasonic, and connectivity through Wi-Fi, W-iMax, and ZigBee.

The challenges to IoT system is systems integration and the need for constant connectivity. There is significant complexity associated with integrating and deploying sensors in the field into a single system. This will be especially challenging in the distributed environment where the distance between elements is likely to be significant. Maintaining connectivity of things to the IoT network will be threatened by malicious attempts to disrupt connectivity, and through loss of connectivity due to complex or disparate geography. Units separated by long distances in austere conditions may lose connectivity to the IoT network. Conversely, in the networked urban littoral, there is the potential for IoT service to be denied in connectivity dead-zones, common in the complex, highly angular urban terrain. The benefits of IoT are premised on continuous connectivity. If connectivity is lost or interrupted, the effectiveness of the network is stalled until connectivity is re-established.

Autonomous Systems are expected to do some dull, dirty or dangerous jobs that expose humans to risk or prolonged repetition. The most sophisticated systems employ state-of-the-art technology and algorithms to allow goals and tasks to be assigned by human operators, with the technology determining the specific routes and approaches to achieve the desired outcome [15], navigating land, air or sea. Systems include autonomous helicopters, small boats, and wheeled or tracked land vehicles. These systems have varying degrees of autonomy, with some capable of doing things with limited human intervention, and others requiring more human direction to achieve their missions. The CSS missions with the highest potential for autonomous system support are replenishment and cargo movements, carrying supplies for operational units in the field, shipping and delivery, supply chain management and convoy protection from automated systems [15]. The expected benefits these systems will deliver is reducing the risk to personnel (reduced casualties), decreasing the cost of CSS, reducing the burden carried by the individual soldier, extending the range of dismounted operations by having more reliable resupply, and enabling resupply in austere, denied, or remote locations that current platforms cannot access.

The challenge for autonomous systems are primarily energy use, communication issues, coordination with other autonomous devices, and limited performance under complex conditions. To navigate and avoid obstacles in autonomous mode, these systems need to have a real-time understanding of where they are, where the obstacles are, and what lies behind and ahead of them. This requires a constant GPS or spatial location signal to tell the device where in the physical space it exists. There will be some challenges – especially driving vehicles in urban terrain – where autonomous systems will not be capable of reacting as quickly or effectively as human-driven vehicles. Because these systems are machines they don't get tired as human operators do, but they still need energy to operate, whether from batteries or liquid fuels. The technology for fully autonomous systems is still relatively new, relying on machine learning technology, GPS, radar, LIDAR, and a human-interface of some kind to assign tasks to the device. Each of these technologies will undergo further development, moving them closer toward operationalization Table 4 below shows an overview of the expected level of development these technologies will undergo [15].

Table 4: Roadmap for Technology Development [15]

Technology	Army of Tomorrow – 2021 Horizon	Future Army – 2040 Horizon
Logistics Decision Support	• Supply chain visibility but partial system interoperability at the tactical level. Real-time visibility of situations and events. Intra-organizational collaboration. • Cloud-enabled Total Asset Visibility (Automated identification) • Net-enabled supply chain management (distribution) • Recognized Logistics Picture (CSS) Sense-and-Respond logistics (first generation) with distribution-focus: • Provide the right item to the right customer at the right place and right time	• ***Net-enabled CSS:*** Full system interoperability at the operational and tactical level providing near supply chain optimality; Integrated logistics picture; • ***Shared sense-making***; Virtual distribution (resource planning and pooling); • ***Anytime on-demand support***: Rapid responses to events and situations. • Adaptive and collaborative sense-and-respond logistics capability; External, inter and cross -organizational collaboration. • Revolutionary Data Analytics & Machine learning • Cloud-enabled Logistics Decision Support • Mobile & Wearable computers to enhance memory and physical performance (Human augmentation) • New requirements for LDS imposed by new topics such as Synchromodality, Big data, Machine learning, and revolutionary analytics
Internet of Things	• Intra-organizational sensor network; • Internal real-time visibility of assets, situations and events • Watching every move: flexible smart grids/systems for transportation and in-theatre distribution • Smart cargo handling: sensors embedded in containers • Unified and smart battlespace awareness • Autonomic Logistics (condition-based monitoring) on key high-value assets.	• Cross-organization visibility of assets, situations and events; • Flexible smart grids for utilities • Virtual agile and adaptive distributed mixed sensor/effector, agent network (Inter-organizational);
Autonomous Systems	**Vehicle convoys** • likely deployment in real-world applications. • feasibility and reliability demonstrated in many long-range tests on military vehicles. • semi-autonomous convoys for distribution in	**Dismounted Load Carriage:** • Increasing number of robot mules • Possible assignment at the squad level • Continual support, mule assistance

Technology	Army of Tomorrow – 2021 Horizon	Future Army – 2040 Horizon
	structured environments **Tactical Resupply** • UGVs likely to be tele-operated or semi-autonomous • last tactical mile" distribution Search and rescue/health services **Search and Rescue / Health Services** • improving robot mobility and communications. Expected to work for some limited ground-based applications e.g. Surveillance and reconnaissance support for robustness purposes **Material Handling and Logistics Support** • automate warehouse logistics operations.	**Vehicle convoys** • autonomous convoys for distribution in unstructured environments: unmanned convoys able to plan their own route and dynamically adapt to changing conditions. • decreasing risk to logistics personnel. **Tactical Resupply** • last tactical mile" distribution of critical logistic supplies including medical equipment in unstructured and contested environments • UGVs accomplished through teams of fully autonomous unmanned systems • UAVs as prime delivery systems. UGVs to be used for resupply operations where UAV point delivery is not an option **Search and rescue/health services** • largely automated, and performed by teams of heterogeneous unmanned systems • medical assistance and evacuation **Material Handling and Logistics Support heavily automated in the future.** • Humanoid robots may also play a role in performing tasks in ad hoc or forward supply depots where more permanent systems cannot be installed Maintenance • condition-based maintenance assistance, spare parts supply and long-term fleet management

The common elements for each technology type is the fielding of baseline capabilities on the 2021 horizon, with expanded capability on the 2040 horizon requiring less human intervention, more autonomous activities, and greater visibility of assets. For logistics decision support, the vision of 2021 includes partial interoperability for the supply chain system, a recognized logistics picture, and providing timely delivery to meet the needs of operational units. The 2040 vision provides the same core elements, but with greater capability. Partial visibility is replaced by total visibility; a recognized logistics picture is replaced with virtual sense making; meeting operational unit needs is replaced with anytime on-demand support. The IoT vision does not change significantly between 2021 and 2040. In 2021 the IoT will develop a network of sensors embedded in things, enabling better visibility of assets, greater flexibility in grids and systems for transport, and conditions-based monitoring for key assets.

The expected changes in the capability of autonomous systems between 2021 and 2040 is significant and is focused on reducing the role of humans in directly controlling autonomous systems. The 2021 vision shows long range, semi-autonomous systems for bulk transport, and tele-operated systems for 'last-mile' delivery. By 2040 greater reliance on fully autonomous systems for long range delivery, unmanned ground vehicles (UGVs) and UAVs for front line re-supply, and automated robot "mules" embedded with dismounted personnel are all envisioned. UAVs are envisioned to take on the role of prime delivery for resupply operations, where the environment (terrain and threat) makes UGV delivery impractical [15]. Medical assistance and material management are expected to be performed entirely by automated means, whether by purpose designed systems or humanoid robots.

There are two important observations from this document [15]. The first is that the expectation of what future technology can deliver is not fundamentally different in the 2021 and 2040: it is simply a matter of what becomes possible as emerging technologies and concepts mature. In the case of autonomous systems, the concept is unchanged between 2021 and 2040: the expectation is that autonomous technologies will have matured sufficiently that there will be no need – or very limited need – for humans to control the devices while in transit. The expectation appears to be that material will be ordered, and the autonomous system will do the rest. This speaks to the second observation: the tightening of the relationship between human and computer. LDS and IoT are envisioned to provide total visibility within and across organizations. This will be enabled by configuring the IoT to fuse data into a near-real time understanding of the current situation, all relying on automatic movement of information with limited intervention from humans.

As with all network and IT based technology, the resilience and reliability of the network is of paramount importance in the effectiveness of LDS, IoT and autonomous technology. This means that network security is imperative, protection against disruption or modification of data is essential, maintaining connectivity across wide space (likely with the use of satellite technology) and redundancy to prevent against data flow interruptions are all essential to realizing the 2040 vision.

3.6 Canadian Concepts – Summary of Implications for CSS

The documents that define the army of today, AoT, and the Future Army share a number of commonalities. This is expected, given that capability development and force generation concepts of today should align with the vision of the future, to allow for continuous progress toward the future vision from the current state. This section provides a summary of what is envisioned for the Future Army.

The Operating Environment:

The Future Army is expected to operate in domestic and expeditionary environments, in urban and rural environments (possibly the urban littoral), in close contact with civilians, with a force that is distributed across a wide geographic range and operating as units and sub-units. The proximity to civilians will require the Future Army to understand not only the physical terrain, but the human terrain also. Threats in the operating environment can include broad range of actors, including states, non-state actors, terrorist networks, organized criminal syndicates, and potentially violent elements of civil society.

The environment is not expected to be stagnant, with the situation evolving depending on environmental, political, and social conditions. This will require CSS units to be able to operate in permissive and non-permissive environments, anticipate the support requirements of forward deployed units, and be capable of operating in all weather. The velocity of the supply chain is expected to accelerate, and greater asset visibility (with anticipated delivery times) will be important for units operating at a significant distance from either a Brigade Support Area or JTFSC. This environment can be domestic or foreign.

The Mission:

The Future Army will be called upon to execute military missions along the full spectrum of operations, from humanitarian relief operations to warfighting. For expeditionary operations the Future Army will be part of a coalition of allies and will be a leading agency in the whole of government (WoG) effort. In the domestic context, the Future Army will be called upon to provide support to other government departments (OGDs). CSS units will need to be capable of operating in combat and non-combat missions, be capable of providing local area combat capability, and be interoperable with allies and OGDs.

Force Structure

The mechanized brigade group is still the standard unit of measures for the army's force structure. ECATs are a sub-unit within the brigade that are detached from the brigade to conduct discrete operations across the operating environment, in support of the brigade's objectives. When operating domestically or overseas, the Future Army will be engaging with OGDs in support of their mandates. The distributed nature of operations will require CSS support over wide areas, and where possible, supplies will be procured from the local economy. The concept of "lines of support" (4th line, 3rd line, 2nd line, and 1st line) will persist, though the means by which support is provided include the local economy, contractors, and support from allied nations, as the mission requires.

Equipment

The Future Army will continue to rely on large quantities of energy, ammunition, and water to sustain operations across a wide operational area. CSS units will continue to fulfill those needs, though future improvement in machine and equipment efficiency, and future energy production solutions at the local level may reduce the total volume of energy that must be transported to forward areas.

The use of logistical decision support, harnessing the internet of things, and autonomous and/or unmanned systems are all expected to have significant impacts for CSS, particularly for supply, maintenance, and medical support. Current technologies are under development for autonomous and unmanned systems to support bulk cargo transport, small load transport through uninhabited ground, sea and air systems and vehicles.

Information Management and Information Technology

Computing technology, sensor and data fusion, and global network connectivity will enable the transmission and sharing of information at a rate never before seen. The internet of things, advanced artificial intelligence, big data and predictive analytics will allow for insights to be generated in near-real-time, with decisions taken on providing CSS autonomously (as required). This has major implications for managing CSS requests and operations. Forward deployed units will be integrated into a network that allows for total visibility of personnel and assets. The volume of useful data will enable the development of a logistical information system / decision support system capable of anticipating maintenance needs, automatically generating supply requirements and requests, and will provide users with total asset visibility on when deliveries can be expected.

Security of the information enterprise is paramount. This includes integrity and security of information that is collected by sensors and transmitted via space and cyber means. Any future information management and information technology enterprise is only as effective as the data it is provided. To ensure that the CSS system is provided effectively, data integrity IT security is essential; which means that cyber-security and space-system security are also essential.

3.7 International Perspectives

3.7.1 Combat Service Support (CSS) in the Networked Urban Littoral (Australia)

This document [17] was written for the Australian Defence Force (ADF) and provides a vision of the future challenges for CSS in the networked urban littoral environment. Given the nature of the South Pacific operating environment (archipelagos, cities built on the ocean), the urban littoral environment is a logical choice for the ADF. The key elements of the ADF concept are an assumption of a non-linear operating environment, where close contact with the civilian population and the adversary is constant, and threats can materialize quickly. Regardless of the specific mission, the challenges envisioned in the future networked urban littoral environment are of [17] a crowded, connected, lethal, collective, and constrained environment.

Similar to Canadian and NATO doctrine, this Australian document makes the distinction between 'logistics' and 'CSS', and the types of activities that comprise each term. 'Logistics' is the overarching term used to describe force generation, force deployment and redeployment, and force sustainment (a joint activity); while 'CSS' is the term used to describe the primarily logistic *actions*, processes, functions and services that are undertaken during the sustainment of a combat force [17] (i.e.: 3rd line support and forward). That is to say, CSS is an operational sustainment activity under the overall umbrella of logistics.

The challenges for CSS operations in the networked urban littoral environment are as follows:

- **Crowded**: CSS elements will be required for small teams where enemy interdiction is likely.
- **Integrated:** an integrated common operating picture will be required to maintain awareness on CSS activities.
- **Lethal:** force protection will be a priority, including CSS elements surviving first contact and then fighting to extract from contract on their own
- **Collective**: the need for inter-operability and compatibility with allies, host nation and industrial partners.
- **Constrained:** there will be significant competition for resources inside the ADF establishing to fund and sustain capabilities.

CSS units must be capable of rapid organization to meet emerging tasks and have the ability to self-defend. The urban littoral environment will likely require small, dispersed teams, increasing the likelihood of interdiction for both the supported team and the CSS team supporting. The document also highlights the need for effective synchronization of logistics and CSS activities to enable the full spectrum of mission outcomes, whether for combat operations, or for operations where combat is less likely and not the main objective, such as humanitarian aid and disaster relief.

The ADF vision includes nodes as the main conceptual building block [17]. Each node – regardless of whether it is for supply, maintenance, water, power generation – will be part of a larger network, moving away from the rigid system of echelons. Nodes will be mobile, as required, to accommodate the operational needs of the combat force in the networked, urban littoral. To meet this need for mobility, CSS must be integral to the combat force, and CSS specialists need to be trained accordingly to manage the CSS activities for the combat force and to provide their own combat capability for the integrity of the supply chain.

Future technologies will improve the following functions, in order to realize the future vision for CSS [17]:

- **LOGIS (Logistics information system):** this will provide the effective means for managing CSS functions within the larger logistical system.
- **Supply Chain**: this is the distribution network, from industrial base to the end-user. Optimizing the supply chain is essential in meeting the demand of

mandatory supplies like water and fuel.

- **Contracting:** integrating contractors into logistics and into CSS functions is currently an operational reality and will likely continue as capability acquisition will be linked to the original equipment manufacturer (OEM).
- **Future technology:** the advances in technology like computing power, power and energy sources, nanotechnology, biotechnology, robotics, and automation are all likely to have an impact on CSS and the supply chain in general.

The LOGIS and supply chain concepts go hand in hand: a well-designed and integrated LOGIS will allow planners and operators to maintain visibility of material moving along the supply chain, from storage locations to combat forces in the field. This will allow for greater awareness on exactly when supplies will arrive, when maintenance will be required, and optimizing delivery times for consumables and spares. A real-time logistics common operating picture (LCOP) will be necessary to provide real-time visual situational awareness of CSS activities [17]. The expectation is that by using computer-enabled projections of CSS requirements across the whole supply chain, CSS can be optimized for greater awareness on emerging requirements, and improved efficiency of overall delivery. The key constraints to implementing an effective LOGIS, beyond cultural acceptance of a technology-driven solution, are challenges to bandwidth, threats of cyber-attack, threats of degraded satellite communications, and effectively integrating LOGIS into existing battlefield management systems without causing erosion of either system.

The future of technology remains an open question, however academic think-tanks and defence researchers in Australia [17] have identified the likely areas of technological advance on the 2025-2050 timeframe will include energy sources, nanotechnology, biotechnology, robotics, and automation. Advances in energy sources will provide opportunities to increase the efficiency of military equipment (i.e.: a reduced rate of consumption for equal or greater output), and reduced volume of fuel cargo due to increased efficiency or endurance of military equipment. This is noteworthy, given the heavy reliance on machines like tracked and wheeled vehicles, generators for electricity inside military camps, and fuel for aviation assets like helicopters and airplanes. Advances in electric sources, like batteries, are likely to reduce – or perhaps even eventually replace – reliance on liquid fuels like diesel, gasoline, and aviation fuel. Robotics and automation can serve to reduce the number of tasks performed by humans, and thereby reduce the risk of casualties in those task areas. Advances in nanotechnology brings the possibility of massive reductions in the size of military equipment, reducing not only the soldier’s combat load but also the amount of energy required to operate it. Biotechnology brings the possibility of implants to improve human performance in soldiers and enable new surgical capabilities to save lives and facilitate faster recovery for soldiers that are physically wounded in combat.

The noted constraints to realizing this vision are [17] the culture of the army, the existing force organization and the resources necessary to fund this vision. The army culture represents a risk due to limited integration in the joint environment (i.e.: integration with air force and navy), a distrust of new technology when supplanting existing and proven methods, and the desire for ownership the CSS chain as opposed to the trust that CSS will be delivered as designed. The current force organization is therefore unlikely to be adequate to support CSS in the networked, littoral environment in a dispersed operating environment. The observation provided is that greater level of CSS command is needed at the formation level and be included in the battle-grouping process (i.e.: integration of

CSS during mission capability definition). The final constraint is resourcing, and this pertains to internal competition for resources, specifically in prioritizing CSS modernization as a dedicated item in strategic investment plans for defence spending.

This document provides a comprehensive overview of a future concept and includes the organizational challenges inherent in this kind of vision. The expectations of the networked, urban littoral environment are reflected in the vision of where technology changes will maintain the advantages the ADF has over potential adversaries. The organizational changes, however, are an essential point to implementing the vision of the future. Current structures exist to support the current force; it therefore follows that a next-generation vision will need a next-generation operating model. Beyond the discussion about which technologies are most suitable to provide CSS to the future force, there is also a need to consider the implications on the force structure.

This document considers a very specific threat environment: the networked, urban littoral. The expectations of dense urban areas, civilians going about their lives, and an adversary that can materialize and disperse rapidly apply to all urban environments. The nuance is the littoral component in the Australian context compared to the Canadian. Though Canadian army combat forces are capable of landing from the sea, there is no integral capability in the Royal Canadian Navy comparable to the Canberra class ships of the Australian Navy. These ships are purpose designed with space for landing craft, small boats, and space for amphibious vehicles below [18]. There is nothing comparable in the Canadian inventory, or as part of future procurement plans. The “networked” and “urban” components of the Australian vision reflect the assumptions in Canadian doctrine and documents that address the ADO concept; however, caution should be exercised in evaluating any concepts that pertain specifically to the littoral. This does not mean that any reference to littoral should be ignored, but rather that these concepts should be closely evaluated to determine overlaps with Canadian concepts and practices, and an evaluation where current capabilities and future capability plans do not overlap with those of allies.

3.7.2 US Marine Corps Hybrid Logistics

The US Marine Corps released a concept document for discussion among its members on the future of logistics. Titled *Marine Corps Hybrid Logistics: A Blend of Old and New* [19] this document defines the ‘hybrid’ mentioned in the title as the ongoing need to move large quantities of fuel, water, and ammunition through the battlespace, while also taking advantage of uninhabited platforms, additive printing, and computer-enabled predictive supply and maintenance management systems. Hybrid Logistics envisions a mix of existing and emerging technologies to sustain and meet any future requirements. In this way it is similar to *Close Engagement* [10] as the AoT, because it envisions some technological advances with similar military challenges to those faced by the army of today.

The most notable inclusion in this document is that the space and cyberspace domains are included as part of the logistics operating model and accepts that Marines may not have the same type of spectrum dominance they enjoyed during conflicts in Afghanistan and Iraq. In both of those conflicts all American forces enjoyed a clear advantage in combat power, air supremacy on a massive scale, cyber dominance, and no space threat. This document identifies that near-peer rivals will be capable of anti-access / area denial (A2/AD) technologies against American forces, making it more challenging to put forces ashore and sustain them [19]. To survive in an A2/AD environment, Marines will need the capability to use their digital, networked systems, and also revert back to analog systems, when required, to maintain connectivity. Future systems are expected to be powerful and enhance situational awareness; however reverting to more manual methods is required when there is credible threat of A2/AD disruption.

Similar to the ADO concept discussed previously [9], Hybrid Logistics envisions a distributed force that can aggregate and disaggregate as it manoeuvres and repositions, using a ‘modular’ approach. The challenge is that the modern force brings more lethality, agility, speed and range than any force before, and is a very resource intensive force; meaning that as lethality has grown so too as the requirement for greater CSS capacity. Hybrid logistics does not envision this situation changing in the near future and requires improved logistics concepts to maximize the warfighting output of new and emerging combat capabilities.

Existing and emerging capabilities and concepts are discussed, such as uninhabited aircraft for supply delivery (the uninhabited variant of the K-MAX used in Afghanistan – see Section 5.4.2 for more on K-MAX), additive manufacturing, expeditionary medicine, and using predictive analytics and connected systems for sense-and-respond demand-drive logistics supply chain. Sense-and-respond logistics is already used by the Marines for aviation maintenance, and Hybrid Logistics envisions expanding that across the Corps. The sense-and-respond concept also corresponds with the Marine logistics concept of “wholesale” (large scale CSS and basing on ships: warehouses, medical facilities on ships, helicopter launching decks on ships, etc.) and moving to “retail” (distributed facilities) locations ashore. Sense-and-respond systems will provide clarity on the CSS requirements in those distributed facilities, and with the appropriate level of asset visibility, planners and commanders can anticipate when their logistical requirements will be met.

This document does not provide a direct solution for addressing the volume of the “big three” consumables on the battlefield (water, fuel, and ammunition). This is especially important for the Marines, given that their fuel requirements have expanded significantly with the introduction of the MV-22 “Osprey” tilt-rotor that consumes fuel at a rate *seven times* that of the CH-46 helicopter it replaces [19]. The only partial solution is for each Marine to become a “producer” of energy using solar panels to charge batteries for personal equipment and using individual water purification kits to create clean water from whatever source is available. Exoskeletons, robotics and polymer ammunition are mentioned as concepts, but without a clear approach or application to reducing the volume of consumables that are moved from warehouse to battlefield. However, neither of these solutions addresses the fuel sources for vehicles and will remain a challenge for the Marines into the foreseeable future. Introduced in 2009, the MV-22 was forecast to serve until at least 2032 [20], however this could be extended well into the mid-2040s, with a mid-life update program scheduled for the late 2020s [21]. For the Marines, the challenge of liquid fuel for its combat aviation assets is likely to remain.

3.8 International Concepts – Summary of Implications for CSS

The concepts provided by the ADF and USMC documents are not fundamentally different from the Canadian concepts documents presented above, however there are some differences in priority. These are defined below.

The Operating Environment:

The future concept for both the ADF envisions a networked, urban littoral environment where operations similar to the ADO concept will be executed. Likewise, the USMC concept still envisions landing from the sea, and the need to put the “mountain of steel” ashore to deliver operational effects and to the sustain them. The urban littoral, like in Canadian concepts will include an operating environment with civilians in close proximity, and a broad range of potential threat actors, including states, non-state actors, terrorist networks, organized criminal syndicates, and potentially violent elements of civil society. The ADF and USMC anticipate the delivery of lethal force in a contested environment. This operating environment will require CSS to be delivered in permissive and non-permissive environments, with asset visibility enabled by a digital logistics management system.

The Mission

The ADF anticipates the need to deliver multiple mission types simultaneously in the networked urban littoral, and the need for maximum flexibility in the CSS necessary to sustain operations. Support from partners, the host nation, and contractors is envisioned to optimise the CSS footprint for operations. The USMC hybrid logistics models does not explicitly include the use of contractors, though America has relied extensively on contractors in Iraq and Afghanistan. The range of missions articulated by the ADF and USMC fits into the range of missions Canada envisions for the future.

Force Structure

The ADF concept indicates that the future force structure is likely to need adaptation in order to meet future requirements. This will be the result of a re-conceptualization of what CSS is required to provide, and how it will provide it. The USMC concept does not assume any changes in the force structure, but both the ADF and USMC concepts anticipate a more modular use of the existing units. The functions that each unit provides (maintenance, resupply, water delivery, etc.) will not change in the ADF model, however, nodes are likely to be geographically dispersed to meet the needs of supported units. The USMC envisions greater cross-training to provide wider flexibility in what personnel can provide. Canadian documents have not articulated a further vision for force structure, aside from the ADO concept.

Equipment

The ADF and USMC will continue to rely on large quantities of energy, ammunition, and water to sustain operations across a wide operational area. Increased reliance on automated technology – for land and air – will allow for reduced risk to personnel doing supply convoys. The use of 3D printing will enable maintenance and spare parts to be pushed closer to the 1st line, reducing the complexity of managing the supply and delivery of a wide inventory of parts. This is consistent with Canadian concepts.

Information Management and Information Technology

The major accelerator in both the ADF and USMC is the use of technology to anticipate maintenance and supply needs, and to optimize the supply chain using predictive technology. The ADF is envisioning a logistics common operating picture (LCOP) and a modernized LOGIS to manage, and maintain visibility on, the overall logistics enterprise. The USMC has identified the use of A2/AD technologies as a key threat to all information management and information technology systems. This means that information security is essential, both to harness the benefits of an LCOP and LOGIS for operational planning, and to prevent the adversary from accessing logistical information. This is consistent with the Canadian concepts of a Land Equipment Management System (LEMS) and maintaining a recognized logistics picture (RLP).

3.9 Summary of Concepts and Emerging Technologies

This section provides a summary of the concepts for the future security environment, and the emerging technologies that are envisioned for the future of CSS. These concepts will form the basis of the remainder of the discussion in this document on the role of emerging technologies for CSS of the future.

3.9.1 Concepts

There are some concepts that are common to all the Canadian concept documents, and the Australian and US Marines concepts. They include:

- **Geographically dispersed operations**: as the range and agility of army forces has expanded, so too has the geographic range across which effects can be projected. Operations are therefore likely to be widely geographically dispersed.

- **Urban and Rural:** growing global urbanization will drive a mix of urban and rural operations for future operations. This was the case in Iraq and Afghanistan since 2001, and Syria since 2011, and is expected to continue.

- **Domestic and Expeditionary:** operations will be domestic and expeditionary. The Canadian vision for the Future Army includes many more domestic operations than expeditionary.

- **Complex Information and Technological Environment:** the acceleration of technology is the last 20 years will virtually ensure a networked and connected operating environment in the future. However, this means that potential adversaries will likely seek to weaponize technology against friendly forces, and/or seek to negate the technological advantages of friendly forces.

- **Basic Doctrinal Concepts:** the basic doctrinal concepts for 4th line, 3rd line, 2nd line, and 1st line CSS and logistics will remain unchanged in the future operating environment, though how they are expressed (fewer installations, more long-range delivery) may change based on distance and the technology to enable dispersed operations.

- **Diversity of Global Supply Options:** though basic doctrinal concepts still apply, there is an expectation in the future that the private sector, contractors, partners, and the host nation can provide some support. This means that future Canadian operations can expect to procure some of the needed materiel in the 3rd line or 2nd line environment. Proprietary technology, or technology with security requirements will still need to come from secure locations, though where this is not a concern local procurement is a possibility.

3.9.2 Technologies

Emerging trends identified by Canada and allied partners are as follows [12] [17] [19]:

- **Autonomous Systems:** semi-autonomous and uninhabited systems are already in service for tasks like intelligence, surveillance and reconnaissance, and for some CSS tasks like aerial resupply. The development of new technologies for land and air will be considered, and any applicable sea-based technologies. These technologies have applications for all levels of the CSS chain.

- **Power and Energy Technology:** as battlefield technologies expand, so does the need for energy to power them, whether through greater requirements for liquid fuels, through batteries, some mix of fuel and batteries, or through modern fuel cell technology. Advances in power and energy technologies are envisioned to improve the efficiency of platforms and equipment, and to reduce the volume of fuels that must be transported to units operating in the field.

- **Data integration and information management**: advances in information technology will enable the fusion of sensor data, advanced sense-making, and improved and automatic analytics. This is expected to have significant contributions to data management for logistics and CSS, and will enable improved logistics shared situational awareness, and provide total asset visibility. This will allow service providers to maintain awareness on all un-finished tasks, and will enable supported units to better anticipate

- **Cyber and information security:** the anticipated reliance of advanced information technology raises concerns about ensuring security and integrity of data. This can include sensor data, navigational data, and overall network security to prevent adversaries from accessing, altering or interrupting the data flows that will be so vital to future CSS operations.

4. GAPS IN CURRENT TECHNOLOGY

This section provides a summary of the gaps in current technologies for military applications (regardless of whether or not they were conceived for civilian or military purposes), based on the observations in official documents and from research on existing systems.

4.1 Unmanned and Autonomous Systems

The main challenges for autonomous systems today are to reach the level of sophistication where they require less human input, and to move beyond the narrow purpose that most autonomous systems serve today. Autonomous systems today still require considerable human input in order to rival the effectiveness of existing human-controlled systems [22], and are primarily used for intelligence, surveillance and reconnaissance (ISR) or for performing dangerous tasks. As we will see in Section 5.4, the primary challenge for using autonomous systems for CSS is the payload volume that can be delivered compared to other systems already in service, like fixed wing aircraft dropping parachute loads or rotary wing aircraft delivering bulk cargo.

Land-based systems especially are still largely reliant on human operators to either directly control unmanned systems or to provide waypoints for autonomous or semi-autonomous systems. While the purpose of reducing the risk to human operators is retained when relying on unmanned systems, there is no savings in terms of human resources required, because a human operator is still the driving element; without the human operator many unmanned systems are not capable of functioning. Even those systems that are autonomous tend to fall below the capability and performance of human drivers, especially in complex interchanges, construction zones, snow covered roads, driving in the sun at low-angles, in precipitation, in dust or other battlefield obscurants [22]. There are also challenges associated with operating autonomous systems in urban areas with other vehicles, traffic, obstacles, and avoiding pedestrians in a dynamic environment [22]. Until unmanned systems can operate more effectively as autonomous systems in complex environments there will be no savings in the number of humans required.

For autonomous navigation, most unmanned or autonomous systems rely on GPS to know the vehicle's location. This provides reliability where connectivity is maintained, and not subjected to disruption; however, it would be naïve to assume connectivity will be ubiquitous. There is a need for redundancy in GPS, or reliance on another system such as Galileo (from the EU) [22] to provide alternate means of navigating if one means of navigation becomes compromised. There are other systems developed by countries like Russia (GLONASS), China (COMPASS navigation), and India (IRNSS), though these may not be prudent given some of those countries are reputed to engage in cyber-attacks.

4.2 Visibility of Supply Chain

Demand-driven and near-real time logistics in the future will require visibility on each stage of the logistical chain, from 4th line to 1st line. DRDC produced a scientific letter in late 2014 in response to an army request for an evaluation of the current capabilities for in-theatre combat service support, from theatre support base (TSB) to the front-line soldiers [23]. The intent of this document was to identify specific capability deficiencies, and to address them as part of realizing the 2021 horizon for adaptive dispersed operations (ADO) [23. The objectives for a future recognized logistics picture (RLP) system is one that shows: A) a shared understanding of the tactical sustainment situation with higher, lower, and adjacent commands; B) information management to allow access to sustainment requests, calculations, predictions and other tools to allow for more efficient use of logistics expertise; C) decision support to enable rapid sense-making for sustainment requirements; D) visualization to allow the display text, graphs, and geospatial information to meet client's needs, and; E) collaboration among multiple geographically distributed users, with higher and lower commands, in near-real time [23]. These represents the full realization of the 2021 horizon and align with Army of Tomorrow (AoT) vision.

A number of deficiencies identified in the supply chain present serious challenges to realizing the 2021 vision. The largest challenge is that there was no means of total asset visibility (TAV) in real-time [23]. As a result, maintaining and establishing situational awareness on CSS operations, or presenting a recognized logistics picture (RLP) is impossible to achieve in a sufficiently timely manner to inform decision making [23]. This is driven, in part, by the fact that there are insufficient data exchanges between the tactical and operational level; and that the exchanges that do exist rely on manual data entry [23], a process that is both time-consuming and error-prone. When data is entered into computer systems that support CSS operations (resource management, enterprise planning, movements systems, fleet management, etc.) there is no integration between those systems, further widening time delays and limiting the ability to generate situational awareness [23]]. Setting that aside, once data is entered into system there is a weak visualization of that data to enhance sense-making.

In sum, the state of technology was insufficient to provide logistics situational awareness to support the AoT and the ADO concept; establishing ground truth in a timely manner was not possible, impacting the ability to make fully informed decisions about logistics planning, and the ability to recall or change plans using automate means once they are approved. A future logistics decision support system will need the ability to provide shared tactical situational awareness, in real-time, fused from multiple data sources, compare options for plans, generate plans, support synchronization, share progress in real-time using a common command support system, provide visualization, and present updates in real-time as the situation evolves [23]. The presentation of these gaps is important to understanding how much work is necessary to realize the vision of the AoT. To best position the Canadian Army to address these gaps, a methodical approach to defining requirements and accountabilities should be pursued to better understand how these gaps can be addressed.

4.3 Cyber Integrity

Cyber integrity is vital to the AoT and Future Army's vision, given the reliance on technology and on maintaining wireless connectivity between deployed units and databases. The West is not envisioned to maintain the advantage in technology it currently enjoys over the long-term, or at least it is not taken as granted. The globalization of science and technology is a significant megatrend, and countries like China, India and others are making significant contributions to science, technology and innovation, previously domains where the EU, Japan and the United States were the global leaders [11]. Given the central role the internet plays in government, business, entertainment, and connectivity across seemingly every aspect of society, it is safe to assume that many of these innovations will come in digital and communication technologies. With enhanced connectivity comes the increased risk of exposing cyber vulnerabilities and the potential of adversaries exploiting those vulnerabilities during time of conflict to inflict maximum impact at relatively limited cost [11].

The current cyber security picture for Canada's Army is challenging. Canada reportedly does not have full situational awareness of the network environment [22]. This presents a number of challenges. Firstly, it means that there is no recognized cyber picture of the health and integrity of all necessary networks. This means that when a cyber-attack happens, or worse, if there are coordinated attacks on multiple command and control network nodes, awareness of multiple attacks will not be detected in real-time or near-real-time. Lacking situational awareness on the overall network will limit the ability to identify patterns in real-time, and to begin taking stock of the impacts of an attack, perhaps until it is too late and the damage has been done or information compromised. Deterrence in the cyber domain is effectively unachievable because of the diffuse nature of the internet and the number of potential attackers [22], meaning the risk of retaliation does not inform the decision-making of would-be attackers the same way as for a traditional physical attack. The assumption is that attacks will happen, in part, because attackers are unlikely to perceive a mutually assured destruction, the baseline assumption around the concept of nuclear deterrence during the Cold War. This means that the ability to deliver a rapid response is necessary when an attack inevitably does happen, and without situational awareness of the network this becomes more challenging.

Action is being taken to address the cyber challenge, at the enterprise level. As part of *Strong, Secure, Engaged,* Canada has announced that it will be opening a new Cyber Operator occupational speciality within the CAF [24] for already serving members, with plans to open to occupational speciality to people joining the CAF by 2019 [25]. While this does not directly address the network awareness issue, dedicating resources to addressing the cyber domain brings promise of enhanced capability.

To take full advantage of a network with global reach, satellite technology is necessary to connect elements deployed over the world with strategic command and control in Canada. Currently, Canada needs to rely on allies and commercial providers, because Canada does not have its own space communications capability [22]. This does not present a threat in and of itself, but without a national capability Canada's global network connectivity is at the mercy of allies and commercial providers. It also means that when allies or commercial operators are targeted, Canadian systems may be interrupted or impacted as a result. The lack of national capability does not make Canada any more vulnerable per se, but it does make Canada just as vulnerable as whoever Canada contracts to provide satellite service.

4.4 Energy-Intensity for Forward Operations

Contemporary armies use significant amounts of energy. According to a recent US study, the US armed forces consumed 22 gallons of fuel per day (roughly 83 litres) per person deployed to Iraq and Afghanistan, and that the cost was *at least* $45USD per gallon (or roughly $14.75CAD per litre) to ship the fuel into the theatre of operations [26]. That equates to a cost of roughly $990USD (or roughly $1225CAD) per day per soldier in fuel alone. This does not include water, ammunition, food, quarters, equipment, medical, and all the other things that support personnel on deployment. The USMC claims that it cost them 7 gallons of fuel to ship each gallon of fuel or water into Afghanistan [27]. That is an amazingly inefficient ratio. Beyond the material cost there is also a very real human cost. Roughly 10% of total US casualties in Iraq and Afghanistan were sustained by soldiers involved in maintaining supply of fuel and water [28]. Canadian data is not readily available, though it is safe to assume that figures were comparable for sustaining Canada's mission to Afghanistan, given that the geographic supply challenges that applied to the United States applied to all NATO partners. In fact, given the economies of scale that a force as large as the United State enjoys, it is plausible that Canadian operations were *even more* inefficient than the figures quoted in American studies.

Based on these estimated figures, the army clearly does not have a capability gap, in terms of being capable of shipping liquid fuels into theatres, and to the forward areas to supply and sustain operations: it has a massive dependency on fuel. Paying costs of delivery orders of magnitude more than the substance is worth is acceptable because of the reliance on fuel. Also, incurring10% of the total casualty load in support of this effort was deemed to be worth the price. The capability gap is not to do with the inability to deliver liquid fuel: it is the necessity of doing so. Given the effort that was dedicated to sustaining fuel, there is clearly no gap in the ability. Liquid fuel sustains virtually everything: all of the aircraft, the vehicles, and the generators in military installations that power the computers and radios and recharge the batteries. These systems are too vital to operations for the sustainment effort *not* to be a top priority. This is a gap in a negative sense, in that all efforts must be made to sustain liquid fuel operations.

The gap is effectively a constraint: every convoy or air transport mission that is dedicated to fuel represents a sortie of that transport asset that cannot be used for other missions. Fuel storage, vehicle marshalling areas, safety distances, and the infrastructure necessary to support fueling operations. Those other missions could include supply missions carrying other supplies like ammunition, rations or mission equipment via land convoy, or it could mean an additional helicopter that is not available for a transport mission or available for a casualty evacuation. Potential solutions to this gap are discussed in Section 5.7.

4.5 Maintenance for Complex Systems

The ability to anticipate preventative maintenance and predictive maintenance is predicated on the idea that doing corrective maintenance (i.e.: replacing parts after the break) is not the best approach, and that preventative and predictive maintenance extends the service life of equipment and allows for optimization of maintenance schedules [29]. Effective application of condition-based maintenance (CBM) requires active monitoring of components in each platform, to communicate the overall health of the system. This integration effort requires real-time or near-real time monitoring of systems, and the ability to extrapolate emerging maintenance requirements based on the readings generated by the system [29]. Figure 8 below shows the data architecture for CBM.

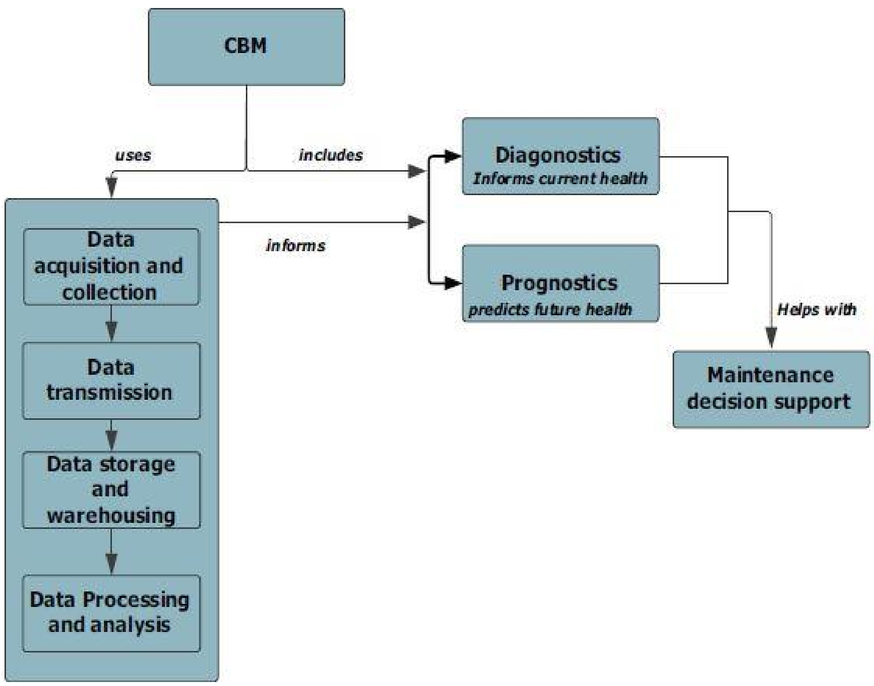


Figure 8: Condition-Based Maintenance - Data Architecture [29]

The left side of the diagram shows the data requirements for maintenance for complex systems. The data collection, analysis, storage and transmission capabilities are the backbone of this system. According to a DRDC report there is no automated equipment monitoring capability from which an optimized maintenance system could be built [29]. Currently, most maintenance is failure-based, in that parts are replaced after they break: preventative maintenance is possible, however, the time-based or usage-based tools necessary to calculate time or usage-based maintenance are inefficient and resource intensive [29]. There is currently no capability to monitor equipment states in a distributed environment [29], which is worrisome given the view of the future involves adaptive, distributed operations.

At present, the necessary groundwork – capturing data on equipment-life, analysing that data, transmitting that data to enable distributed monitoring – is not even present to begin building on existing capability for maintenance of complex systems. This shows a significant capability deficiency; however, it also means that no existing system needs to be displaced in order to introduce a new system. This will allow for much less constrained requirements development and system design. However, in the interim maintenance planning will be limited by inefficient time or usage-based models or continuing with a failure-based model.

4.6 Force Protection for Resupply

The most important figure to present for force protection for resupply is that 10% of casualties sustained in Iraq and Afghanistan by US forces were sustained as part of fuel and water convoy operations [28]. This is the result of using convoys of trucks to move hundreds of thousands of litres of fuel to forward areas to sustain operations. Convoys are complex undertakings, requiring days of planning and staff work, evaluation of the threat environment, weather, rehearsing actions of contact, actions on the objective, and alternate routes [30]. During these operations, dozens of vehicles – lightly armoured or unarmoured – move in an extended line, making them easy targets for deliberate ambushes, or targets of opportunity due to their relatively slow speed and deliberate movements.

In all military combat vehicle design there are three factors that must be balanced against each other: mobility, firepower, and armour protection, whereby additions in any of the three will necessarily come with drawbacks for the others [31]. For CSS vehicles, the focus is not on firepower as it is for combat vehicles. However, CSS vehicles need sufficient firepower for local defence and to ensure the safety of the crew. However, the primary purpose of CSS vehicles is not combat, limiting the number of weapons it should carry. This leaves concerns about mobility and armour protection. Large fuel or supply trucks require a significant amount of armour to protect the cargo, impacting mobility and total payload. Enhancing mobility will require reduced armour, and therefore restrictions on the kind and volume of cargo that can be carried safely. CSS vehicles, because of their purpose, are vulnerable to attack.

One method used by US forces in Afghanistan was to pay warlords and militants in order to refrain from attacking supply convoys. A US Congressional report, titled *Warlord Inc.: Extortion and Corruption across the US Supply Chain in Afghanistan* is not available on the internet; however, the contents of the report have been well detailed by the press. The report indicated that eight firms were paid a total of $2.16 billion in order to secure US supply routes (i.e.: protect them from IEDs and ambushes) through Afghanistan [32]. The allegation is that the payments to trucking companies are not for actual protection, but rather the means by which the trucking company paid off the Taliban to not attack US convoys [32]. These payments are well known to fund the Taliban's operations against US forces, and further exacerbate the issue of corruption and gangsterism in Afghanistan [33]. However, these methods raise a number of questions about ethics and sustainability. This was a reality in the Afghan theatre and may or may not be repeated in future theatres.

Currently, the most viable alternative to maintain force protection is to fly supplies to forward areas, rather than relying on roads. While this is costlier in terms of platform and fuel costs, it is less casualty-prone. Another method is to avoid the roads altogether and rely on fixed wing or rotary wing aircraft to deliver supplies. Other means of delivery are discussed in more detail in Section 5.

5. EMERGING TECHNOLOGIES

This section provides an examination of emerging technologies, and an overview of their suitability for future application. The contents of this section will provide the basis for analysis in Section 6, Discussion in Section 7, and the Conclusion and Recommendations in Section 8.

5.1 Containerization and Logistics Physical Internet

The concept of the 'physical internet' is to optimize the supply chain by making improvements to the way that material is transported and handled in order to reduce wasted energy that comes from the inefficiency of current supply chain approaches [34]. The digital internet allows for information in packets to be transmitted across the globe, using and open architecture regardless of what is being transmitted. The physical internet concept seeks to reproduce this concept, but for the physical transportation of goods. There is a role for containers in this physical internet concept, in that standardization of the containers allows for all calculations on shipping to be based on the maximum payload and volume of a single container. By using containers, a baseline will allow for a common unit of measure (i.e.: the container) for shipping. It is estimated that in the United States that – as an aggregate measure – only 60% of container payload is being used at any given time [34]. This is a major inefficiency that the physical internet concept seeks to address. Other concepts with CSS implications are the volume of packaging that is shipped, optimizing production and storage facilities, balancing the volume of supplies that are rarely used with those that often appear to be near shortage levels of stock, and transporting large volumes of good through urban centres [34]. The challenge of urban sustainment is a major concern, given the future concepts of operating in urban terrain, specifically the networked littoral. The concept of the physical internet remains largely a concept at this stage, however, challenges like efficiency and velocity of the supply chain are not exclusive to the physical internet concept. Other concepts, like the internet of things, mobile asset optimization, and others below can contribute to address the challenge posed by inefficiency.

Containerization is a concept familiar to civilian supply chains, where a standardized series of containers is used for shipping and can be transferred between ships, trains and trucks without being unpacked. Containers range in size from 8-foot to 53-foot containers, and all sizes are standardized as per the International Organization for Standardization (ISO) [35].

The United States is developing the Joint Modular Intermodal Distribution System (JMIDS) for CSS. It applies similar concepts to ISO containers, by standardizing and modularizing containers. The JMIDS consists of a series of standardized pallets and containers that can be individually packaged or linked together to form larger containers, and a standardized set of sensors on tags like a radio frequency identification (RFID) tag for each container that stores information about the cargo, its conditions, and the location of the cargo in the defence transportation network [36]. JMIDS is shown in Figure 9 below.

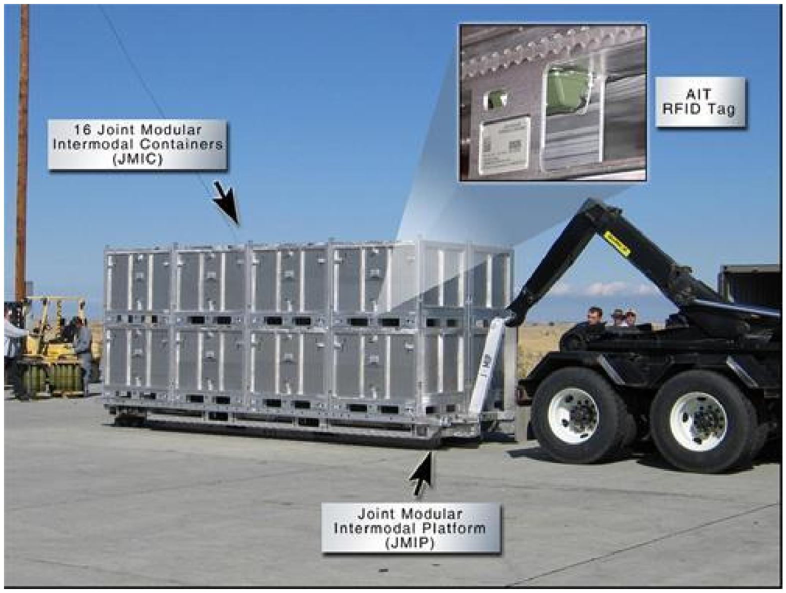


Figure 9: JMIDS Modular containers with RFID tags [37]

The core of the concept is to provide a standardized set of containers and tracking equipment allowing for compatibility with ships, aircraft, land vehicles, and cargo handling equipment. The JMIDS system has clear application for internet of things (below) for communicating its location in real-time, allowing both shipper and recipient to view where the cargo is located and when it is expected to arrive. This applies to any means of shipment (rail, ships, fixed wing aircraft, helicopter, land vehicle etc.).

The benefits of relying on a standardized container that originated in the civilian shipping world is that the containers can be moved using non-military means into theatre. Ocean-going ships transport hundreds of thousands of shipping containers every day using a proven approach, and militaries can contract the strategic lift of supplies to these experienced contractors. In more permissive environments where rail traffic is available, containers can be used the same as they are for civilian application. Once in theatre the containers can be repurposed as sleeping quarters, offices, storage facilities, workshops, or any other small buildings as required. This is particularly useful when establishing an installation in an austere environment with limited infrastructure, whether domestically or overseas. This concept was used heavily by the Canadian Army operating in Afghanistan during its operations there, using sea containers for sleeping quarters and as storage lockers. The use of containers does not need to be limited to Canadian Army installations. Providing temporary facilities for local partners, NGOs, etc., becomes possible if there is a surplus of shipping containers.

The potential drawback of the use of shipping containers is that as they are shipped to a theatre of operations, they will accumulate. Repurposing or recycling shipping containers provides options for building materials, however, over long-term operations it may become an operational necessity due to the accumulation of containers, not because there is an operational need. The other drawback of containers is that outsized cargo will not fit into containers. This does not preclude transporting outsized cargo by other means and is only meant to illustrate that containerization will not solve all cargo challenges.

5.2 Internet of Things

The Internet of Things (IoT) is the concept that physical things can be connected into a digital network by embedding each physical thing via digital telecommunications in order to allow the 'things' to communicate and collaborate with one another [15]. This technology relies on existing internet technologies and allows each thing to be an entity in the larger network. This has significant implications for tracking assets, and for monitoring their status. As discussed in Section 4.2 on the visibility of the supply chain, using the IoT approach could allow for assets to be tracked in real-time.

IoT as it applies to CSS and logistics, can be understood as an expansion of the model used by commercial shipping companies who rely on barcodes to track every stage of a package's journey. Technology currently allows for packages to be tracked from the point of shipment, through sortation, to point of delivery, and eventually to post offices if the receiver cannot sign for the package immediately [38]. Carriers like Canada Post, UPS, DHL, etc., allow customers to login to websites to track the last 'checkpoint' a package passed in its journey from shipper to receiver. The difference with the IoT over those technologies is the ability to track the item's location in real-time, and for the package to send and receive data about the route. The IoT concept replaces one-way periodic updates on a linear journey with real-time communication between the entity, the network, and other entities in the network.

From warehouse to the last-mile, using internet of things would allow asset visibility of everything that was embedded with a tag or fob device using RFID or near-field communications (NFC), or whatever technology is determined the most useful. The current emerging technologies are the use of embedded sensors and actuators that communicate automatically, RFID and bar code readers, NFC, S-beam, Bluetooth, guidance through GPS or Ultrasonic, and connectivity through Wi-Fi, W-iMax, and ZigBee [15]. This technology could be used for all material, whether replacement parts for armoured vehicle transmissions or a case of ammunition for a crew served weapon, the progress and estimated time of arrival could be tracked in real-time using IoT technology.

There are implications for CSS planning and operations beyond simply knowing where all assets are located, though that is important. When things are connected to a single network a huge amount of data is created and updated about location, speed, time of travel, time to arrival, etc. All of these data points can be integrated as part of a broader sense-making effort to enhance situational awareness about IoT enabled device. This can be extended to not just CSS operations, but to the broader operating environment by integrating ISR sensor data using the IoT concepts. This can provide greater situational awareness which can be developed and maintained through constant updates. This is vital for the ADO concept, where units are expected to be operating in a dynamic environment, far away from other units. By providing real time or near-real time updates to CSS units, changes in plans and operations can be made to accommodate for a changing situation. Updates on things like enemy activity, a roadway closed, heavy traffic in an urban area, power outage, or anything that could affect either roadways or airways for CSS can be communicated in real time using IoT technology.

Deloitte has developed an Information Loop [39] that shows the decision cycle for making a decision by acting, and how that decision is predicated on creating data, communicating that data, aggregating that data, analysing it to make sense of it, and then making decisions to act based on that data (Figure 10**)**. The Information Loop shows the sensors, networks, standard, augmented intelligence and augmented behaviour that add value at each stage of the loop. It is not sufficient to have all IoT enabled devices simply communicating into a central network; there needs to be the ability to contextualize that data in order for commanders to make the most informed decisions possible. This will be increasingly vital when conducting dispersed operations – particularly in the networked urban littoral – where the situation is dynamic with situations rapidly evolving. Computer assistance in this environment will reduce some of that complexity by presenting information in a useable format.

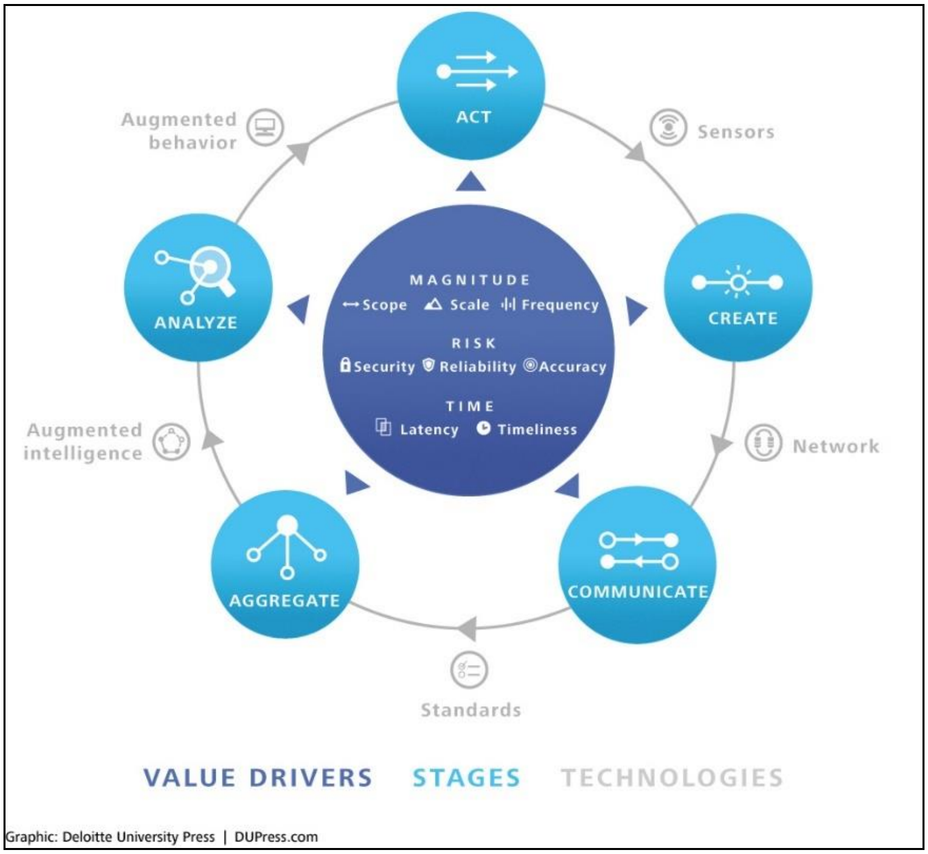


Figure 10: Deloitte Information Loop [39]

The challenges to successful implementation are in maintaining transmission, and in designing the network. As with any wireless digital technology, IoT-enabled devices are only effective so long as they maintain network connectivity. A growing degree of connectivity means more portals that can be potentially compromised by cyber attackers targeting the IoT specifically [40]. Those who may target the IoT via cyber attack are not limited to countries or peer-rivals anymore. Small countries are investing in cyber capabilities specifically because of the larger-than-proportional returns that can be achieved when comparing the effects that can be generated for rather modest investment [41]. There is the added benefit of very low risk to human life from the perspective of the attacker. Connectivity is essential to enable IoT enabled devices to send and receive information; without it the concept does not work. Cyber security of the IoT is necessary. The network also needs to be designed in such a way to enable maximum simplicity for users, ease of querying information and sufficient automation of data inputs to allow the system to work with as little operator interference as practical.

There are two significant challenges to realizing an IoT-enabled vision for the CAF. The first, as highlighted in section 4.2 is the current status of technology for maintaining total asset visibility (TAV) across the supply chain. An IoT solution could provide significant benefits to the CAF, in terms of visibility on assets and developing and maintaining shared situational awareness of supply and logistics; however, the current status of technology shows fragmented systems, little automation, and limited real-time capabilities. The current state is well behind what would be necessary to implement such a solution. The second challenge (related to the first) is developing requirements for what kind of assets and how many assets need to be integrated into an IoT solution, and any constraints or requirements presented by joint and allied interoperability requirements. This could include things like data formatting, the IT hardware backbone necessary to store and transmit information, and the necessary equipment in the field to support the implementation of such a solution.

Developing the requirements for a future IoT solution for the CAF will clarify the vision and scope for implementing a future solution. The requirements could include only large assets (vehicles, computers and IT materials, electronics, weapons), or alternatively, smaller assets like equipment carried by personnel, items in FOBs (fridges, generators, cabling, etc.) could be included. Deciding which assets will be included will inform the total number of assets integrated into an IoT solution, meaning there are implications of the scale of the solution based on the number of assets. Considerations will also need to be made for the global reach of such a system (i.e.: is this required for all operations?). Understanding the number of assets would provide the first step toward an order-of-magnitude estimate of the resources and effort required and provide an appreciation of how long and how costly developing and implementing a solution would be.

5.3 Mobile Asset Optimization

Mobile asset optimisation (MAO) relies on data patterns to increase the efficiency of supply chain operations. IBM and Vodaphone are marketing a system that relies on IoT technology to manage data, which integrates with advanced analytics to provide predictive insights [42]. MOA will allow for any traceable asset – whether a container or pallet or individual asset – to be tracked, with its arrival time predicted, accounting for weather and other delays that can be built into the data model [42]. This technology directly addresses the gaps highlighted in Section 4.2 about the limited asset visibility that currently exists for CSS in the Canadian Army, meaning there is direct relevance for MAO to address current gaps.

Private sector companies championing the technology are promising reduced maintenance costs by up to 30%, up to 40% increase in the amount of use each asset can deliver to the organization and reduce the amount of inventory stored due to increased visibility on where assets are in the supply chain [42]. These estimates should be approached cautiously because they are calculated based on societies at peace where security and the rule of law are assumed. The MAO technology will likely provide improved efficiency for military operations, however the exact figures on improvement efficiency and reduced maintenance are likely to be lower, given the complexity and rigours of military operations; particularly future dispersed operations in the networked urban littoral.

To fully harness MAO technology, some have said that asset visibility is not sufficient to be counted as success. Asset visibility is not for its own sake, but to forecast and plan delivery times of supply, maintenance, and other sustainment activities: planning visibility should be the goal of any future MAO system [43]. To realize this vision clear requirements for reserve stocks and thresholds should be established, changes to allocation in real-time need to be enabled, multiple scenarios need to be compared using modeling and simulation techniques, channels and routes need to be defined, and overall targets for the optimization of procurement of supply and timelines for delivery [43] need to be established. All of this requires a clear definition of requirements, and validation of clear performance parameters. Some vendors are broadening the use of asset optimization technology to include more than just assets used in active theatres, but are including the tracking of documents, monitoring rental housing on domestic bases, tracking for sensitive documents, and integrating contractor-based delivery in the model [44]. Tracking these items will likely improve the efficiency and traceability of movements and should be explored further.

The implications of this technology could be significant for optimization of the supply chain. Implementation will be challenged by the same vulnerabilities as other network-enabled technologies; maintaining connectivity to a larger networked database and ensuring cyber security to protect the confidentiality of data and the integrity of the network.

5.4 Systems for Supply and Distribution

This section will provide an evaluation of where emerging and in-service technologies provide opportunities for supply and distribution for the AoT. The different types of technology include airships for supply and distribution, UAS for bulk distribution, smaller platforms for last-mile logistics, unmanned ground systems (UGS) for distribution, and automated and autonomous systems for material handling. A summary of how emerging technologies can be applied across the full logistics supply chain is shown below in Figure 11.

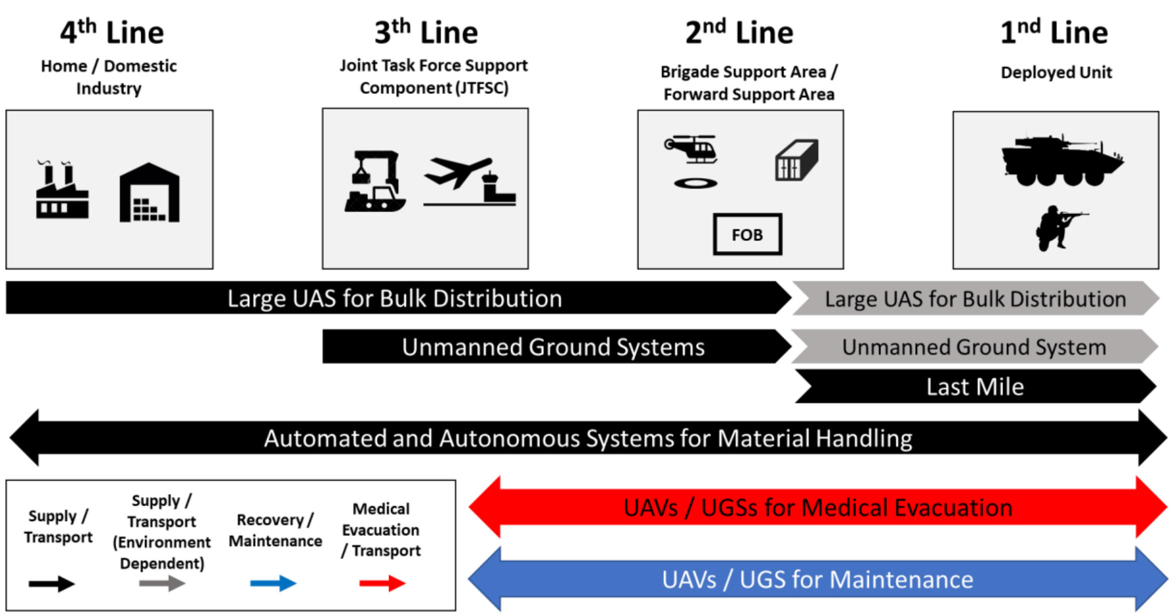


Figure 11: Overview of the Potential Application of Technologies for Supply and Distribution

5.4.1 Airships

Airships are not a new concept for the transportation of bulk goods and passengers. The most famous airship is probably the Hindenburg, a German airship that was filled with hydrogen and caught fire in a 1937 collision with its mooring tower. The German airships were filled with hydrogen because the United States refused to sell the Germans the helium gas they required because it was considered a war resource; one which American airships of the day were already using [45]. The airships currently in service carry a maximum of 23 tonnes (the Lockheed Martin LMH-1 [46]), though concepts exist for larger airships like Lockheed Martin's future plans of a 500-tonne capable airship [47], and the Aeros ML 86X, also claiming a target maximum payload of 500 tons [51].

Figure 12:Lockheed Martin LHM-1 Hybrid Airship [48]

Figure 13: Airlander 10 Hybrid Airship [49]

Figure 14: Aero ML86X Hybrid Airship (concept) [50]

The biggest advantage that airships provide over fixed wing aircraft for bulk delivery is that they do not require prepared airfields, roads or helipads to land, and they require relatively limited facilities at a landing site to unload them [51]. The benefit to an airfield, however is not that the airship requires it, but that the significant space provided could allow multiple airships to land simultaneously or in rapid succession. Compared to an airfield that allows for one aircraft at time to take off or land, the apron around an airfield has the potential to enable many airships to land in a short time frame, potentially allowing more cargo to be landed than using fixed wing aircraft (depending on the load the airship can carry) during a given time window.

An additional benefit of airships requiring relatively limited airfield facilities is that airships can deliver supplies to forward support areas (FSA). If an FSA has a large enough helicopter landing zone (HLZ), or a wide-open area, airships can potentially be landed. If operating in an adaptive, dispersed environment, where the FSA may be mobile to follow deployed units, airships will be capable of providing CSS anywhere there is a sufficiently sizeable space to land and off-load cargo.

The survivability and size of airships is a key challenge for providing CSS directly to units in expeditionary operations, and specifically those in the networked urban littoral. The Airlander 10, produced by Hybrid Air Vehicles is capable of carrying 10 tonnes of cargo and measures 92m long [51], and is capable of a semi-vertical take-off, with the company claiming the vehicle is capable of taking off in the space 1.5 times its length, or roughly 150m [46]. Lockheed Martin manufactures a similar airship called the LMH-1, capable of carrying 23 tonnes, and like the Airlander 10 claims the airship needs 150m of space for a vertical takeoff [52]. These airships would present a large target to an adversary, and given their relative slowness transitioning from landing to flight, an attacker would have ample opportunity to target an airship. Combined with the need for a 150m circle in which to execute a take-off or landing, airships will not be suitable for direct delivery to units deployed in an urban or contested environment. For these operations, an FSA is the closest to deployed units that airships should deliver supplies. For landing at BSAs or prepared airfields, airships are a suitable option.

Airships may be capable of delivering supplies to forward units in domestic or uncontested environments, provided there is sufficient space available for take-off and landing. They can also be used to evacuate casualties or remove equipment in need of recovery or maintenance, provided the casualties are sufficiently stable to travel and the weight of recovery equipment is within the parameters of the airship. The possible domestics operations outlined in *Canada's Future Army* [13] include sovereignty patrols (including the arctic), border patrols, support to other government departments (OGDs), and aid to the civil power. It is reasonable to expect that some of those army operations – the arctic especially – will be away from populated centres and from airfield infrastructure and may not be connected by roads. A mining company in Canada signed a memorandum of understanding with a private sector aviation operator to provide a fleet of seven airships to its proposed mine facility at Strange Lake in Northern Quebec, to carry up to 20 tonnes of ore, 19 passengers, and/or other cargo [53]. The mining company did so specifically because it was more cost-effective than building and maintaining a road from its railhead to the site of the mine. Similarly, austere environments with limited airfield or road networks could be presented by humanitarian relief operations abroad, especially after a natural disaster like a hurricane or earthquake. The CAF has previously supported humanitarian operations of this kind, most recently for Hurricane Irma in Puerto Rico [54] in 2017, and after an earthquake in Nepal in 2015 [55]. *Canada's Future Army* [13] envisions humanitarian relief operations overseas, and airships could provide the appropriate means to deliver relief supplies to army units deployed under austere circumstances, in which there is no major threat to the airship being attacked. The ability of any airship to land without local infrastructure is an added benefit for humanitarian operations, where airfields and roadway infrastructure could be damaged or destroyed.

In terms of fuel efficiency, airships are expected to consume as little as one tenth the fuel of rotary wing or fixed wing platforms carrying comparable payloads [51]. This has two significant benefits for logistics and CSS planning. Firstly, it means that deliveries will be much more cost effective in terms of the amount of fuel required to move supplies either to the BSA or from BSA to FSA. Secondly, it means that less fuel will be required for stockpiles at BSAs to refuel airships, meaning that less fuel needs to be shipped into the theatre of operations. Reducing the rate of fuel consumed will reduce the cost operations and can reduce the overall infrastructure footprint of fuel storage required.

The current payload of the LMH-1 is 23 tonnes, comparable to the 24 tonnes that the CC-130J tactical airlifter can carry [56]. The CC-130 has been the backbone of the RCAF's tactical airlift since the original airplane was procured in 1960 and has flown thousands of missions to support Canadian force whether deployed domestically or internationally. The airships provide a comparable loading; however, they have a cruise speed of roughly 80kts [51] compared to the cruising speed of the CC-130J of roughly 350kts [56]. This means that despite carrying roughly the same payload, the airships will take almost four times as long to deliver cargo, whether to a BSA or FSA. The AoT and allied logistics documents all mention the need for a rapid, responsive, or “higher velocity” supply chain. The airships, as proposed, are not capable of providing delivery as timely as fixed wing aircraft. However, for bulk supply of items that are constantly consumed throughout operations, where stockpiles exist at BSAs and FSA, – fuel, rations, batteries, ammunition, etc. – the timeliness of a single supply run may be less important than maintaining a constant rate of resupply (i.e.: regular flights of airships). For less timely requirements, airships may provide a viable and cost-effective alternative to using fixed wing aircraft.

There are some technologies that remain purely in the conceptual stage, today. The Aeros ML 86X, claims a target maximum payload of 500 tons [51], though this concept is still a drawing. Another company’s concepts include the SkyLugger, claiming a 30-ton payload, and the Sky Lifter claims a payload of 150 tons [57], however there is no evidence available in the public domain that these technologies have progressed beyond the drawing board. Though the idea of replacing or supplementing the use of sea-going vessels and strategic airlifters with high-payload airships is interesting and could be highly valuable, until there is something beyond a concept these technologies are impossible to evaluate. The current Canadian strategic airlifters – the CC-177 Globemaster III, and the CC-160 Polaris – are capable of carrying 80 tonnes [58], and 35 tonnes [59] respectively, and have proven more than adequate to sustain the army of today. As high-payload technologies mature they should be considered for supplementing strategic airlift; however, until then they remain only concepts. The applicability of 20-tonne airships that are currently flying should be examined in much more detail.

5.4.2 Large UAS for Bulk Distribution

Large UAS provide the opportunity to automate or semi-automate the delivery of bulk supplies into theatre and between bases in theatre. They may also be capable of doing last-mile deliveries, depending on the size and sophistication of the system, and the permissibility or threats in the operating environment.

There are effectively three types of technologies in service and that are emerging that can be characterized as large UAS for bulk distribution: helicopters whether manned or unmanned and precision air drop systems – most notably the joint precision air drop system (JPADS) that has seen operational service in Afghanistan. Each of these systems provides a very different capability for CSS, with different strengths and limitations.

Hybrid / unmanned systems

Helicopters are versatile platforms and have been vital in providing bulk cargo transfer to FSAs and FOBs since the Vietnam War. In 2008 the Independent Panel on Canada’s Role in Afghanistan chaired by former Federal Minister John Manley recommended that Canada continue its mission in Afghanistan, and that medium-lift helicopters should be procured to improve Canadian mobility in the region, and to rely less on road-based convoys for resupply [60], and thereby reduce the risk to crews doing delivery. New hybrid unmanned systems are making further steps to reduce potential casualties by removing the human pilot altogether. The hybrid unmanned systems are either after-market conversions of platforms originally designed to have a human pilot on-board, or systems designed to fulfill both flying and driving tasks.

The most notable example of an after-market conversion is the Lockheed Martin K-MAX used by the US Marine Corps in Afghanistan. The Marines started using a manned version of the K-MAX, and eventually trialed and fielded three examples of the unmanned variant for three years in the operational theatre of Afghanistan. Capable of carrying 6,000lbs per load, the K-MAX was operationally capable of making five trips in one day, for a total of 30,000lbs delivered to FOBs, all without a pilot [61] in the aircraft. There is still a mission commander responsible for the deliveries, though not in the vehicle. The unmanned K-MAX has GPS and inertial navigation to establish its location, and its waypoints are programmed from a ground station, with line of sight (LOS) and beyond line of sight (BLOS) ability to dynamically re-task the aircraft while in flight [62]. Using this technology there was only one reported crash, and it occurred due to the swinging of the load under the aircraft during heavy tailwinds that were contrary to what the mission computer was expecting [63]. The mission commander could not recover the aircraft, and it crashed, destroying both the aircraft and the load [63].

Figure 15: K-MAX in unmanned configuration lifting load [64]

A corollary program to the K-MAX program is the use of the Squad Mission Support System (SMSS) unmanned ground vehicle that is dropped by the K-MAX. In collaboration with the US Army's Tank Automotive Research, Development and Engineering Centre, the SMSS is a multi-sensor, autonomous or remote-controlled six-wheeled platform that is dropped by the K-MAX to test remote location for threats, including chemical, biological, radiological, nuclear or explosive (CBRNE) threats [65]. The CSS applications of the SMSS are discussed in more detail below in Section 5.4.7

First, Using CBRNE detectors the SMSS system could be useful reconnaissance for a potential future FSA or supply depot, with the SMSS confirming that there is no CBRNE threat in the proposed location. Second, the SMSS is capable of carrying roughly 1,000 lbs, including water, batteries, ammunition and supplies, and can traverse a number of obstacles that would be expected in the operating environment. The onboard sensor suite allows the vehicle to follow a route while avoiding obstacles. In a situation where airspace was contested and the K-MAX could not land, the SMSS could be dropped, and programmed to bring a bulk load to its destination, providing a hybrid air/land solution for bulk delivery. The SMSS payload of 1,000lbs is far less than the 5,000lbs the K-MAX can air-drop, however in a non-permissive environment this is a potential solution. The SMSS is discussed in more detail in the unmanned ground system section of this document.

The Marines sought to expand the K-MAX concept through the Office of Naval Research, through a program called the Autonomous Aerial Cargo Utility System (AACUS). AACUS will retrofit any new unmanned rotary wing system, or legacy manned helicopter to fly resupply missions without a pilot. The supply requirements and general landing area will be selected by an operator in the field, without any special training, using a tablet like device [66]. The helicopter will select the final approach and choose the specific landing spot autonomously relying on sensors and advanced computing, as close to the designated landing spot as possible, based on terrain [67]. The helicopter will then drop its cargo and return to base autonomously. Aurora Flight Sciences is the company that developed the architecture to AACUS and uses modular and open standards that can apply to any helicopter. So far, the Boeing AH-6 Little Bird, the UH-1H Huey, and Bell 206 have been successfully tested [68].

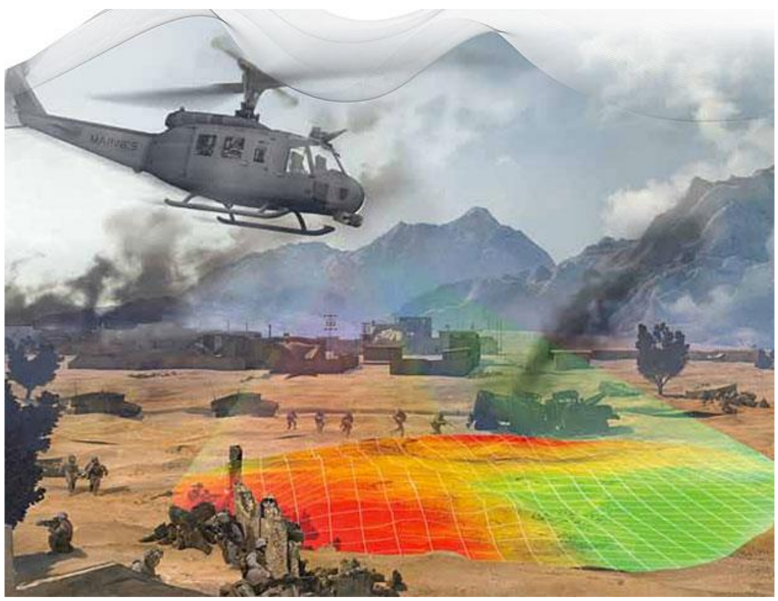


Figure 16: AACUS identifying optimal landing zone, simulating terrain sensors [69]

Sikorsky has a similar project called the optionally piloted Black Hawk (OPBH), as part of the US Army's manned / unmanned resupply aerial lifter (MURAL) program [70]. MURAL uses an existing helicopter – in this case a UH-60 Blackhawk – that is retrofitted to allow for missions to be delivered with only one human pilot on board compared to the usual two. This will reduce the overall crew requirements for UH-60, reducing the potential for crew casualties and allowing for a human pilot to scan for threats and re-take control from the autonomous system if required. Though the MURAL Program does not eliminate the need for humans, the UH-60 does carry a larger payload than any of the other autonomous or semi-autonomous systems, capable of carrying a maximum payload of 9,000lbs [71]. Though this is larger than any of the AACUS platforms, the MURAL platform is not yet fully unmanned, and still requires a single pilot. This enables MURAL to be used in higher-threat environment than the autonomous / unmanned systems, as a human pilot can respond to threats and land faster under emergency situations.

Figure 17: OPBH being controlled by ground crew [72]

For all retrofitted / hybrid helicopters there are two important factors for the delivery of bulk cargo: the maximum payload, and the automated landing zone selection. First, the cargo capacity of the platform is not changed by the implementation of AACUS or MURAL. The AH-6 for example was designed as a light attack and reconnaissance helicopter, and is capable of carrying a maximum of 1,400lbs in the unmanned configuration [73]. The UH-1 was designed as a cargo and transport helicopter, and a maximum of 4,800lbs of load [74], and the UH-60 for 8,000lbs [71]. To contrast this with the existing RCAF bulk cargo capability, the CH-47F has a maximum load of 24,000lbs [75]. The reduced risk to pilots and aircrews is a significant advantage of the AACUS system over manned aircraft, however the payload capacity of manned platforms is still far greater, meaning more AACUS flights are needed to meet the same level of delivery of bulk cargo. There is currently no evidence of the AACUS system being trialed or evaluated for the CH-47. If this were to happen, concerns about load would be eliminated. MURAL still requires three flights to match the capabilities of the CH-47, and still retains a crew of at least one pilot. While this reduces overall crew-risk compared to a fully staffed CH-47, the MURAL is not autonomous.

The concern with unmanned platforms is the ability of the navigation systems in autonomous systems. According to the information from manufacturers, these autonomous systems are concerned primarily with flying a route safely and selecting the appropriate landing zone irrespective of adversary activity or incoming fire. The system that is used tracks the route of flight and uses advanced sensors when scanning the ground to find the optimal landing zone. During this time the aircraft is moving slowly, close to the ground, scanning for a suitable landing zone. The current trials of the system show AACUS enabled helicopters scanning wide open areas using advanced terrain sensors in a rural or lightly built up area. The vision of the AoT and the networked urban littoral will provide highly complex urban terrain, with many different buildings, angles, and obstacles. The AACUS system test and evaluation footage available so far does not indicate that AACUS is capable of performing an autonomous landing in complex urban terrain.

Additionally, the time necessary for the AACUS system to select a landing zone provides a more attractive target than a helicopter piloted by a human that moves faster and more decisively toward the landing zone. For this reason, the AACUS is likely to be an attractive target for an adversary targeting resupply, given the relatively slow and deliberate process of landing compared to that of human pilots. MURAL allows for autonomous flight but retains a pilot that is capable of retaking control of the aircraft. In this situation, the MURAL system could be used in higher-threat environments, however the UH-60 would benefit even more from a second pilot and a flight engineer and door gunners in those circumstances to defend the airframe, negating the value of MURAL altogether. For transport of bulk cargo, retrofitted helicopters provide a viable alternative for non-urban and permissive environments. The current technology is not yet viable for urban environments or higher-threat environments, and under those circumstances a human crew is currently preferable to the experimental technology.

Hybrid systems intended as helicopter and land vehicle hybrids are an interesting development. The Black Knight Transformer is an unmanned hybrid between a helicopter and truck. Capable of driving up to 110km/h on the ground, it also has eight rotors that allow it to fly like a helicopter at an altitude of up to 10,000ft [76], and capable of carrying a payload of 1,000lbs if equipped to drive, and up to 1,500lbs if only equipped to fly [51]. Similar to the SMSS, this platform has potential delivery applications when airspace is contested, and areas can only be accessed by road. The Black Knight Transformer could fly as long as airspace is permissible, and then switch to land mode and drive the rest of the way to its destination. Given the relatively small payload for a vehicle that is 25 feet long [76], this system is not optimal for bulk delivery, and would be better used for medical evacuation.

Figure 18: Black Knight Transformer [76]

In terms of systems that are currently at the conceptual level and not in production, Lockheed Martin is also developing a purpose built autonomous systems concept called the Aerial Reconfigurable Embedded System (ARES) concept, in collaboration with DARPA in the United States. This concept has a tilt wing vertical take-off and land (VTOL) with two fan engines as the baseline flight module, with custom mission payloads attached to it. The baseline flight module is self-contained, and includes the engines, avionics, fuel, and command-and-control system. The missing payloads include cargo boxes, medical evacuation or delivery modules, small vehicles attached to the flight module, ISR platforms for information and data collection [77]. The fan engines allow for a smaller landing zone than helicopters carrying similar payloads [77]. Though still a concept, the maximum estimated payload will be up to 3,000lbs [78]. Interface for the ARES is similar to the one described for the AACUS: an operator on the ground uses a tablet to call for support, and the ARES will then identify its landing zone and drop its cargo without any intervention from the operator. The concept includes all operating environments, including off of the back of ships, in deserts, woodland terrain, and the urban operating environment. According to DARPA, as of 2014 the ARES system was in the third and final phase of testing for the flight module, which is the core of this technology [79].

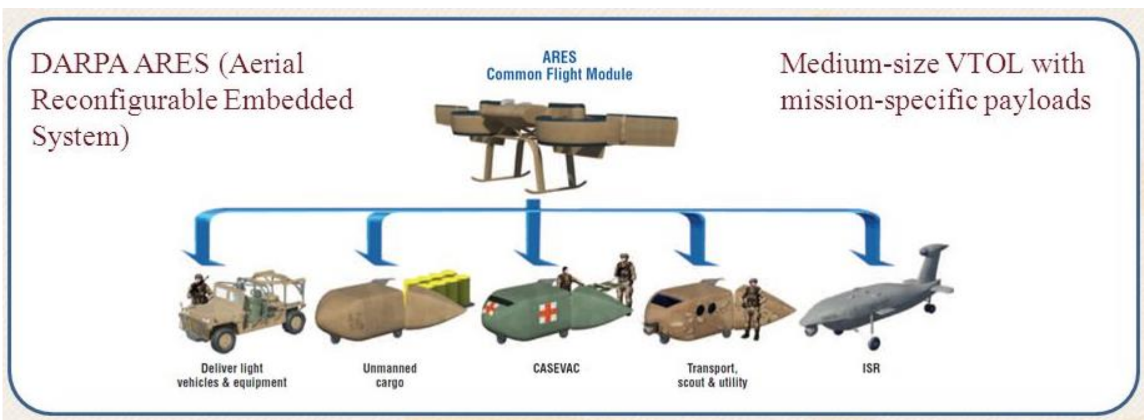


Figure 19: ARES concept, with mission-specific payloads [80]

The advantages of the ARES project over existing retro-fitted autonomous and semi-autonomous systems are the integral and custom load containerization and the reduced landing footprint. The ARES system consists of a flight module with custom payloads fitted as required. Though the overall payload weight of 3,000 lbs is less than the 5,000lbs the K-MAX carries [61], the K-MAX is dropping slung loads attached by a hook that must then be unpackaged. The ARES containerization allows for box cargo, or ready-to-use vehicles to be dropped. This means that the ARES can do some bulk cargo delivery – albeit with less weight than the K-MAX – however it may also be capable of last-mile logistics if the environment is sufficiently permissive. The other advantage of the ARES over the K-MAX or similar helicopter-based systems is the smaller landing space anticipated for the ARES [77], allowing more versatility in the networked urban littoral, or in thick vegetation or rocky, mountainous terrain. A smaller footprint for landing provides greater versatility in terms of potential landing zones, expanding the range of options for dropping bulk cargo, and for HLZs to directly support 1st line units.

Joint Precision Airdrop System (JPADS)

The Joint Precision Airdrop System (JPADS) is a satellite guided palletized-load parachute system that allows for bundles of 2,000lbs or 10,000lbs of bulk cargo to be dropped as close as 8km and as far as 25km from the intended drop point, from a maximum altitude of 24,500ft [81]. The JPADS bundles can be dropped from any military aircraft with a rear ramp and has a claimed accuracy of better than 150m from the intended drop point [81]. The JPADS allows the aircraft to avoid air defences or hostile air space by maintaining a 25km standoff range, allowing the aircraft to fly high enough to avoid most air defence guns and small missiles, while enhancing the precision of the drop well beyond what can be achieved flying at the lowest safe altitude. With a 24,500ft maximum altitude for JPADS drops, the aircraft can also likely avoid auditory detection, allowing for silent night-time resupply. Additionally, in cases where there is bad weather or poor visibility close to the surface of the ground that would prevent visual confirmation of the drop zone, JPADS will be capable of finding the target where traditional free-fall drops would not. Future development of JPADS includes the JPADS-30k capable of dropping 30,000lbs, the JPADS-60k capable of dropping 60,000lbs, with a maximum drop altitude of 35,000ft [82] which would be expected to extend the current maximum glide distance of 25km to a longer range.

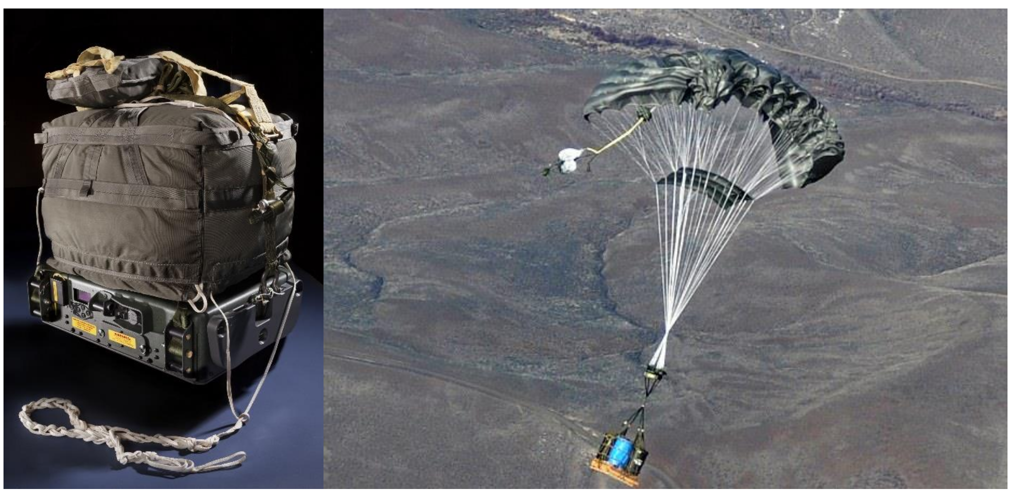


Figure 20: JPADS, without load (left) [83] and falling to target (right) [84]

JPADS is a significant improvement over traditional free-fall parachute drops, due largely to the accuracy of the system. The smallest possible drop zone allowed by the US Army for dropping heavy equipment without JPADS (i.e.: free fall drop) is 915m long and 550m wide and dropping equipment into a drop zone that small requires the aircraft to fly at 1,100ft (335m) [85] making it vulnerable to ground fire. To fly the aircraft at a higher altitude, requires a larger drop zone to ensure that equipment lands inside the target area. Traditional free-fall drops require the aircrew to time the drop of the cargo based on the expected glide path of the cargo given a specific payload weight and type of parachute. Once the cargo leaves the aircraft it is at the mercy of gravity, wind and weather. The JPADS can steer and flare in order to land at a specific location and guides itself to the target throughout flight. This gives significant versatility in planning air operations, compared to free fall operations, and provides greater certainty as to where the drop will land. This provides greater versatility for resupplying FSAs in the networked, urban littoral, and for distributed operations where multiple units require precision resupply. The JPADS can be dropped by virtually any aircraft that can carry the load (C-17, C-130, etc.), meaning that units hundreds of kilometers away can be resupplied by the same flight.

For maximum flexibility, the designated target(s) can be changed in the back of the aircraft right up until the moment of drop, based on updated information from the ground force about a change in the drop point, or changes in weather identified by the aircraft that could impact the flight path of the cargo [86]. Using a laptop computer, the flight crew delivering the JPADS can customize the delivery of each unit, allowing for multiple units to be resupplied in a single sortie. This system has been used in Afghanistan from a C-17 Globemaster, dropping seven pallets in a single mission [87], and is fully compatible with the C-130. This system has also been evaluated for use aboard the CH-53 helicopter [88] by a Marine Corps Operational Test and Evaluation Squadron to determine if the JPADS is viable for helicopter drop. The test was successful, with the JPADS exiting the aircraft and reaching target without incident.

Figure 21: Aircrew member programming JPADS in-flight [89]

This technology has proven sufficiently mature that there are after-market modifications being made for different delivery options. Capewell aerial systems has developed a system that will allow a CH-47 Chinook to deliver as many as 8 JPADS bundles slung externally, with the aircraft maintaining flight and flying above the range of most air threats [90]. The challenge of this application model, compared to those where the JPADS are carried internally, is that once the drop coordinated are programmed into the JPADS they cannot be manually changed because an operator will not be able to safely reach the load. This means that the JPADS should only be used in the underslung configuration if the drop zone will not be subject to change from the time of take-off to the time of air-drop; something that is not always possible in higher risk or highly dynamic environments.

A potential vulnerability of this technology is its reliance on GPS guidance as the means of delivery for the JPADS. Unlike the autonomous and semi-autonomous hybrid systems mentioned above (helicopters) that use terrain detecting sensors and GPS to help navigate, the JPADS relies on GPS and has no optical or terrain sensors. This makes the JPADS reliant on GPS satellites for navigation. Commercially available jammers are on the market today that are relatively cheap and available. Some are small, plug into a cigarette lighter, and block out GPS signals within a range of 5 meters, and retail on eBay for about $45USD [91]. Others are larger and have impacted civil aviation by blocking the GPS signals that passenger planes use to assist with landing. This was the case in Newark, New Jersey in 2013 when a person in a company vehicle tried to hide his location from their employer using a GPS jammer, and was fined because the device was blocking the GPS signals necessary to operate the ground-based augmentation system (GBAS) for air traffic control [92]. These systems emit a local signal, operating close to the ground. In this case, commercially-available GPS jammers would disrupt only the final descent of a JPADS. This would not affect the stand-off range from target of the aircraft dropped the JPADS, however the stated accuracy of 150m would be likely be impacted during the final part of the flight.

Larger systems that require significant military systems have been developed and fielded by North Korea. North Korea has been accused of jamming GPS signals near its border with South Korea in the past on hundreds of occasions, interrupting the navigation of commercial aviation and commercial fishing vessels [93]. Reportedly capable of a jamming range of thirty to sixty miles, the suspicion is that North Korea wants the capability to interfere with precision guided munitions that rely on GPS signal for guidance, to limit the accuracy of American and South Korean weapons in the case of a war [93]. This has prompted some experimentation from the American military to develop new systems. This kind of jamming system clearly has the potential to jam JPADS even when still inside the aircraft dropping them, rendering the vital navigation system useless. Effective GPS jamming up to the JPADS maximum operating altitude of 24,500ft. would effectively render the JPADS the same as a conventional parachute supply drop.

The US Air Force is sensitive to the potential of GPS jamming in future conflict zones, and has been taking steps to develop new position, navigation and time (PNT) systems to supplement GPS. The US Air Force intentionally blocked out GPS signal over an area for 500 miles around White Sands, New Mexico in 2016 in order to test the military's ability to operate in a GPS-denied environment [91]. The purpose was to test the new Ultra High-Accuracy Reference System (UHARS) used for positioning, navigation and time (PNT) in a GPS-denied environment. The test was successful, showing that the UHARS system is capable of providing sub-metre precision PNT when GPS is being jammed, declaring Initial Operating Capability (IOT) for this system [94]. While the jamming technology appears promising, counter-GPS jamming counter-measures will be necessary in order for these systems to operate effectively.

A potential complication for the fielding of JPADS is dealing with the accumulation of parts of the JPADS kits in FSAs after the package is delivered. The JPADS includes either a 1,025 or 3,500 square foot parafoil, a GPS unit including the battery, guidance, navigation and control system (GN&C) software package, and the hardware required to steer the JPADS to target [95]. Over the course of a deployment or operation an FSA will require many of those drops – depending on the supply intensity of the mission – and these parts will start accumulating. This equipment, once dropped, will stay in the FSA without a clear purpose. If the batteries in the JPADS still have power in them, they could be used for the remaining life of their charge in the FSA or FOB. However useful this may be, there will still be an accumulation of guidance hardware and parachutes in the FSA or FOB as a result of JPADS drops. This creates a salvage logistical issue, either for reuse or recycling.

5.4.3 Small and Medium Autonomous helicopters

The Northrop Grumman MQ-8 Fire Scout is a variant of unmanned helicopter originally designed for reconnaissance and light attack. There is a “B” variant based on the Sikorsky S-43 light utility helicopter and a “C” variant, the latter based on the Bell 407 utility helicopter, both initially designed as manned platforms. Both are currently in service with the US Navy; the B variant flew more than 6,200 sorties in Afghanistan, primarily in the counter-IED role [96], and the C variant is being tested by the US Navy to extend the range of fires and reconnaissance from the ship [97]. The B variant can carry a load of a maximum of 300lbs with no sling load [98], and the C variant can carry 500lbs internally and a maximum of 2,650lbs in a sling load [99]. Both of these helicopters were developed in their unmanned capacity to fill reconnaissance and light attack roles, however could also be used for resupply and utility tasks based on their initial designs. The constraints for landing zones using unmanned helicopters in non-permissive and urban littoral environments are the same as for operating manned helicopters. The Fire Scout platforms are not optimal for the resupply role, given their maximum payload. The B variant cannot carry a sling load, and the C variant carries a sling load half of the volume of the K-MAX, and roughly the same as the smaller available JPADS. While these platforms are capable of doing resupply to 1st line units, they carry less payload than other platforms capable of providing similar support.

Figure 22: MQ-8B Fire Scout [100]

Figure 23: MQ-8C Fire Scout [101

The MMIST *Snowgoose* is an innovative vehicle, relying on a parachute foil as its wing and a rear-mounted "pusher" propeller to give it propulsion. The *Snowgoose* is capable of carrying 575lbs of cargo in six individual cargo bays, flying autonomously from the point of take off to its landing [102]. During testing, the *Snowgoose* was capable of dropping other free-fall packages from its cargo bays, though this has not figured prominently in the manufacturer's material. The main drawback of the *Snowgoose* is the method by which it takes off. The current approach involves the *Snowgoose* being placed in the back of a vehicle or trailer behind a vehicle, which then accelerates to a sufficient speed for the parachute foil to generate enough lift to bring the *Snowgoose* airborne [103]. The vehicle is then powered by its pusher engine until it reaches its landing zone. However, once it lands to drop its cargo, the current version is still reliant on a vehicle to assist it with taking off again. This requires sufficient straight road for the vehicle to accelerate fast enough to allow the *Snowgoose* to take off. That requirement for space makes a traditional helicopter or JPADS a more viable way to bring in cargo. In a non-permissive environment, or in a complex urban environment, it is not reasonable to have a vehicle drive down a straight road to assist the *Snowgoose* in getting airborne. A newer iteration of the *Snowgoose* is under development, and is using a gyro-copter design, capable of taking off and landing vertically without assistance [104]. This is essential for the *Snowgoose* to be viable. This gyrocopter model is a much more viable option because it does not require the supported unit to assist the platform in leaving after delivery supplies.

Figure 24: MMIST Snowgoose, shown during take-off from a moving truck [102]

The US Army Research Laboratory has been working on the Joint Tactical Aerial Resupply Vehicle (JTARV), also referred to as the “hoverbike”, that is a quad-copter design. Unlike the commercial delivery quad-copter type devices that usually carry a load of roughly 5lbs, the JTARV is capable of carrying 300lbs for short-range resupply [105]. Future development concepts include expanding the operating range from nap-of-the-earth to thousands of feet, at speeds up to 100km/h [105]. Another concept includes adding payload capacity to a maximum of 800lbs [51]. The JTARV is a purpose-built design that carries payload on top or slung under the body of the aircraft. Its relatively small size and footprint, compared to the Fire Scout and *Snowgoose* with the aerofoil, means it can land in the tight terrain expected of the networked urban littoral. The JTARV will be flown autonomously only and will not require any joystick input from operators [106]. The relatively small size of the JTARV compared to the Fire Scout or *Snowgoose* also presents a much smaller target to adversaries. The main draw-back of the JTARV – in its current iteration – is the relatively small payload it carries. If the 800lb target weight for the next iteration of the JTARV is realized, this will be a potentially highly valuable technology for delivery.

Figure 25: Joint Tactical Aerial Resupply Vehicle (JTARV) [107]

The Chinese-manufactured Ehang 184 is a rotary drone platform that is approaching the point of marketability. The Ehang 184 is electrically powered and has a range of 50km on full charge, and a top speed on 160km/h, and capable of carrying 100kg. Its purpose is as a flying taxi for one person and is being reviewed by the Dubai Civil Aviation Authority for possible implementation in Dubai [108]. The system will generally be limited to 100km/h in urban centres and will take 1 hour to re-charge [109]. The design includes a passenger compartment and is powered by 8 rotors attached to 4 that control the device while flying. The passenger does not fly the drone, but rather indicates their destination on a control screen, using a similar interface to the one used by Uber to indicate pick-up and drop-off point. The drone was designed to fly people around cities with tall buildings and complex urban terrain. The flight control systems have multiple back-ups to allow the system to recovery from rotor failure and can safely land in the case of emergency. The flight control and route management system was designed for an urban operating environment, making this design very interesting for short flights in the urban littoral. Its footprint is roughly 4m by 4m [109], meaning small drop zones will accommodate the Ehang 184. It's relatively short range limits the application for widely dispersed operations and would require landing and recharging in order to make a round trip. This is a mature technology, compared to others above that are still in the experimentation phase. The payload is sufficient for delivery of supplies to 1st line units, though is still less than the JTARV, *Snowgoose* or both Fire Scout variants.

Figure 26: Ehang 184, with person inside [110]

The Flyt Aerospsace has two designs similar to the Ehang 184 (rotary drones for transporting a single person). The Flyt 2.0 uses 16 rotors around a single seat to lift a person and fly for about 10 minutes. The current technology demonstration has not shown capability beyond a low hover [111]. This technology is far less mature than the Ehang 184, lacking automated flight: the Flyt 2.0 is still piloted manually.

Common to all autonomous systems designed for military application, is the concern over regulatory standards for use domestically, where aviation standards and regulations must be met, as applies to any aircraft. This is especially concerning when considering where human accountability lies for flying the devices [51]. These challenges may not be insurmountable, though it is not clear today how automated systems will be used in a domestic military context.

There are two unmanned platforms in the experimental stage that are focused on casualty evacuation (casevac), though are capable of cargo delivery: the AirMule and the DP-14. The AirMule has internal lift rotors that allows it to hover and fly like a helicopter, without any risk of being struck by rotor blades. The platform is capable of lifting roughly 1,100lbs with 1,540 litres of volume in two internal compartments, with an operational radius of 50km [112]. Given that the AirMule has two compartments, the aircraft could notionally carry two casualties. It is unlikely that 2 soldiers would weight 500lbs each, meaning the AirMule is constrained by the cargo containers, not by the total payload. The platform is specifically designed to land in tight spaces in urban environment. The lack of exposed rotors was an explicit design choice to eliminate the danger to personnel on the landing zone, and to minimize the size of potential landing zone and reduce the risk of a rotor strike on landing [113]. About the size of a pickup truck, this platform is suitable for casualty evacuation or for the delivery of bulk goods. Compared to the Fire Scouts or K-MAX, the AirMule cannot carry nearly as much payload, however the manufacturer claims it can land in a zone roughly one quarter the total size of other unmanned helicopters [113]. Using smaller landing zones gives the

AirMule an advantage in urban environments over the other helicopter platforms, however where larger landing zones are available the AirMule’s small payload makes other platforms more attractive.

Figure 27: Air Mule [114]

The DP-14 is a dual-rotor helicopter drone that resembles a small CH-47 chinook, with a rotor at each end and cargo capacity in the fuselage. It is capable of carrying more than 400lbs at a cruising speed of 130km/h for a radius of about 150km [115]. The DP-14 has an internal bay in which a casualty or supplies can be loaded by human operators. The largest and most worrying design limitation with the DP-14 is that it is a helicopter with exposed rotors that rotate at chest and neck level [116]. The process of loading a casualty – or unloading supplies as part of a resupply mission - would require the personnel to crawl to the DP-14 in order to prevent being grievously injured by spinning blades. Crouching under the blades to load is possible in testing where time is not a factor, however under operational conditions with low-light, smoke, fatigue and ongoing activity, the risk of casualties to other personnel presented by the throat-height rotors of DP-14 is unacceptably high in its current configuration. The only way to limit the risk is to have the DP-14 fully shut down while loading a casualty or unloading equipment, and then initiate start up once all other personnel are clear. This flaw with the DP-14 seriously limits its viability.

Figure 28: DP-14 [117]

It is important to differentiate between casualty evacuation and medical evacuation, and the different applications for rotary wing aircraft, manned or unmanned. Casualty evacuation is the use of any vehicle or platform to evacuate injured personnel and is the first step in moving personnel into medical care, but without specialized medical personnel doing the evacuation [118]. This is *not the same* as medical evacuation (medevac) where there are medical personnel onboard the vehicle providing medical evacuation concurrently with flying or driving. There is recent, observable benefit, in improved outcomes when medics and even soldiers with some medical training treat wounded personnel in the first hour after they are injured; the term used is “golden hour”.

As of 2015, an estimated 359 lives were saved in Afghanistan by establishing and maintaining a 60-minute standard from the time of a call for evacuation until the casualty was being treated in a medical facility [119]. During the time of evacuation – whether casualty evacuation or medical evacuation – the casualty can be treated in the back of a helicopter, aircraft or vehicle. Using either the AirMule or the DP-14, the casualty should be fully stabilized by the time they are loaded in the back to reduce the risk. If they are not, there will be no one to provide additional care during the flight. The autonomous helicopter solution should only be used for casualties that are stabilized, or when the flight time is sufficiently short to minimize the risk window during flight. When ongoing care is required, only a platform sufficiently large to house a medic or soldier with some medical training will suffice. An unmanned platform capable of housing casualties and a medic / soldier with medical training would be sufficient, however neither the AirMule or DP-14 is capable of housing the casualty and another person.

5.4.4 Small, Unmanned Fixed Wing Systems

Many militaries have been using small, unmanned fixed wing platforms for intelligence, surveillance and reconnaissance (ISR) tasks over the past decade. The CAF used the Scan Eagle in Afghanistan, and the Australian and American militaries have used the Shadow UAS. The Shadow has been used in a similar application to the *Zipline* for delivering up to 9kg of medical supplies to forward areas [51]. As noted with the *Zipline*, this technology is very useful to providing much needed medical support to those in need, however there is limited tactical application beyond very small items. Scan Eagle, built by Insitu, was purpose-built for full-motion video collection. It carries a payload of electro-optical sensors relaying data in real-time [120] and does not have bay-doors capable of dropping a payload. The same manufacturer has developed two new devices, with longer wingspans and more robust payload capability that provide potential options for CSS. The RQ-21A Blackjack and the Integrator are both capable of carrying 40lbs of mission equipment in a payload bay in the ventral of the aircraft [121] [122] and do so for hours at a time. However, the Blackjack and Integrator were designed to carry their mission kits – electro-optical sensors, signals intelligence packages, communications and data relay equipment – internally throughout the mission, and not for dropping anything mid-mission. *Zipline* has proven the concept that small unmanned fixed wing platforms can be retro-fitted to drop packages, however this was not the initial purpose.

Figure 29: RQ-21A Blackjack [123]

Small, unmanned fixed wing platforms are much more useful for executing ISR tasks than supply tasks, due to the rather limited payload. There is still the potential for medical supply tasks, however, the effectiveness of this application depends on a casualty having time to wait for medical delivery. Urgent surgical casualties need assistance immediately, and it may be faster and/or more effective to dispatch a medical evacuation helicopter or vehicle with medical personnel on board than to fly supplies to a casualty that then remains in the field.

5.4.5 Last-Mile Logistics

Commercial delivery technologies

New technologies for last-mile delivery have been dominated by commercial enterprise, both from shippers like DHL and UPS, and from mail-order businesses that rely on shippers, most notably, Amazon. The key commonality that all of the systems have is that they rely on small, pilotless aircraft to deliver a load under 10 pounds (most systems carry about 5lbs) directly to your door, with a maximum range of 15kms or less. It must be emphasized that these systems will be useful primarily for delivery of small items (medical supply, ammunition, specific light equipment, etc.) to the 1st line units on operations.

In terms of specific technologies, the most notable are from DHL, UPS and Amazon.

DHL introduced its initial *Parcelcopter* in 2013, using a four-rotor UAV to deliver packages up to a maximum distance of 12km over salt water for emergency or express delivery [124]. The system used a human pilot flying the aircraft manually in its first inception and was later improved to fly automatically to a predetermined drop location. The *Parcelcopter 3.0* is a new design, based on a tilt-wing aircraft that takes off vertically, and then transitions to traditional fixed wing flight for the trip before landing vertically like a helicopter. Parcelcopter 3.0 was trialed in the German Alps, flying a total distance of 8km over mountainous terrain, including 480m of elevation change [125]. The concept includes the *Skyport,* a small building that serves as the drop-off point for the package, mailbox, and the launching and landing zone for the parcelcopter. The sender drops the package at the skyport, where it is automatically loaded into the internal bay on the parcelcopter. The package is carried internally through its flight and dropped at the next skyport where the recipient picks it up. The limitation for this technology is that the parcelcopter requires a skyport in order to collect and drop packages. This means that for 1st line support, a unit would need to bring its own skyport type technology in order for the parcelcopter to land. The relatively limited payload also presents challenges in terms of the volume of material that can be delivered.

Figure 30: DHL Parcelcopter 3.0 [126]

UPS has both a fixed wing and rotary wing platform. The UPS Foundation funded the development and fielding of a fixed wing project called *Zipline* which relies on a rail-launched UAV to drop medical supplies in Rwanda. The intent was to shorten the time for delivery of blood, vaccine and other medically supplies to villages in Rwanda, a country that is exceptionally hilly, has many unpaved roads, and frequently experiences wash-outs on the existing road network. Zipline is capable of launching and delivering in 25 minutes, much shorter than the hours it may take to travel by road [127]. Zipline is launched, flies to target, and then opens its bay doors where the package falls, using a parachute. The vehicle does not land over the target; it is launched by rail and then recovered using an arresting wire because it does not have landing gear. The entire system can be transported in a single sea container, and then set up close to the medical supply depot. *Zipline* focused on blood delivery because postpartum hemorrhage is the leading cause of post-natal death for Rwandan women. The orders are placed for blood or health products using cell phones, either using SMS text or WhatsApp; the requestor receives an SMS or WhatsApp message directing them to the package in a target area the size of a few parking spaces [128]. The system is all-weather, day or night, can carry up to 1.5kg of cargo, and has an operational radius of 75km. This technology has a much longer range than any of the other commercial delivery technologies and does not need to land in order to make the delivery. In the CSS context, it could be used for its intended purpose: delivering blood and medical supplies to 1st line units. This would be particularly useful for casualties that have lost a considerable amount of blood and would benefit from an additional transfusion in order to increase the likelihood of survival. The rather limited payload prevents this platform from being effective for delivery of sufficient quantities of batteries or ammunition to make a significant difference on the battlefield.

Figure 31: Zipline dropping package via parachute [129

The rotary-wing UPS drone is an octo-copter design that launches from a roof-mounted cradle on the modified, brown UPS delivery truck. The operator manually loads the underslung cargo bin from inside the truck, then using a tablet device and an aerial-photo interface to select the drop point for the package. The drone then performs the delivery. While the drone is performing the delivery, the operator continues with other deliveries. Once it has completed its delivery, the drone flies back to the truck and lands on the cradle awaiting its next package for delivery [130]. The rotary wing drone program is intended to save time and money and reduce emissions for rural delivery but avoiding the need for drivers to go down long laneways and gate-roads to deliver packages directly to houses. By having the drone do much of the delivery, less driving is required. This drone has an apparently simple interface, where an operator selects the drop zone visually, and the technology handles the rest, including the flight back to its initial launch point even when that launch point is a vehicle that has moved. This technology would be useful for ferrying small supplies to the farthest reaches of a brigade or combat team's footprint, when it would be faster and more convenient to deliver supply forward autonomously. The maximum weight limits the utility of this system, for things like ammunition, batteries, and liquids like water or fuel.

Figure 32: UPS Rooftop Drone Delivery [131]

Amazon has trialed its Prime Air delivery in the UK using a quad copter design to autonomously deliver packages to customers. The basic approach is similar to the solutions being used by other commercial providers. The customer places an order online. The order is sent to an Amazon warehouse where the order is automatically loaded with the selected product, up to 5lbs, and flies at a maximum altitude of 400ft to drop the package at the customer's home [132]. Another Amazon project used a similar process, but rather than a quad copter uses a tilt rotor design that transitions to fixed wing flight en route, and transitions back to hovering to make the delivery [133]. For both airframes, Amazon is claiming 30-minute delivery from the time the order is placed.

Figure 33: Amazon Prime Air tilt-rotor [134]

Amazon has patented a concept that is unlike any other drone-based delivery model currently on the market. Amazon's Airborne Fulfilment Centre (AFC) concept calls for an airship filled with consumer products that will hover at roughly 45,000ft., and from it, small drones will fly down to do individual deliveries of goods to customers [135]. Originally conceived for selling souvenirs and concessions to sports fans at open air venues (baseball, football) [136], Amazon has received a patent for this technology. Though the total payload of this system is unknown because it still exists as a concept, there are some challenges for first line military supply.

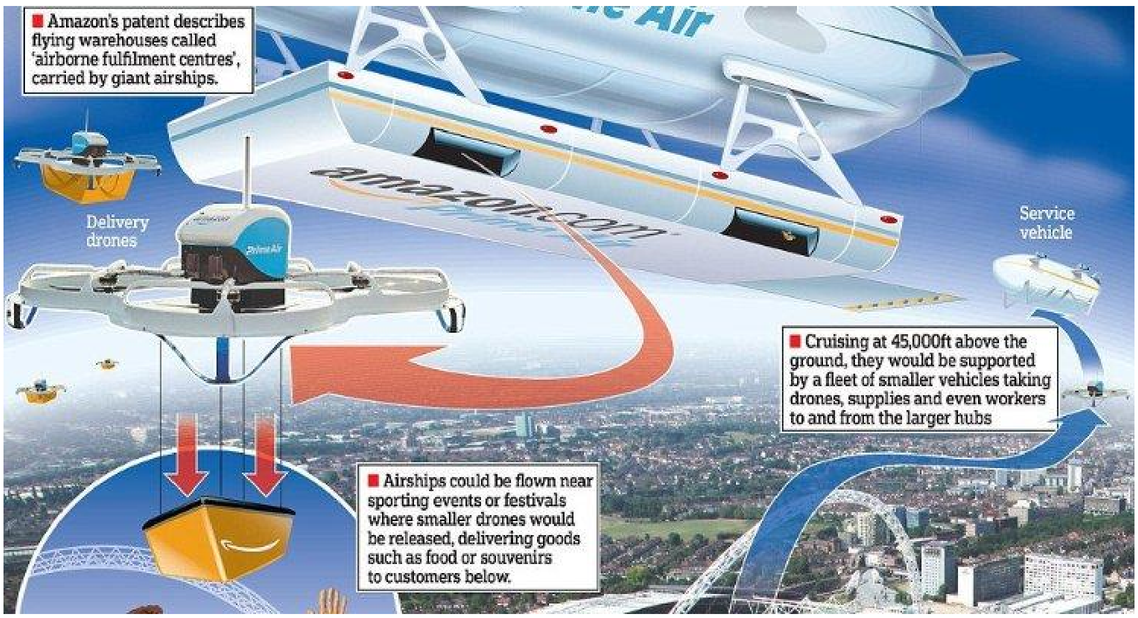


Figure 34: Amazon's Airborne Fulfillment Centre (AFC) Concept [137]

The first is that the AFC is only capable of delivering what is already inside the main airship. For first-line support where the list of expected goods is well known – ammunition, water, batteries, fuel – the idea of having smaller drones deliver them to the front line adds convenience and reduces (or eliminates) the need from ground re-supply. The challenge is for battlespace deconfliction of the airspace for dozens of drones flying through the air at any given time between the main airship and soldiers on the ground. With the airship overhead at 45,000ft and drones flying to ground level, this concept effectively blocks out a cylinder of airspace where the AFC is located. This is a challenge for requesting air support from or attack aircraft and aviation, or supplemental delivery from other manned or unmanned platforms like helicopters. Those pilots and crews are likely to have concerns about a collision with a drone carrying a package to soldiers on the ground. While Amazon is claiming their drones have collision avoidance technology for flights below 400ft [138], it is not clear if this technology is sufficient to avoid collision with high-speed aircraft between ground level and 45,000ft.

5.4.6 Unmanned Ground Systems for Distribution

Bulk Supply

The use of heavy trucks in convoys to move large loads of fuel, ammunition, water and other bulk supplies is standard practice. The volume of convoys required to move supplies in the recent conflicts in Iraq and Afghanistan was significant, prompting the US Army to commission research to determine specifically the rate of casualties for fuel and water deliveries, and to measure the number of causalities per convoy [139]. The figures were significant, with 186 US casualties in Iraq in 2007 as a result of water and fuel convoys, and 53 in Afghanistan, accounting for roughly 10% of total casualties that year [139]. Canada also had concerns that ground convoys were vulnerable to attack, and these concerns were articulated in the Manley report [60] that recommended greater reliance on helicopters for logistics as a means of reducing the risk of road casualties. Emerging technologies for ground delivery of bulk supplies could reduce the risk of casualties by reducing – or possibly eliminating – the need for personnel to be involved in ground convoys.

Lockheed Martin has two systems in development for making heavy truck convoys autonomous or semi-autonomous: the autonomous mobility applique system (AMAS) and Convoy Active Safety Technology (CAST). Both systems include the use of sensors to detect the environment to navigate large trucks for delivering supply. CAST was developed and tested first for autonomous navigation, with human drivers remaining in the cab to set waypoints. Speeds up to 50mph were sustained by the CAST system automatically on straight roads, simulating conditions of long-haul resupply to a maximum distance of 100 miles [140]. Cast proved capable of avoiding single obstacles (simulated pedestrian) automatically and continuing on the assigned route. The convoy was then split into two packets of two vehicles, and then rejoined, followed by an emergency braking test to halt the entire convoy unexpectedly [140].

Figure 35: AMAS system vehicles in convoy [141

The AMAS program represents an improvement over the CAST system by adding the complexity of convoy operations in the urban environment on secondary roads [142]. To address the complexity of the urban environment the AMAS system was evaluated for its reaction to oncoming and passing traffic, the right of way of other vehicles, navigating barriers and obstacles, dynamic re-routing, responding to pedestrians, 4-way stops, emergency braking situations, and traffic circles [142]. Under daylight conditions with light traffic the AMAS system was configured to two heavy palletized load carriers and tractor (without trailer) and met all of its objectives. A subsequent test included 7 vehicles, including two tractors with trailers, under rainy conditions, which performed within the parameters. The AMAS system was capable of detecting pedestrians, was capable of navigating to destination, of conducting emergency stops, and was capable of navigating test-condition urban terrain (i.e.: closed course, limited traffic).

Figure 36: Convoy Active Safety Technology (CAST) in a simulated built up area [143]

Oshkosh has developed the TerraMax system for its trucks to automatically navigate to the desired location. The manufacturer claims the system reaches its destination on a test course of 7 miles in rural terrain, followed by a 60-mile simulation in the urban environment [144]. The system made by Oshkosh can be installed on any truck and is therefore not limited to their specific design. More recent developments include the advanced driver assist system, which is reputed to recover from slides and skids more effectively than human drivers [145]. The system has a GPS receiver, though the manufacturer claims that with active sensors developing a detailed synthetic picture of the environment and terrain, the vehicle can maintain situational awareness by its picture of the terrain, without relying on GPS signal. TerraMax can be used for a single vehicle or for a whole convoy of vehicles, all under the control of a single human operator.

Figure 37: Oshkosh TerraMax, configured without cab [146]

The challenges that both the Lockheed Martin and the Oshkosh systems face is that, based on the material available, they are untested in actual urban environments. Though test conditions have included built-up areas with some cars, and isolated pedestrian tests, the vehicles have not been tested in an active networked, urban littoral environment with literally thousands of vehicles, bicycles, carts, pedestrians, children, animals, etc., to provide a real sense of what the future operating environment will look like. Both systems are capable of stopping and avoiding obstacles – like pedestrians – in the middle of the road. However, this could work against the concept, as an insurgent could stand in the middle of the road, comfortable in knowing that the vehicle or convoy of vehicles would stop. This could have the unintended effect of providing supplies to the adversary forces, who could seek to stop convoys for the sake of looting them of their supplies. To prevent this kind of thing from happening, human soldiers would need to ride on board these convoys, defeating the purpose of making them autonomous. This technology is capable of delivering supplies with fewer drivers, though is only capable of doing so in very simple or low threat environments; which limits the range of potential application for expeditionary and urban operations.

Dismounted Load Carriage

The Squad Mission Support System (SMSS) is a small six-wheeled vehicle that is intended to accompany an infantry squad on operations with the purpose of carrying some of the load that soldiers typically carry on their person. With combat loads often exceeding 100lbs for a dismounted soldier, the intent of the SMSS is to extend soldier endurance, reduce fatigue and enhance the overall mobility of an infantry squad without having to sacrifice mission-critical equipment. The SMSS can carry packs, water, ammunition, fuel, spare parts, and mission equipment to support the infantry squad, and carries a maximum of 1,500lbs a maximum distance of 60 miles one-way [147]. Reducing the payload will extend mission range, and the SMSS can be configured for ISR missions. The SMSS can be dispatched to provide re-supply to a unit already deployed, can follow a unit while it moves forward, can be sent to retrace its path, and can be programmed to follow a series of waypoints [147]. This provides the versatility to have the system follow along to directly support a unit on operations, acting as a mobile quartermaster of sorts, or it can be sent forward to provide resupply to a unit already deployed.

Figure 38: Squad Mission Support System (SMSS) [148]

The system relies on LIDAR and infrared cameras for sensing its environment, GPS to know its location, and has a radio to manage command and control. Operators control the vehicle through a ruggedized tablet, controller, and data radio [147]. The controller unit allows the operator to program waypoints, modes of operations, and evaluated the status of all systems onboard the SMSS [149]. When being used autonomously (i.e.: following the infantry squad) the SMSS does not use beacons but recognizes the soldier that is the operator. The unit can then be safely stowed, and the SMSS will follow the infantry squad without further input. This technology has undergone extensive testing, including an active-theatre trial in Afghanistan in 2011. Subsequent trials have taken place as recently as 2014 [150]. As part of one of those tests, the SMSS was transported as slung cargo under the K-MAX unmanned helicopter.

Another unmanned ground vehicle program was the MULE (Multi-Function Utility/Logistics) vehicle. This program was cancelled in 2011 [151]. The MULE was a similar concept to the SMSS, functioning as an autonomous platform to transport equipment and supplies to dismounted soldiers. It used a six-wheeled platform, like the SMSS, but with independent electric motors on each wheel. It weighed almost 4,500lbs and was capable of carrying 2,000lbs [152]. The MULE was cancelled by the US army primarily because other systems had equalled or bettered the autonomous navigation of other comparable autonomous or semi-autonomous platforms [151]. This appears to be a reference to the SMSS, which has undergone additional research trials since 2011.

Figure 39: Multi-Function Utility / Logistic Vehicle (MULE) [153]

General Dynamics is making a wheeled platform called the Multi Utility Tactical Transport (MUTT) that weighs 750lbs and is capable of carrying 600lbs of fuel, water, equipment, ammunition and mission equipment, and is designed specifically to support dismounted infantry [154]. The vehicle is electric and is specifically designed to be small enough as not to incur additional CSS challenges for logisticians, while attempting to address a CSS challenge for the infantry. The MUTT is controlled by attaching a tether to a soldier, which notifies the MUTT to follow closely behind or in front of the soldier to which it is tethered. Multiple MUTTs can be joined together in a convoy if payload above 600lbs is required. Using a remote control, the MUTT can be pushed up to 100m ahead or behind the soldiers it is supporting [154].

Figure 40: Multi Utility Tactical Transport (MUTT) [155]

Of the wheeled vehicles for dismounted load carriage – the SMSS and the MUTT – the SMSS has a much broader range of applications. The MUTT is limited to 100m from the soldier it is ‘tethered’ to, while the SMSS is capable of crossing distances of up to 60 miles autonomously and is capable of carrying over twice as much as the MUTT is capable of carrying. However, given that the MUTT does not rely on GPS for navigation, and relies on physical inputs from the tether, it is less vulnerable to cyber interference, whether through GPS denial of service, or through other means. This presents a major trade-off for wheeled support. The MUTT carries fewer electronics, and is therefore less susceptible to cyber interference, but is much less capable in terms of weight and endurance than the SMSS and is incapable of autonomous tasks.

There is an entire class of dismounted load carriage platforms that do not rely on wheels, but rather rely on legs, resembling large robot dogs or cats. Most of these platforms are made by a company called Boston Dynamics, in partnership with DARPA's Legged Squad Support System (LS3) project. The most prominent of the legged carriers is the Boston Dynamics Big Dog. The Big Dog weights 190kg is capable of carrying 45kg payload, and navigates using LIDAR systems [156], similar to those of the wheeled vehicles mentioned above. The Big Dog is capable of maintaining control when crossing obstacles, ice, or even when sustaining a kick from a human being [157]. The purpose of this test appears to show that the Big Dog can retain control even when faced with external pressures and challenges. The Big Dog has a top speed of 5mph, slightly faster than the average walking pace of soldiers.

Figure 41: Boston Dynamics Big Dog [158]

The Wild Cat is another platform that operates in a similar fashion to the Big Dog, though is capable of much faster speed, with a top speed of almost 20mph [159]. However, the Wild Cat is incapable of carrying any payload [159] and appears to be for the purposes of testing maximum speed. Another vehicle called Cheetah is capable of running at 28 mph [160] and carries no payload.

The advantage that all of these legged systems have over wheeled systems is that they can move over terrain that wheeled vehicles cannot. They can climb hills where no roads exist, they can climb stairs (indoors if required), step over rubble rather than rolling over it. This means that legged vehicles could accompany soldiers indoors, in a situation where stairs are the only means of access. However, similar to the MUTT, the trials show that all of the Boston Dynamics robots are controlled by a person, meaning they must stay close to the supported group. There is however a near-fatal drawback to all of the Boston Dynamics robots. The main drawback with all of the legged vehicles is their power source. Indoors they are tested using a wired system that gives them direct power. When operating outdoors in realistic test conditions, they run on a loud, high-pitched gasoline engine. For military application, specifically for supporting a dismounted rifle section that relies on the ability to move quietly and undetected, this is not acceptable. If the issue of engine noise can be resolved this technology may be viable in the future, however without it the unit's sound will prevent it from being fielded. Interest in the technology appears to be waning, with parent company divesting itself of some of the LS3 programs [161].

5.4.7 Automated and Autonomous Systems for Material Handling

To increase the load that a human can carry or work with, automated and autonomous systems for material handling are being developed. The most common application is using 'exoskeletons' that a human operator wears, transferring the burden of the load from the human operator to the exoskeleton and then to the ground. Many of these systems began as therapeutic aids to assist paraplegics to walk again [161], there are clear applications for material handling. Lockheed Martin's FORTIS exoskeleton is an unpowered device weighing 27lbs that the user wears and can be customized for all body types with a height range between 5'4" to 6'4" [162]. FORTIS allows heavy tool operators to hold tools for an extended period of time without incurring muscle fatigue and allowing an increase in work rates between 2 and 27 times, according to the manufacturer [162]. Initially designed to be used in industrial and manufacturing settings the system is claimed to be capable of holding a 36lb tool such that it is weightless to the operator [163]. The US Army has conducted testing for infantry soldiers with purpose of reducing the strain of carrying crew served weapons, like general purpose machine guns [164].

Figure 42: FORTIS Exoskeleton [165]

Special Operations Command (SOCOM) in the United States is evaluating an experimental system called the Tactical Assault Light Operator Suit (TALOS), intended to increase personal payload, providing active armour, and integrate visual sensor data into a single helmet. TALOS can be unpowered enabling 75lbs to be carried, or powered enabling 150lbs, including physiological monitoring of the user (heart rate, blood pressure) an active fluid-based armour system that redirects fluid across body armour when a bullet impact is detected [166]. The use of sensors to monitor bullet impacts and user physiology could be useful in anticipating when the user is approaching exhaustion, and in detecting when someone has been injured due to increase or decrease in heart rate or blood pressure.

Figure 43: TALOS Exoskeleton [167]

The exoskeleton has a number of potential implications for CSS. In terms of supply and materiel management, the exoskeleton will allow for warehousing to be conducted with greater safety and less fatigue for personnel moving material for distribution. In terms of maintenance, the ability to hold tools for long periods of time without fatigue will allow for less reliance on maintenance in forward areas. The exoskeleton user could be capable of performing maintenance on vehicles, aircraft and other systems without relying on some pieces of equipment (lifts, hoists, etc.) under some circumstances. If this is possible, it could contribute to reduced energy consumption in forward areas and reduce the footprint of equipment required for maintenance. The ability to carry more weight over a longer distance indirectly impacts CSS by allowing soldiers to move longer distances with a greater load, potentially reducing the demand and frequency of resupply. Also, the ability to detect physiological status could be integrated into an internet-of-things or digital thread / digital twin system to notify of the need for medical attention in near-real time.

The biggest challenge for exoskeletons is determining the costs and benefits of implementation. Though the systems promise to reduce injury, improve endurance, and improve output of human operators, we cannot tell at this stage in development if this is offset by the need for maintenance of the exoskeletons, the costs and complexity of data integration, and the power requirements for those exoskeletons that require a powered source

5.5 Digital Thread / Digital Twin

Both the terms digital thread and digital twin are relatively new concepts in defence engineering. DoD defines digital thread as:

> "An extensible, configurable and component enterprise-level analytical framework that seamlessly expedites the controlled interplay of authoritative technical data, software, information, and knowledge in the enterprise data information-knowledge systems, based on the Digital System Model template, to inform decision makers throughout a system's life cycle by providing the capability to access, integrate and transform disparate data into actionable information." [168]

The Digital Thread (DTh) is a proposed framework for integrating technical data, cost data, predictions, and other data and knowledge accumulated over the course of design, testing and development, and the operation of a system: it is intended to provide usable information for decision-makers in the design process [169]. The DTh provides the framework for evaluating specific platforms while under development. The Digital Twin exists within the DTh to digitally represent the physical entity, including the physics, fatigue, lifecycle, sensor information, performance simulations, etc., of that physical entity, and reflects any manufacturing defects and the level of wear-and-tear sustained during its field life [169]. DOD defines it, technically, as follows:

> "An integrated multi-physics, multiscale, probabilistic simulation of an as-built system, enabled by Digital Thread, that uses the best available models, sensor information, and input data to mirror and predict activities/performance over the life of its corresponding physical twin [168]."

For real-time application the Digital Twin and DTh concepts can be applied to measuring and monitoring the *actual* wear and tear and failures of machinery [170]. This technology offers the promise of monitoring the health and life-remaining on all kinds of machinery: traditional equipment like helicopters components, armoured fighting vehicle components, support systems like generators, ISR systems, or emerging technologies like drones, UGVs, UAVs could all be monitored in real-time to provide data on maintenance and repair horizons. This could have major impacts on forecasting maintenance and optimizing timelines for pre-emptive maintenance and replacing critical parts in order to have the minimum number of systems down for maintenance at any given time. The data generated using DTh could allow for rolling maintenance and increase the percentage of a given fleet of equipment that is available at any given time.

For maintenance, DTh and digital twin technologies have the potential to create a digital environment that could prove very valuable, firstly, in providing total asset visibility that is currently lacking, and, secondly, in enabling better planning and decision support by providing real-time status of assets and their sub-components in order to anticipate maintenance requirements and plan them accordingly in order to limit impacts on operational readiness. The outputs of using the DTh and digital twin for maintenance can give planners visibility on the asset-level maintenance requirements, and also fleet or unit level outputs to evaluate the efficiency of a single fleet of vehicles, or overall efficiency of maintenance in one type of unit with many different fleets.

There are also major potential implications for supply chain management. Rather than maintaining digital twins of components or assets being used, cargo items will be assigned a digital twin that corresponds with their physical location, allowing for near-real time monitoring of the location of material in the supply chain, building historical database to identify opportunities for optimization, and thereby make informed decisions about any necessary changes to the supply chain approach [171]. Using digital twin technology will generate massive amounts of historical data about the location, time, speed, and condition of items that have a digital twin. The data generated presents the opportunity for simulations-driven evaluations for predictive analytics, prescriptive analytics to provide better guidance, and optimizations of the efficiency of the supply chain [172].

Using digital twin technology presents opportunity not only to understand how to improve efficiency based on existing data, but also to test hypotheses on what might make the supply chain more efficient through the use of simulation. This will be very useful in the context of dispersed operations and operations in the urban networked littoral where complexity allows for a range of potential solutions to be tested and evaluated in a simulation environment to determine the expected efficiency and effectiveness of options. Efficiency improvements will either reduce the amount of input required to sustain the supply chain or increase the volume of supply that can be delivered.

> Based on the current state of asset visibility discussed in Section 4, there is a very long way to go between the current status of limited asset visibility to a DTh/digital twin system. The technical challenge will be significant in developing requirements, integrating systems and trialing a fieldable system. In addition, there will need to be a standardization process for all DTh/digital twin systems that has not occurred yet [169]. Standardization and intellectual property (IP) issues will be the most significant challenges, outside of the technical challenge of building the system [163].

5.6 Conditions Based Maintenance (CBM) / Health Usage and Monitoring Systems (HUMS)

Conditions Based Maintenance (CBM) and Health Usage and Monitoring Systems (HUMS) are both intended to provide near-real time diagnostics on the health and safety of critical equipment components for the purposes of predicting maintenance needs. CBM is the idea that maintenance on equipment or components is conducted as a result of a verifiable test of that equipment to determine if it does require maintenance due to wear or degradation. This differs from preventative interval-based maintenance, where components or fluids are changed because sufficient time has passed. CBM techniques provide an assessment of the system's condition based on collected data from continuous monitoring or via inspections and is intended to deliver maintenance prior to predicted failure [29]. This represents a shift in philosophy from the 'run-to-failure' approach this is often applied to asset management, where components are only replaced when there is failure [29]. When considering the consequences associated with component failures in the military context – specifically with respect to aviation, where failure can have disastrous consequences – run-to-failure has not been generally accepted. Land forces tend to rely on time-based constructs whereby components are replaced after a set number of hours of use [29]. HUMS is a propriety technology developed by Honeywell, that serves effectively the same purpose as CBM, but with a specific focus on safety for aviation [173]. The system is intended to provide monitoring for vibration and wear in aviation components for the purpose of verifying airworthiness. The data is transferred from the aircraft to a database, where fleet level analysis can take place [174]. If applied in a network environment, HUMS has very similar application potential to CBM.

The potential advantages of implementing CBM / HUMS for the army is the benefit of real-time assessment of the health of equipment while it is being used, improving operational capability by conducting regular diagnostics and avoiding failure during use, improving the ability to predict maintenance requirements, reducing maintenance induced errors through regular diagnostics, exercising greater anticipation in the supply chain, and the ability to generate aggregate fleet life data [29]. These benefits extend across the full supply chain. The ability to measure the health of a system in real-time allows decisions to be made about removing equipment from service for maintenance before it fails. This cuts down in the need for recovery of vehicles, and the time-in-planning costs of experiencing an unanticipated failure. Anticipating maintenance allows for optimizing fleet maintenance to have the least impact on readiness possible, and to maintain a steady flow of replacement parts through the supply chain to reduce the need for surges of supplies. The overall benefit of CBM is that the spikes and valleys of maintenance volume are smoothed out, creating greater predictability in maintenance timelines and normalizing the proportion of the supply chain that is dedicated to supporting maintenance.

The challenges for implementing CBM / HUMS is the status of the IT infrastructure that currently supports the army. This is not a conceptual challenge, but given the gaps observed in Section 4.2 about asset visibility and the flexibility of current IT systems that support CSS, the current state of technology is not likely to support this vision. The IT challenges presented in 4.2 (no means of TAV, insufficient data exchanges between the tactical and operational level, too much reliance on manual data entry, no integration between systems for resource management, enterprise planning, the movements system, fleet management, etc. [29]) raise questions about the ability of an enterprise concept like CBM or HUMS to be successfully implemented. Without TAV no system can be rolled out to track assets that can't be seen simultaneously; without sufficient data exchanges there will delays in communicating information, meaning whatever information is available cannot be fully relied upon; manual data entry defeats the purpose of automating systems; and without integration of systems warnings for maintenance times will not act as automatic triggers to order spare parts or to alert planners that some assets will not be available. These are enterprise-level IT obstacles that must be addressed before a CBM / HUMS type system can be implemented for the Canadian Army.

5.7 Power and Energy Technology

The use of power and energy by modern militaries is significant, both in terms of the energy requirements and the cost sustaining energy reserves to meet daily needs. According to a recent study, the US armed forces were consuming 22 gallons of fuel per day (roughly 83 litres) per person deployed to Iraq and Afghanistan, and that the cost was *at least* $45USD per gallon (or roughly $14.75CAD per litre) to ship the fuel into the theatre of operations [26]. This was the total cost for shipping fuel across strategic lines of communication, to theatre level depots, and then to brigade and forward supply areas. The approximate cost of energy was a total of $990USD (or roughly $1225CAD) per day per soldier. As mentioned previously, roughly 10% of total US casualties in Iraq and Afghanistan were sustained by soldiers involved in maintaining supply of fuel and water [26]. Any effective means of consuming less energy, either by relying on fewer liquid fueled generators in forward support areas or by reducing the fuel consumed by air and land platforms, would necessarily reduce the number of fuel convoys required to sustain the force, and therefore reduce the risk of casualties.

For dismounted soldiers, batteries are essential for sustaining the electronics carried onto the battlefield. To reduce this load and improve electronics endurance there are many battery technologies that are being evaluated for potential operationalization. These include solid state batteries, redox-flow batteries, batteries using sodium-ion, magnesium-ion, lithium-air, sodium-magnesium hybrids, and silicon [161]. Advances in supercapacitors also bring the promise of shorter charge times for batteries once they run out of power. There are technologies that are wearable, printable, or woven into textiles that are still in the experimental stages [161]. The main challenge with experimental battery and supercapacitor technologies is that the technology is not sufficiently mature enough to replace the existing technologies [161], and therefore not sufficiently reliable to replace the existing batteries for military use. Given the weight of batteries that soldiers are currently required to carry to support field situation awareness and command and control systems, major improvements in the power and life of batteries will therefore reduce the load that soldiers are required to carry.

Fuel cells could reduce (or eliminate) the need for liquid fuel generators to generate energy at military installations. The system with the most promise is solid oxide fuel cells (SOFC), proton exchange membrane fuel cells (PEMFC), and hydrogen cells [161]. SOFC are being used at large installations such as building sites, data centres, and other places with large power requirements. SOFC are more efficient than liquid fueled generators, with the promise of future improvements to electrolyte material for even greater efficiency. PEMFC are being used in China with the intent of providing more affordable sources of energy to factories, to reduce the costs of manufacturing of consumer goods. Hydrogen cells are smaller than SOFC or PEMFC also being explored as an alternative source of energy for UAS. Hydrogen cells weigh less than the batteries they replace, providing greater range and endurance when used in UAS, though have much greater risk of flammability and leakage, raising questions about reliability and risk if something does go wrong. Artificial photosynthesis is an emerging technology that mimics the process used by plants to generate energy. By artificially recreating this process to split water molecules, hydrogen is generated that can be used as a fuel and has applications for pharmaceuticals and creating biodegradable plastics [161]. Artificial photosynthesis is still very much in the experimental stage. The development of all these fuel cell technologies should be reviewed further to better understand how they can replace existing power sources in installations and for platforms like UAS.

Rather than using a single system to generate power, there is potential for energy to be harvested from the environment using new technologies. Energy harvesting technologies are being developing that seek to capture energy from heat sources, pressure sources, sound, EM emitters, and changes in humidity, and store that energy in batteries. [161]. In the low-to-mid level of technology development, is a system called the Kinetic Energy Harvester, that captures energy though the walking movement of soldiers using an exoskeleton at the knee. The system generates power without impacting the soldier's range of motion, mobility or agility [175]. Another system called the InStep NanoPower, developed at the University of Wisconsin in Madison, relies on a jelly moving back and forth in the soles of shoes to generate energy [176]. What is not clear is whether or not either of these systems generates sufficient energy to recharge existing (or future batteries) and whether the energy generated is sufficient to offset the value of implementing the technology. Other technologies include harvesting the wasted EM energy from communications devices, currently being trialed on mobile phones, to extend battery life. This does not provide a new battery technology but does seek to extend the life of existing batteries [161].

Solar technology has been around for decades in civilian application, and improvements are being developed to make solar most suitable for military applications. Traditional photovoltaics have been improved to provide some foldable, lightweight panels that work as a normal panel, though they are much more expensive than traditional panels [161]. Perovskite technology is cheaper and easier to produce than traditional photovoltaic cells, captures a broader portion of the light spectrum, and is more stable [161]. Polymer cells present another cheaper and easier option compared to photovoltaic cells, however, they traditionally have a lower conversion efficiency, therefore generating less power than the existing option, though new manufacturing processes show some promise to improve polymer cell technology 161]. 'Kesterite' solar cells are built using 3D printing techniques, and despite their lower conversion efficiency are much easier and cheaper to produce than photovoltaic technologies [161]. This would require a larger bank of cells using Kesterite than traditional photovoltaic cells, which in rural areas may not be a challenge; however, in small installations any option less effective than photovoltaic cells may not be suitable.

6. EMERGING TECHNOLOGIES – CHALLENGES AND FUTURE APPLICATIONS

This section describes the potential application of information technology to improve Army CSS. The focus of the information technology discussion will be on Internet-of-Things (IoT) technology, and how they can improve supply chain visibility, optimize mobile asset use, maintenance scheduling, and overall efficiency.

6.1 Information Technology: Systems and Management

IoT will be the backbone upon which all the other systems are built. Without an IoT system, none of the other systems are practical because they require the IoT database to collect data and then from the trends, identify ways to improve efficiency. Each of the subsection addresses the concepts individually, and Figure 44 below shows how all these technologies can be integrated into an IoT system.

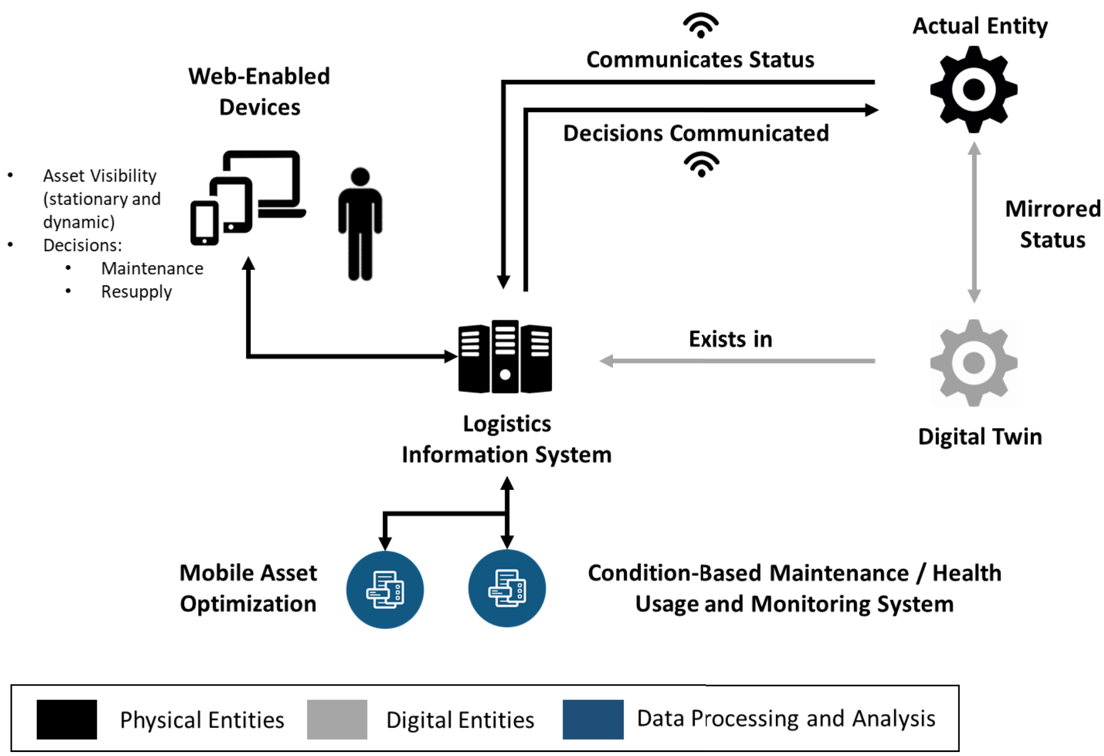


Figure 44: Notional Use of IoT-enabled Technologies

6.1.1 Internet of Things

The IoT offers great promise by networking items into a single system, with real-time data reporting on the location of items, anticipated delivery times, and notifications about delays. The IoT concept involves connecting any network-enabled device to the internet to connect things to things, and things to people, and people to things [177]: in short, it will provide a network of things can be identified in real time. This technology is being driven primarily by the private sector, either for companies who maintain complex supply chains for their own operations, or for international shipping and logistics companies who move goods for clients. Based on the observations in Section 4.2 of this document on supply chain visibility, IoT would provide significant improvement in visibility of the supply chain over existing capability.

The IoT concept has moved well past the notion of “fad” technology: by 2016 there was an estimated 6.4 billion devices connected to the internet, with 5.5 million new devices every day [178], underlining the potential scale of devices already connected and the expectation that growth will continue These technologies also have application for any major industry that has inventory tracking requirements, like healthcare and life sciences, transport, retail, security and public safety, and IT and network providers [179].

The greatest benefits that IoT will deliver are 1) the ability to maintain asset visibility “from floor to store”, which in the army context means from the 4th line to 1st line supply; 2) optimizing ordering relationships by integrating vendors directly into the supply model where applicable; 3) enabling forecasting of inventory use based on what is known about consumption habits given a set of inputs; 4) connecting transport fleets (containers, vehicles, etc.) to optimize delivery of material, and; 5) optimizing scheduled maintenance [180], and reducing loss through improved inventory management [178]. Maintenance will be discussed in more detail in Section 6.1.3. All of these functions are complimentary and require a Logistics Information System (LOGIS) of some kind to manage data intake, data storage, and analysis of data through established and customized algorithms, present data to users in such a way that their requests are easily answered, and place orders and track delivery on par with any contemporary civilian supply chain system.

For asset tracking (from “floor to store”), a LOGIS will need to have entries for each item or container that is moving through the supply chain. The most common way of doing this today is through radio frequency identification tags (RFID) that include a microchip for storing information. This will be represented as the “thing” in the IoT. These can either be active tags using battery power to transmit updates through a low-power wide area network (LPWAN) or they can be passive tags that store information and provide updates only when queried or prompted [181].

Using a LOGIS with RFID tags will allow the location of material (either individual items, or pallets or containers containing supplies) to be tracked in real time. Material can be assigned to the platforms moving it, like ships, aircraft, airships, trucks, or whatever is being used to move equipment. This will allow planners and decision-makers to query detailed information from the LOGIS and will also allow logistics personnel to verify material as it moves through the supply chain. Figure 45 below shows tracking the movement of supplies through the supply chain by querying RFID tags using a mobile device connected to the LOGIS. This figure does not assume connectivity at the 1st line, or that ISO containers will necessarily be used at the 1st line, both indicated with a dotted line.

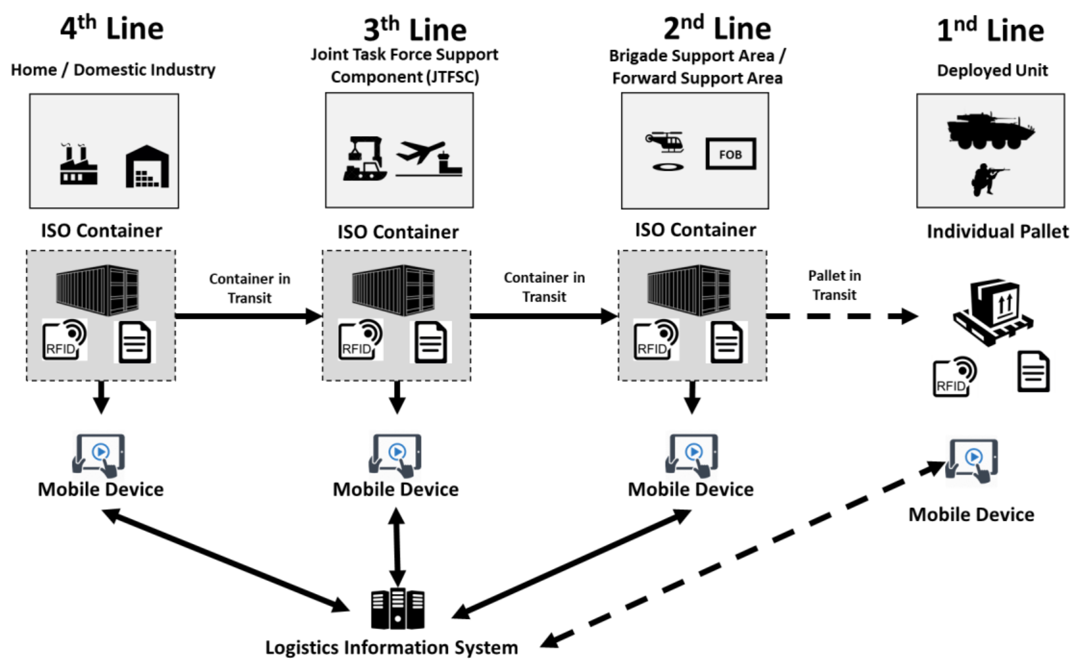


Figure 45: IoT movement of supply - tracking with mobile device (movements)

Using and IoT-enabled LOGIS means that a user's location does not limit their ability to query where a piece of equipment is in the supply chain. The only constraint becomes ensuring that connectivity to the LOGIS is maintained. Figure 46 below shows that a user can access the LOGIS from anywhere the world to view material. This means that planners at national headquarters or logistics in 2nd line facilities can equally use the LOGIS to query where an item is located and when it can be expected to arrive.

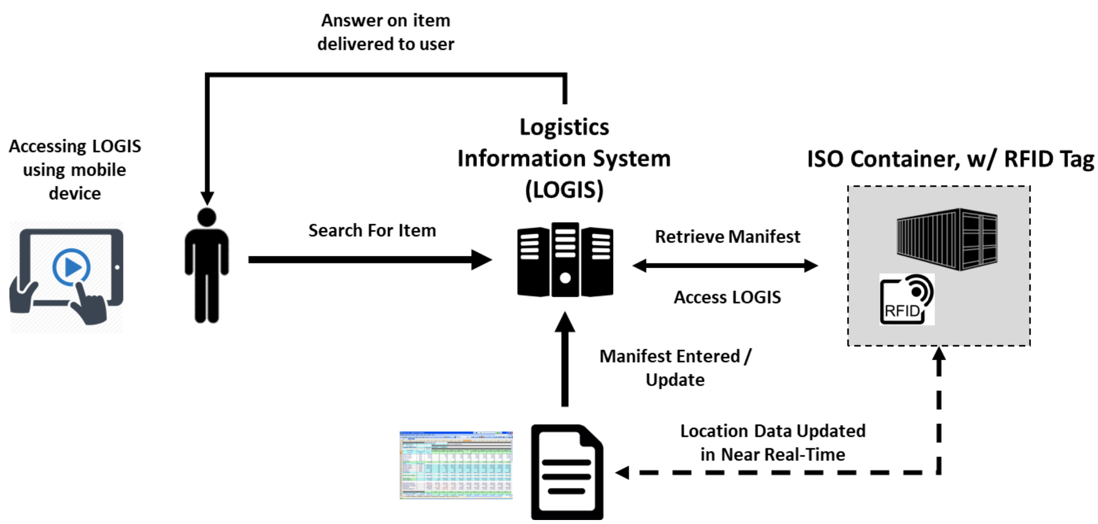


Figure 46: LOGIS - user querying system from anywhere in the world

Any IoT-enabled LOGIS will generate data; huge, almost unfathomable amounts of data, about where previous packages were sent, how they got there, how long it took to get there, and any delays or cancellations along the way. When analyzed, that data will show trends in orders, volumes of material, variation in time of day or time of week, etc., from which drivers can be extrapolated (i.e.: when do we foresee a surge in demand? When do we see less demand? For what types of materials?). The data collected will provide a database of trends and drivers that will enable planners to better forecast supply requirements. This applies to long-standing multi-year operations where trends can be identified. Similarities in mission requirements, flightpaths and flight times, payloads carried, etc., from previous missions could all prove useful for forecasting logistics requirements. Once sufficient data is collected and analyzed, the result may drive changes in doctrine and TTPs *if* improved efficiency can be proven.

The ability to forecast trends could have major impacts across the entire supply chain. This could impact how much material is ordered from manufacturers, how much material is warehoused domestically, how much is moved to forward locations, how much material is purchased in the local economy, and could impact movements requirements for shipping, trucking, air-lift, etc. Forecasting is already taking place, however the power of IoT is that it instead of humans relying on heuristics, data trends can be automatically generated and presented to decision-makers to improve the efficiency of the supply chain [182].

The IoT concept can be extended to the level of individuals or vehicles that self-report on their status, including ammunition on board, fuel remaining, engine status and other system status. General Electric (GE) is exploring similar applications for aircraft engines, wind turbines, and mining equipment to report equipment status to a central location to inform operational decision making [183]. This concept would allow individuals or vehicles to generate status reports and generate orders for supplies automatically, aggregated to the platoon or company level as required. Using a self-reported approach would limit the potential for human error in reporting requirements during operations and would also clearly communicate the location of the unit in need of supplies. An IoT-enabled LOGIS could then cue logisticians and movements personnel to begin coordinating delivery of supplies to deployed units. The concept is shown visually in Figure 47 below. These processes happen today on operations; however, they are all coordinated manually through radios and digital transmissions. The IoT concept could automate data generation and transmission, leaving humans to approve or decline the recommendations generated by the LOGIS.

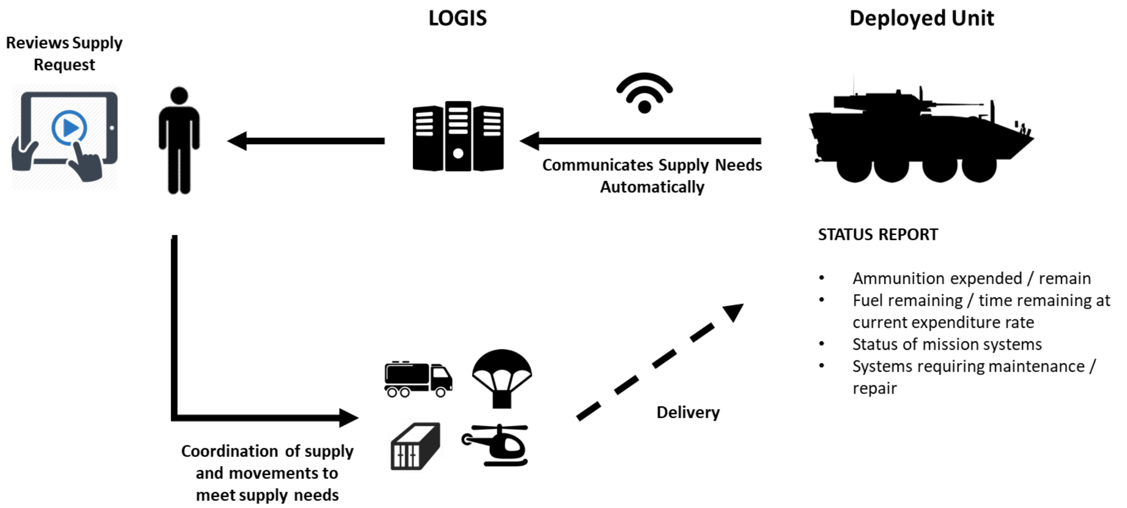


Figure 47: Notional use of IoT for deployed unit resupply

To be effective for military application, certain safeguards need to be in place to ensure sustainability of the IoT-enabled LOGIS. This includes: 1) decentralized infrastructures, 2) network utilization throughout, 3) interoperability across all users (the elements, other government departments, allies, and perhaps suppliers, where possible), 4) security from cyber intrusion and trust in the data, 5) sufficient power to sensors and devices, and 6) application of sematic web technologies [179].

Infrastructures need to be decentralized in order to distribute the potential points of failure and vulnerability to intrusion. Centralized data repositories or clouds are not an acceptable solution to manage the LOGIS enterprise [179]; tactical systems that feed into larger operational or strategic systems would be a more appropriate approach. The future IoT system must be networked and should be able to accommodate more than only the components connected to the LOGIS. Whether through the low-power wide-area network (LPWAN), a military radio network, through secure internet connection, or through cellular connection, to be effective an IoT-enabled LOGIS will need to connect a wide array of entities to a central database. To maintain real-time or near-real-time connectivity, the entities in the IoT network will always need to be connected. Police cars, for example, are already using multiple devices (laptop computers, sensors, mobile devices, etc.) that are bi-directional and rely on high-speed, secure connections [184].

Any IoT system should be interoperable across the Army, RCN and RCAF, given the interdependencies for operations and logistics, and there should be consideration for Whole-of-Government (WoG) interoperability for those departments that work with DND/CAF. *Canada's Future Army* makes clear that future operations envision a WoG effort [13], and an IoT system should therefore accommodate other partners. Suppliers (vendors and manufacturers) should also have some interface with a LOGIS system to simplify orders. The CAF will not likely stockpile all necessary material for every conceivable operation, and during high-tempo operations, shipping material to a DND/CAF facility may inject needless delays when shipping directly to the operational theatre would be more efficient. For those reasons suppliers should have some interface with an IoT enabled LOGIS in order to streamline delivery.

In terms of risks presented by an IoT-enabled LOGIS, there are many; namely, cyber risks, network capacity, architecture and semantic compatibility, and the balance of human-in-the-loop versus automation [179]. Cyber risk will feature prominently in any examination of future technology. This report proposes no solution to managing cyber risks, other than to say that safeguarding the integrity of the network and the integrity of the data on that network is of the highest importance. A system whose value rests on the ability to parse and manage massive amounts data means that data integrity is essential.

For network capacity, there are two challenges: the volume of data, and the volume of transactions. In terms of volume, by 2018 it is expected that 40% of IoT data will be carried at the edge, or close to the edge, of network capacity [185]. In terms of volume of transactions, it is estimated that some devices will require 2500 individual transactions to transmit 1 megabyte of data from a single device [186]. The expectation is that the connection capacity will strain the networks before total bandwidth does [186]. Managing this many connections will be a challenge, with an expected 16 to 135-fold increase in the number of connection by 2020, with IoT connections representing three times the human-initiated connections [186]. These concerns are based on the global use of the internet, including civilians and industry. While the military will typically provide its own networks, the overall strain of the volume of traffic and volume of transactions may present challenges for military application of IoT.

Technology semantics is a concern for any IoT solution. Most IoT solutions are vertical applications used by one company or group of companies to manage knowledge [187]. There are challenges associated with building heterogeneous protocols, data formats, data schemes and services interfaces that will affect interoperability, with other structural challenges posed by scaling, and transmission latency [187]. The benefit for an organization like the CAF/DND is that standard terminology already exists, and common data formats, schemes and service interfaces can be rolled out across the enterprise to minimize those risks. Equally, by defining an enterprise-wide structure the CAF/DND can limit architectural risks. However, this could potentially introduce risk for integrating other government departments, allies and suppliers, if they already use a system that has different data formats and protocols. This is not an insurmountable challenge, though highlights the point that standards must be established to ensure interoperability.

The human-in-the-loop component is also the source of some risk. The algorithms and data analytics in an IoT-enabled LOGIS will be capable of push and pull orders for supplies to be created. The data alone may not tell the whole story, and more context – human-provided context – will likely be required to make decision on authorizing supply delivery. Dangerous areas, planned operations, restricted terrain and other contextual details in the operating environment may not be easily integrated into an IoT-enabled LOGIS. Similar to use-of-force decisions with autonomous or semi-autonomous systems, military accountability requires a human be in the loop to approve the release of supplies. Rather than building a LOGIS where a human-in-the-loop is the exception, to ensure personal accountability a future LOGIS should approach the problem from the other direction: assume that all decision require human approval and define a short list of circumstances and conditions under which pull or push requests can be processed automatically.

Another potential risk is the development cycle itself. Building a system that can meet the Army's logistical needs, while interoperating with the RCN and RCAF, and potentially allies and suppliers, as well as providing data format continuity and appropriate cyber security measures in a distributed environment is a significant technical challenge. Building a LOGIS that integrates into other existing systems like the finance system to ensure that suppliers are promptly paid presents an additional layer of complexity. Large Government of Canada IT programs are complex under the best circumstances, and the number of variables potentially involved in implementing an IoT-enabled LOGIS means that requirements definition and development planning will be a time-consuming and laborious process. However, this process will be necessary in order to avoid the LOGIS becoming another stand-alone system. Implementation of an IoT-enabled LOGIS is likely to be a costly endeavour that will require constant maintenance and modifications to keep pace with new supplies entering the supply chain. A more detailed study of specific options will be required to determine estimated costs, and the potential efficiency savings and improvement in overall performance of the supply chain.

6.1.2 Mobile Asset Optimization

Mobile Asset Optimization (MAO) will rely on IoT technology to improve the efficiency of the transport and movements part of the supply chain. IBM and Vodafone are currently driving efforts to improve analytics on any mobile asset. The IoT-enabled LOGIS mentioned above will be necessary to provide the information infrastructure to manage the supply chain, and MAO will leverage the LOGIS information to improve the efficiency of mobile assets to meet logistical requirements. The initial IBM technology concept was not limited to military application and included other industries that use mobile assets, like utilities (public and private), shippers, aviation, mining, and construction [188]. The focus is on vehicles, ISO containers and pallets, however this could be extended to mobile assets such as autonomous or semi-autonomous helicopters or unmanned ground systems (UGVs) [42]. The system will rely on a global tracking device fitted with batteries that will transmit in real-time and will use existing cellular networks to keep the asset connected to the IoT database [189]. IBM envisions a proprietary dashboard that will deliver insight and predictive value to users to allow them easily see the status of the asset [189].

MAO systems will use big data and IoT to identify trends in mobile asset utilization (payload delivered, routes taken, distance traveled with no payload, etc.) to identify how to maximize the use of mobile assets. Optimization technology can also be used to redesign workflows (i.e.: location of supply depots, time of day for delivery, rate of delivery of bulk consumables, etc.) to more efficiently use mobile assets [190]. The MAO system will also provide contextual details for the supply chain (e.g., weather impacts), predict asset availability, avoid high-risk areas, and provide greater predictability in delivery [191]. It is not known if this will represent an improvement over human-provided context at this time, though the technology promises to provide context through data analytics.

If MAO can deliver on the vision it may provide increased efficiency in the Army supply chain. Based on the observations in Section 4.2 of this document on supply chain visibility, MAO technology would certainly be an improvement over existing capability. This could reduce the cost of the supply chain (cost per thousand pounds of delivery, for example) and therefore the amount of fuel used to operate vehicles and increase the overall fleet availability by optimizing maintenance schedules and crew rest times.

However, the Army supply chain is not exclusively a function of efficiency. Often effectiveness matters more. For example, emergency supply transport to a unit facing threats to life and safety, or emergency medical evacuation for casualties cannot be predicted, and must be responded to urgently. In such situations efficiency is not a success metric: only the effectiveness of saving life and preventing further injury or loss of life. For situations where effectiveness is the key metric, MAO systems will not provide any value. In fact, the emergency allocation of resources is likely to reduce the overall fleet efficiency of those assets, though when balanced against saving life the temporary loss of efficiency hardly matters. Situations where effectiveness is most important will likely tend to be combat missions, peace support operations, and humanitarian relief (either domestically or internationally), though accidents can happen in any operational or training context. The issue of effectiveness is not intended to downplay the benefits of efficiency but is intended to highlight that efficiency is not always the key metric.

The risks for implementing MAO technology are the same as for an IoT-enabled LOGIS, as they will likely operate within a single enterprise. There will be requirements for cyber security, human-in-the-loop, persistent network connectivity, and semantic interoperability with other IoT-enabled systems.

The biggest dependency MAO faces is the requirement for an existing IoT system. An MAO system relies on constant connectivity, like IoT, to accurately track the location of assets and to collect data on asset performance throughout the travel. As mentioned above, an IoT-enabled LOGIS should be part of a larger IoT enterprise. If MAO is determined to be feasible for Canadian Army use, it should be developed on conjunction with an IoT enterprise system. An IoT-enabled system across the CAF/DND enterprise is likely to be expensive and be a multi-year effort.

6.1.3 Conditions Based Maintenance / Health Usage and Monitoring Systems

Conditions Based Maintenance (CBM) is the concept that the condition of key components is monitored to ensure they are still within performance parameters and are replaced proactively once they have crossed the threshold of acceptable life. This replaces the notion of ‘run-to-failure’ where parts in machinery are replaced only after the fail. The ‘run-to-failure’ model risks injuries to personnel and often involves significant higher cost for repair than performing consistent preventative maintenance [192]. The Health and Usage Monitoring System (HUMS) is similar to CBM and is a proprietary system made by Honeywell that has been in service since the mid 70’s and provides on-board monitoring of aircraft component health and is in service with many helicopter fleets doing off-shore oil support work for both passenger traffic and for cargo delivery [173]. Similar systems were implemented by Honeywell for commercial and military fixed wing fleets in the mid-1990s [193].

The use of CBM for military land vehicles follows a similar structure to aviation. The CBM system consists of hardware on-board the vehicle that is integrated with software to measure the use of the vehicle (miles driven, hard turns, hard braking, etc.) that provide diagnostics (i.e.: symptoms of excessive use to determine what is approaching break point) and prognostics (i.e.: predicting how much use parts can endure before breaking or approaching their break point) [194]. The expected outcomes of a CBM system for Army vehicle maintenance are: improved fleet management, provision of more realistic profiles for vehicle testing based on what is learned about the longevity of parts and systems, provision of better data for engineers to improve parts and systems that need greater durability and longer anticipated service life, and most importantly, provide commanders and maintenance decision-makers with near-real time characterization of the overall health of a fleet of vehicles [195].

Use of CBM will provide benefits from the 1st line to the 4th line. For deployed units, using CBM will give accurate status on parts that are approaching the end of their service life, enabling them to be replaced before an operation begins, allowing maintainers to clear vehicles for operations or to ground them for maintenance [196]. Systems are currently available that will allow for mobile devices to access data on the condition of components and systems, enabling a simple interface for 2nd line or 1st line review of vehicle health [197]. It will also allow depot-level maintenance for major systems and components to be scheduled prior to major failures, enabling greater predictability in overall fleet availability [196].

The US Army has attempted to implement a CBM system for its fleets of logistics vehicles and armoured vehicles, and have been facing major challenges with implementation, namely software integration challenges, the lack prognostic maturity due to relatively limited data available on component failure, and conflicting priorities between performance, lethality and survivability of vehicles [196]. As with the observations about IoT systems above, software integration for systems that were not initially designed to be interoperable presents challenges for data formatting and semantic interoperability. This challenge is likely to be reduced over time as more manufacturers consider CBM systems as part of their initial design, but until such a time CBM work is likely to be retrofit. The lack of prognostic maturity is the also the result of the technology being relatively new. Many data points showing failure or near failure on pieces and components will be necessary to improve the accuracy of prognostics for CBM. Like integration, this is a challenge that is likely to be reduced over time. Lastly, the question of priorities for performance, lethality and survivability could be overcome by customizing priorities for each vehicle type and establishing maintenance parameters based on mission type. For example, on humanitarian or peace support missions lethality will likely be second to performance and survivability.

This technology has the potential to improve the overall efficiency of the mobile asset fleet for Army logistics. However, implementation will be a major undertaking, similar to the implementation of an IoT-enabled system. As noted above, it will also take time to realize the full benefits of a CBM system, because it takes time to accumulate sufficient data to observe clear trends.

6.1.4 Digital Twin (DT) / Digital Thread (DTh)

The Digital Twin (DT) concept was initially developed in 2002 and refers to developing a virtual model of an entity, product or service, allowing status monitoring of the real entity, product or service using the digital model [198]. The idea is that the status of things that cannot be physically accessed can still be monitored, and in the case of malfunction, corrective action can be taken. GE is using this technology to attempt to optimize the use of its wind farms using DT technology [198]. Other companies are using the technology to develop 3D DTs to render computer-assisted design (CAD) model for the purposes of experimenting with design [199].

The Digital Threat (DTh) refers to the use of a DT across the full life-cycle from concept development and conceptualization through the production and operations [200]. This means that the ideal DT is developed at the start of the research and development process, included at the start of design [201]. In the IoT environment the DT and the DTh allow for the use of modeling and simulation to predict the future state of assets, and to perform 'what-if' analysis, serve as a documentation and communication mechanism for understanding behaviors that are not easily explained, and connecting disparate systems into a single network once the systems are operational [202].

The DT and DTh concept includes the full life-cycle, from design to field. While this has commercial benefit for manufacturers to better understand how their products behave, the Army is not involved in the specifics of designing vehicles, and manufacturers are not involved in fielding vehicles on operations. Though the Army develops its vehicle requirements, and manufacturers are made aware of how their vehicle components and systems fail, the DT approach implies a single user from design to field. This is fundamentally not the case with Army procurement and fielding of technology. Manufacturers are commercial entities that develop products for Canada's Army and other vendors globally. While these products are designed to meet the Army's needs, the Army itself does not design and test the products. The DT and DTh approach is intended for manufacturers who control the full lifecycle from concept to operations, which is not the case for the Army.

This does not mean that DT technology is irrelevant for the Army, because benefit could be realized by monitoring components and systems. However, CBM, MAO and other IoT solutions are proposing something similar in terms of virtual monitoring of physical entities. If the Army is only in control of the operationalization of vehicles (i.e.: procurement, and then fielding) the full DT and DTh capability is something of which the Army can take full advantage. The DT and DTh technology would likely be useful for maintenance and learning about which components and systems are more likely to fail and under what conditions they will fail. However, an IoT-enabled CBM solution is likely to provide similar insights.

The other limitations of DT and DTh technology are similar to those for all other IoT solutions: the need for persistent connectivity, the need for cyber security and therefore data integrity, and the need for interoperability with other systems in terms software semantics and data format for the DT itself.

6.2 Containers

ISO Containers (also referred to as shipping containers or 'sea cans') are already in use in some countries for managing the military supply chain. Canada, the United States and United Kingdom all use shipping containers to move bulk freight and for road transport.

Figure 48: ISO containers on truck [205], ship [203]and train [204].

The most obvious advantage to using containers is the intermodal nature of the medium. Containers can be loaded in a warehouse or supply depot, and from there can be moved, securely, via rail, ship, aircraft and truck without being opened or the load transferred. This technology is used by major logistics companies over the world and is a recognized global standard. Table 5 below shows the dry weight and the maximum payload of containers from shortest to longest. Given their size – from 8ft containers to maximum length containers of 53ft – there is a range of additional military applications for containers. This includes modified containers acting as metal racks for fuel bladders, workshops, machine shops, medical storage, intelligence and imagery analysis spaces, storage space, ground control stations for UAVs, command posts, washing facilities, generator hosts, map printing shops, temporary housing, or any other purpose that will fit inside the footprint of the material [205].

Table 5: Specifications for ISO Standard Containers

Length (feet)	Max. Volume (cubic meters / cubic feet)	Dry Weight (Kg / Lbs.)	Maximum Payload (Kg / Lbs.)	Means of Transport
8 ft [206]	10 / 353	1,000 / 2,204	5,000 / 11,023	• Stacked on container cargo ships • Train car • Aircraft cargo bay • Airship cargo bay (future) • Truck trailer • Truck cargo bay • Helicopter (8ft)
20 ft [207]	33.2 / 1,172	2,250 / 4,960	30,200 / 66,579	
40 ft [207]	66.7 /2,355	3,700 / 8,157	28,800 / 63,493	
40 ft (tall roof) [207]	76.3 / 2,694	3,850 / 8,488	28,650 / 63,162	
45 ft (tall roof) [207]	86.0 / 3,037	4,700 / 10,362	27,800 / 61,288	
53 ft [208]	109 / 3,849	5,039 / 11,109	25,441 / 56,087	

Ships, trains and trucks with trailers are capable of carrying the maximum weight per sea containers as listed above. The standardized nature of containers means they can be moved through the supply chain and can all be treated equally, in that each container is the same size and has a maximum weight capacity. A benefit of a common standard such as containers is that it provides the Canadian Army shipping options with allies and commercial shippers if organic lift is not available. A commercial standard allows for shipping of goods in containers, without any modifications to the containers. Where practical and where the threat environment allows, this concept could extend to relying on commercial shippers for deliveries to the 3rd line and 2nd line. Global shipping companies already rely on ISO containers for shipping, rail and trucking. Where required, the Canadian Army could rely on commercial shippers for the movement of material. There are, however, concerns with commercial shippers about the security of the cargo, and the timeliness of arrival. The commercial option will be universally applicable, however, where the shipper can be trusted and relied upon to the same standard as the Canadian and Allied supply chains, these options should be pursued.

The size and payload of containers will impose some limitations of movements when relaying on organic Canadian assets. The CC-177 and CC-130J can fly into 3rd line facilities and are capable of carrying loaded ISO containers. The CC-177 is capable of carrying 160,000lbs of cargo [58] and has a cargo capable of taking on all size of containers, up to the maximum payload of any container. The CC-130J is only capable of carrying 48,000lbs [56], meaning that with the weight of the container the actual maximum loading is only 45,000lbs, or roughly 75% of the maximum weight that a container can carry. The CH-47 is capable of carrying a maximum load of 24,000lbs [75] and is capable of sling loading only the 20ft ISO container [209], imposing limits on modular use for the CH-47 both in terms of container size, and how much payload can be put in a container. 53ft and 40ft containers cannot be flown forward, and 20ft containers can only be flown forward with roughly two thirds of their maximum capacity. 53ft and 40ft containers can still be moved forward using trucks, however this a more time-consuming process and makes ground movements more vulnerable to enemy activity. The only other known solution for flying a 20 ft ISO container (or similar load) is the CH-54 Tarhe used by the US Army during the Vietnam war. It is still used by NASA to support research and by civilian operators for heavy-lift work as the S-64 Skycrane [210]. Either variant of the helicopter has an open space where most helicopters have a fuselage and is capable of carrying 20ft ISO containers and other customized container loads. The maximum payload is for 20,000lbs on a hook or using fours hoists to support larger loads [211], meaning there is still a significant payload restriction for air movements compared to what the container can carry.

Figure 49: C-54 Tarhe [212] / S-64 Skycrane carrying custom load and ISO container [213]

Figure 50 below shows a comparison of the maximum payload of containers (in orange) and the maximum payload that aircraft can carry (airships in green, others in blue). The maximum payload for the containers exceeds the capability of all platforms, except the CC-177. When moving containers by ships or trains, this does not impact the supply chain, however this risks the creation of a bottleneck at 3rd line supply depots.

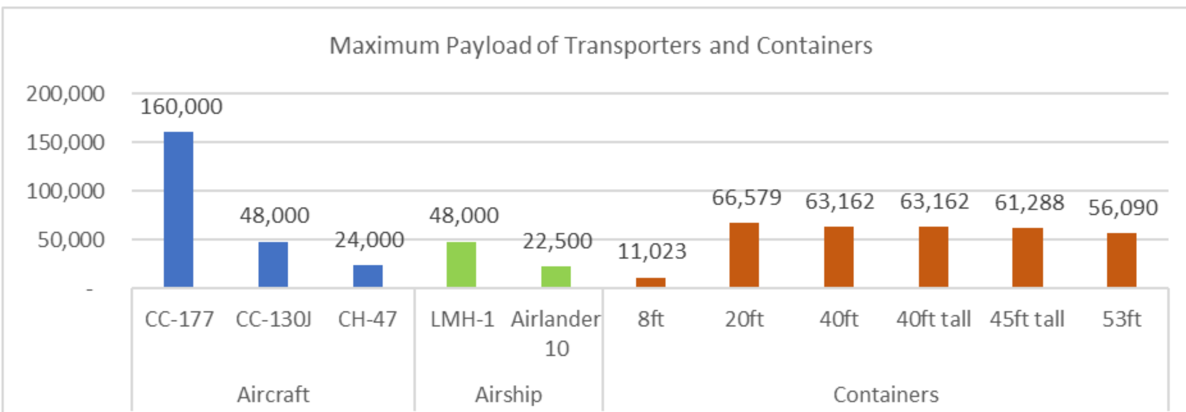


Figure 50: Maximum Payload of Transporters and Containers

This bottleneck for the container payloads applies mostly to moving container cargo between 3rd line and 2nd line facilities. There are only two practical options for moving containers cargo from 3rd line to 2nd line: 1) rely on trucks capable of carrying the full payload in a container or 2) unpack the containers into pallets so smaller vehicles like helicopters, autonomous or semi-autonomous helicopters, UGVs, or UAVs can transport portions of the container's load forward. In a permissive environment with a low threat profile, trucks will be adequate for moving full containers to 2nd line facilities, similar to how civilian trucking operates today. However, in higher threat environments trucking with trailers may not be an option. In this case, the cargo from containers will need to be unloaded into pallets and then moved to 2nd line facilities using other means. This concept is illustrated below in Figure 51.

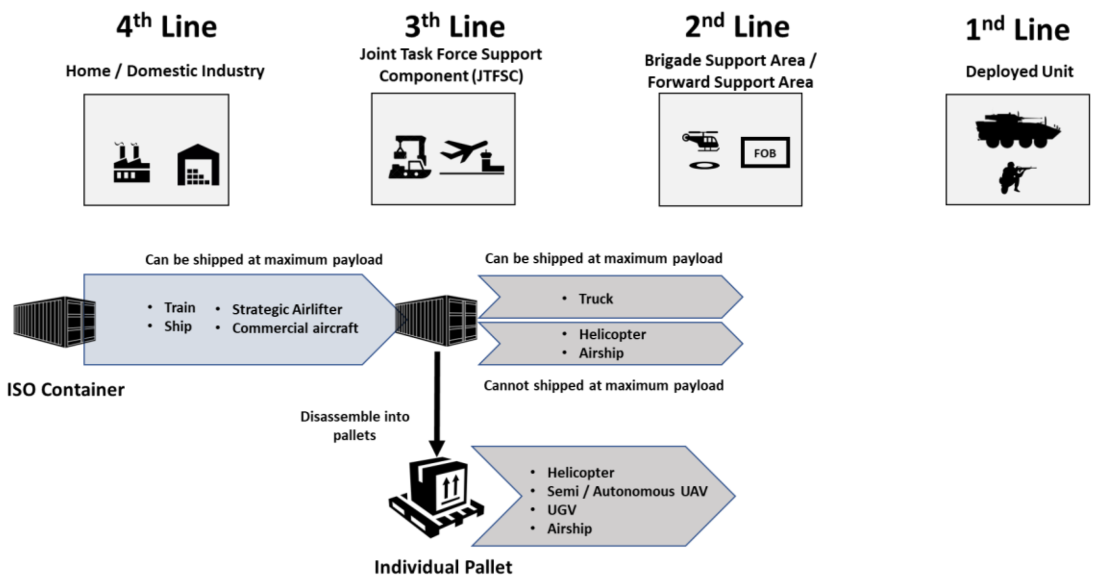


Figure 51: movement of ISO containers, and the challenge of moving from 3rd to 2nd line

The pallet concept can work in reverse, with palletized cargo being shipped in aircraft that cannot handle containers (commercial aircraft without ramps to accommodate front or rear-loading). This applies especially to commercial aircraft, or to converted commercial aircraft like the CC-150 Polaris. Lacking ramps, commercial aircraft can be loaded with pallets for transport to 3rd line facilities, where palletized cargo can be off-loaded into containers once located at a 3rd line facility. Pallets could be loaded directly into a transport vehicle from a 3rd line facility without being put into containers, using semi-autonomous or autonomous UAVs, helicopters, UGV, airships, or used with a JPADS kit for precision drops into contested areas. The benefit of using pallets is the significant weight savings over using steel ISO containers that weight thousands of pounds empty. There is also no evidence available that ISO containers can be safely air-dropped.

There are commercially available palletized solutions currently available that are designed to fit inside ISO standard containers. Inka Paletten manufactures two sizes of press-wood pallets that are configured to fit inside 20ft or 40ft ISO containers, carrying 10 and 20 pallets respectively for the larger pallets and 15 and 30 pallets respectively for the smaller pallets [214]. Boeing makes a series of pallets and containers for cargo carriage in their civilian cargo airlines. These containers are designed to fit in the main cargo area or in the lower hold and are typically a maximum of 96 inches (8 feet) wide [215], the same width as an ISO standard container. The case of pallets is not an either / or endorsement for pallets over containers. Rather, the two should be used together depending on the situation and should be totally modular and compatible.
Figure 52 below illustrates the concept. For train and sea traffic, containers make the most sense due their modularity and interoperability with existing commercial means. Containers may be the best solution for trucks in permissive environments, however in higher threat environments pallets may be a better solution. Using a modular and compatible solution will allow planners to use the appropriate mix of pallets and

containers based on the payload carried, combat unit requirements, the transport options available to move supplies forward, and the threat environment.

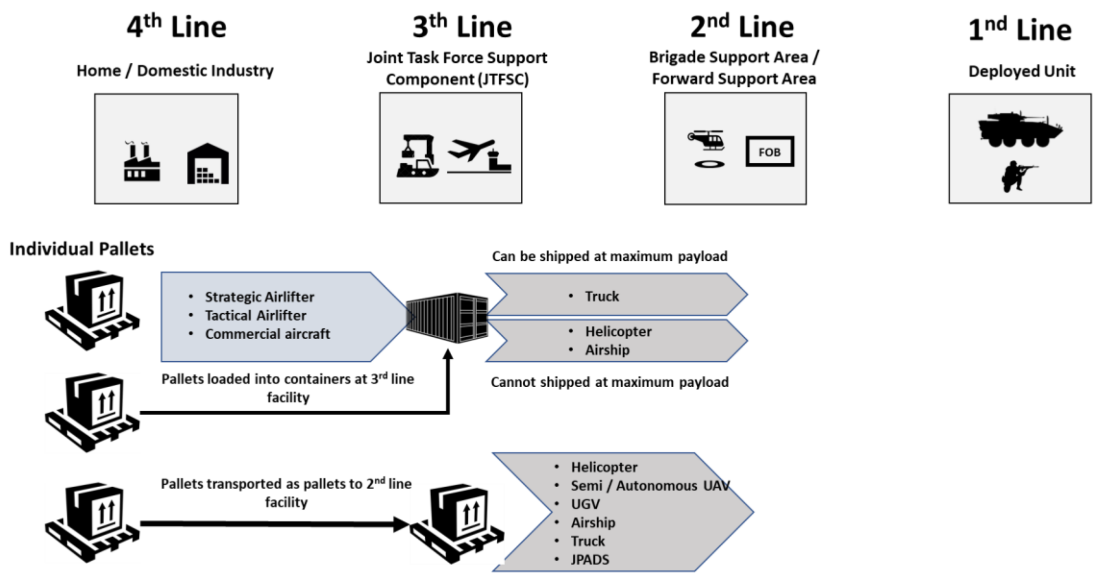


Figure 52: Pallets and containers for supply movements.

In terms of mission types, as envisioned by Canada's Future Army [12] the domestic missions are all suitable for the use of containers, and most likely with trucks doing delivery to 2nd line facilities. The main limiter for domestic operations will not be the threats posed by belligerents, but terrain challenges presented by washed out roads (floods, earthquakes, etc.) or remote and inaccessible areas were roads may not be available or only seasonally available (the arctic). Terrain challenges will apply to expeditionary operations, though the primary difference between domestic and expeditionary operations is the potential for a higher-threat environment for expeditionary operations.

The last challenge for using containers is the weight and accumulation of empty containers. ISO containers are made of steel, and as shown above in Table 5, weigh thousands of pounds empty. For every shipping container used to deliver material to an operation, there will be costs incurred for the delivery not just of the freight but also of the container. This is not concerning when relying on shipping or trains, where thousands of tonnes of cargo are being shipped, and the economies of scale are worth the price. The concern is for using aircraft, where a 5,000lb container means 5,000lbs less useful load that can be carried. There is also the question of what to do with empty containers at the end of the supply chain. Every container that is shipped or flown or trucked into an operational theatre must be either shipped out, recycled, repurposed, sold off, destroyed, or abandoned. As mentioned above, shipping containers have many uses as buildings, however once there are enough buildings the remainder of the containers will simply accumulate. Managing accumulated containers creates another set of tasks for logisticians.

The weight challenge will not, however, affect the improvements that can be made using digital technology to better track shipments and improving visibility on the supply chain. This is mentioned above in the IoT section, though the issue of RFID tags merits its own discussion here. An RFID tag solution to track material could be implemented without being a full-fledged IoT solution.

The maturity options available to container shipping have more to do with data and routing management for cargo using principles from commercial logistics and supply chain operators that with the physical container itself. Companies like Canada Post, the United States Postal Service, FedEx, UPS, Amazon and DHL all provide their customers with tracking numbers that allow them to track to progress of their package in the supply chain. In the case of online shopping, Amazon, for example, allows customers to track when a package was collected from the warehouse, when it entered the mail stream, when the package is in transit to the distribution centre in their region, and when the package is out for delivery. This technology allows customers to see where in the delivery chain the package is, though not the package's real time location.

DHL, UPS and retailer Walmart / Sam's Club are all using RFID tags to track their packages and to provide that data to their customers. DHL uses a website that allows customers to identify where their package is located, and for large-quantity shippers can provide data analytics in a range of downloadable formats [216] [217]. The RFID tags themselves have proven effective in temperatures ranging from -20 to 70 degrees Celsius, with up to 1-year battery life through multi-modal application, showing longevity in all operating environments [179]. Amazon is using the same technology (with the addition of infrared sensors and pressure sensors) for its Amazon Go retail outlets, a store where customers bring only their cell phone with them to shop [218]. A gate at the exit senses all the RFID tags in a customer's basket, and then bills them via their Amazon account for their basket of goods [219].

The use of RFID tags could be useful for tracking containers, and for tracking the material inside them. Containers with RFID tags can contain other items with other RFID tags – such as pallets, cartons or individual items for example – each that has its own RFID tag. Tagging pallets, cartons or individual items with RFID tags and nesting them within a container will allow someone with a handheld reader to identify everything in the container and its destination without opening the container [220]. This concept is shows below in

Figure 53 showing pallets with RFID tags inside a container, and a person using and RFID reader to confirm the contents.

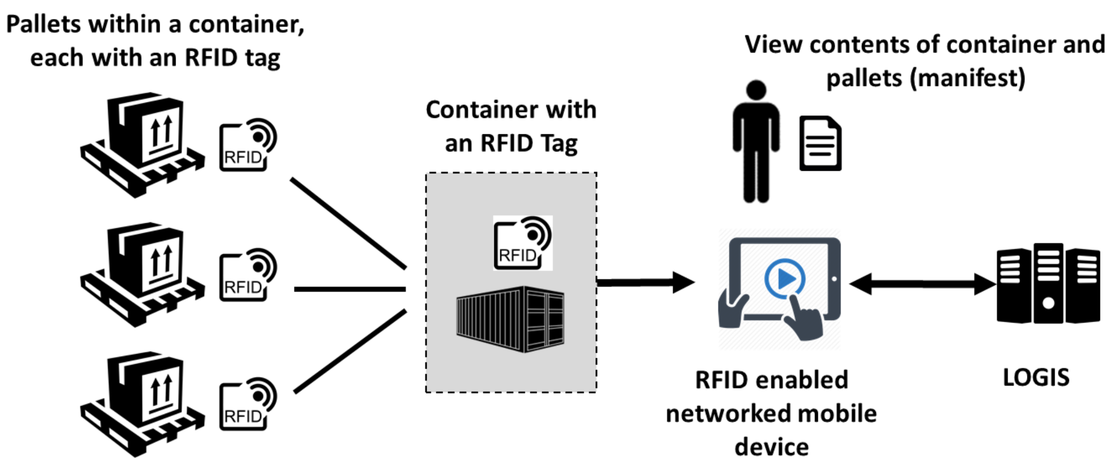


Figure 53: RFID enterprise concept for containers and pallets

RFID solution are currently in service commercially and should be examined by the Army. This could include the use of RFID tags as part of an IoT solution or could be a modification of an existing commercial supply chain system that uses RFID tags or comparable technology.

6.3 Airships

Airships are not new as a concept for military aviation and transport. German airships existed prior to and during World War 1 for scouting and for bombing raids, and British and American variants were produced after the war. However, they had not been meaningfully re-examined for military applications until recently. There are two viable concepts currently in development and on the verge of going into service. The American Lockheed Martin LMH-1 and the British Airlander 10 are the ships in the most advanced state of development. For the purpose of comparison, this report is looking at the two most mature designs in the marketplace – the Lockheed LMH-1 and the Airlander 10 – and one that remains a concept – the Aero ML 86X. The ML 86X was chosen because of its ambitious payload target.

Table 6: Summary of airship technology under development

System	Country of Origin	Cost	Range	Payload	Speed	Other
Lockheed Martin LMH-1 [46]	US	~$40m per unit [221]	1400 nm / 2600 km	47,000 lbs (23 tons)	Max: 60kt	Runway: 730m VTOL: 150m
Airlander 10 [52]	UK	~$40m per unit [222]	~14,400 km, or 5 days	22,050 lbs (11 tons)	Cruise: 80kt Loiter: 20kt	VTOL: ~150m
Aero ML 86X	US	TBD	5100nm / 9,445 km	1M lbs. (500 tons)	Max: 120kt Cruise: 100kt	Still a concept

The drivers for airship development are military, though the cargo mission is a civilian spin-off. The Airlander 10 and LMH-1 began as a surveillance and reconnaissance testbeds for a US Army research program called the Long Endurance Multi-Intelligence Vehicle (LEMS) [223]. The intent of the initial US Army airship competition was to develop a system that could stay aloft for an extended period of time and carry multiple sensors. The Airlander 10 program won the initial competition, beating out rival Lockheed Martin for the contract [224]. Airlander 10 claimed a maximum loiter time of 21 days at an altitude of 20,000ft with a 2,000-mile radius [190] carrying a maximum payload of 2,500lbs [225]. However, the surveillance program was cancelled, and the Airlander 10 was then transformed into a potential cargo platform, with a reduced range and increased payload to reflect the cargo mission. Lockheed Martin had already transitioned its surveillance and reconnaissance testbed into the LMH-1 cargo delivery product that it is in the market today.

The LMH-1 is capable of carrying passengers and cargo with the purpose of delivering workers and material to remote worksites, like mining, and oil and gas operations. Lockheed Martin has a contact in development with Straightline Aviation for moving supplies and for transporting ore from a mine in northern Quebec to the railhead in Schefferville [226], and for moving personnel and equipment in support of oil and gas operations [227]. The driver for both mining and oil and gas is reducing costs of transport by not building permanent infrastructure (roads, rails, etc.) to connect job sites with transport hubs. This is especially true for oil and gas producers, given the major drop in energy prices in recent years. The cost and profit models for a $90 USD barrel of oil drive different calculations compared to a $40 or $50 USD barrel of oil [191].

The primary advantage for CSS and logistics is that airships are much more fuel-efficient than traditional aircraft and require almost no infrastructure at landing and takeoff zones [228]. This means that airship operations will reduce the requirement for fuel supply, compared with tactical airlifters. The limited infrastructure requirements mean that airships can land virtually anywhere there is sufficient space to do so, and then off-load their cargo or take on passengers and cargo. This has potential applications for many expected missions as outlined in Canada's Future Army [12]. Airships will be very desirable platforms for providing missions to Canada's north (as a mining company is already planning to do), outside of areas with prepared airfields, providing humanitarian relief operations, aid to civil power as part of an emergency response, non-combat evacuation operations, and providing general re-supply to other missions at home and abroad.

However, there are shortcomings with airships that may prevent successful implementation, namely: their low airspeed compared to existing tactical airlifters, the fact that they carry roughly the same payload as existing tactical airlifters, and concerns about maturity and reliability of the airships, the slow progress of the large payload concepts, and the potential for helium shortages.

The fastest viable airship – the Airlander 10 – cruises at 80kt, roughly a quarter the airspeed of the CC-130J [56], less than one fifth the speed of a CC-177 Globemaster [229], one sixth the speed of the CC-150 Polaris [59], and only half the speed of the CH-47 helicopter [75]. In terms of payload, though Airlander and Lockheed both have plans for airships with heavier payloads in the future, the best currently available payload, in the case of the LMH-1, is on par with tactical airlifters like the CC-130J. The CC-130J has a maximum payload of 48,000lbs [56] compared with 47,000lbs for the LMH-1, and only 22,050lbs for the Airlander 10. The Airlander 10's payload is less than that of the CH-47 helicopter. The impact of slower speed and less (or at best, comparable) payload is that more airship sorties will be required to meet the same payload requirements.

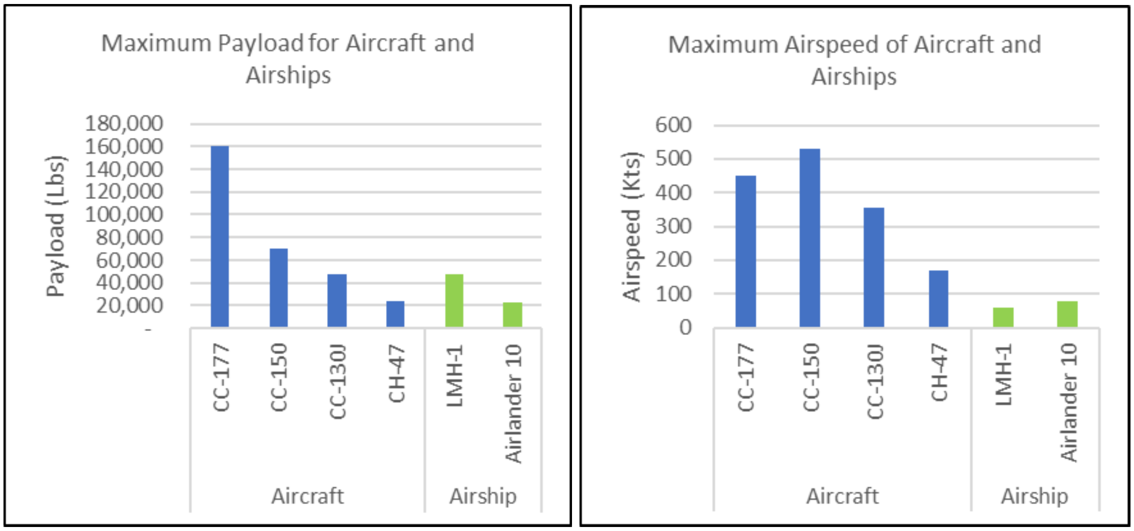


Figure 54: Comparison of Maximum Payload and Airspeed of Aircraft and Airships

The combination of a higher airspeed an equal or greater payload means that fixed wing aircraft currently deliver more cargo, faster. This allows for follow-up trips to be made much faster, resulting a huge advantage for fixed wing aircraft supplying a deployed task force.

Figure 55 shows the time required for a number of platforms to travel 2,000km, and the maximum payload that each can deliver in one trip. The scenario presented (travelling from 4th line to 3rd line) could represent domestic deployment or could represent an expeditionary mission from a strategic supply area (4th line) to the main airhead for an operation (3rd line). The table at the right in the diagram then shows how many return trips (flying into the theatre of operations with maximum payload, and then flying back empty) each platform needs to move 1 million pounds of cargo, and how many hours of flight time that requires (excluding loading and unloading time, crew rest, etc.).

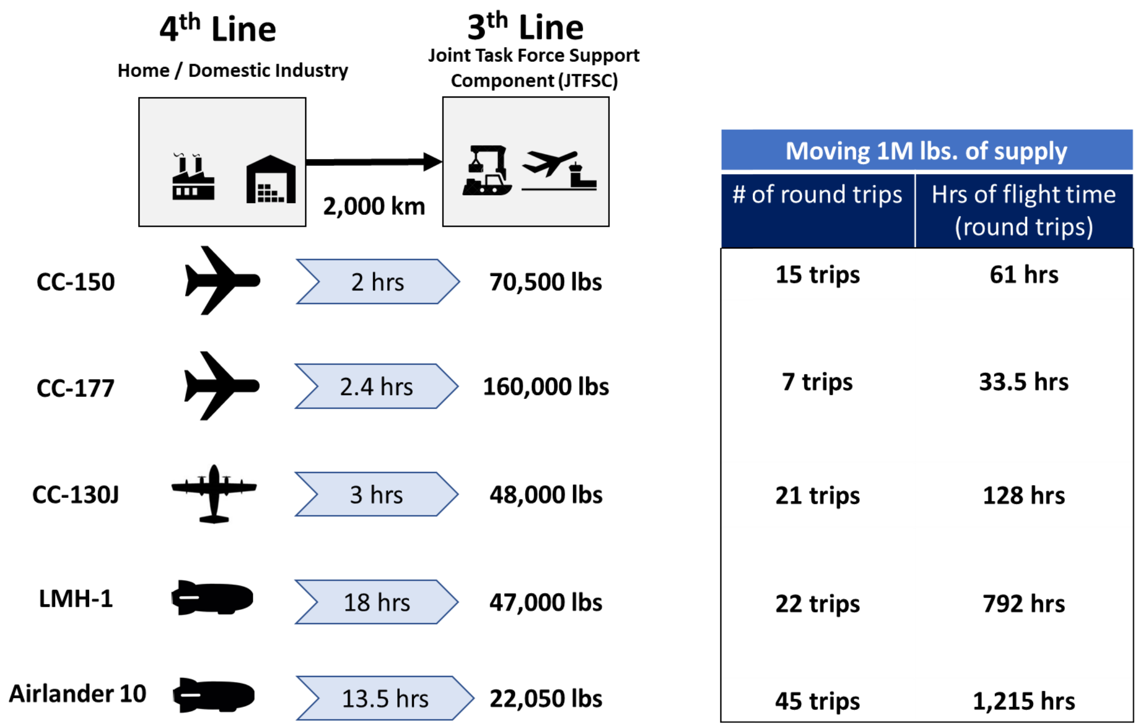


Figure 55: Comparison of airships to aircraft for 3rd line resupply

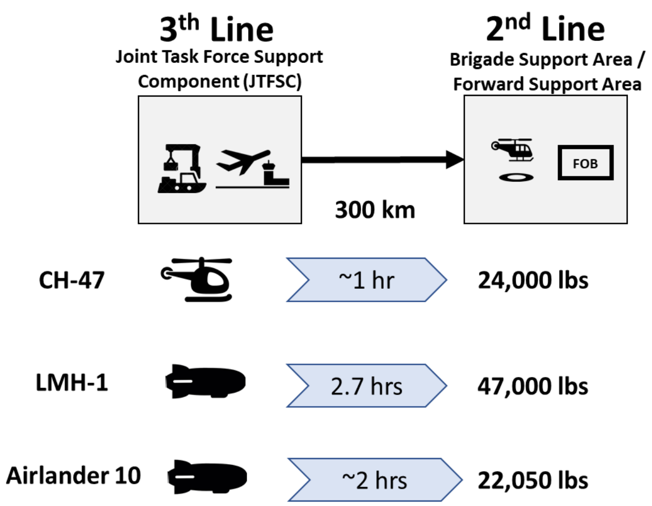
The CC-177 is clearly the most efficient mover, in terms of the weight that can be moved per flight hour. For every CC-177 flight hour, the LMH-1 needs to fly 23.6 hours to move the same weight, and the Airlander 10 needs to fly 36.3 hours. While there are claims that the airships are more fuel efficient that conventional aircraft it is not currently clear if they are 23.6 or 36.3 times more efficient, respectively; though this is possible. More detailed figures on the cost-per-hour for all the different platforms is necessary to accurately compare operating costs.

Table 7: Efficiency of Flight Hours - Comparison to CC-177

Platform	For each CC-177 flight hour, the following number of flights hours are required to move the same payload
CC-177	1
CC-150	1.8
CC-130J	3.8
LMH-1	23.6
Airlander 10	36.3

These figures show us that airships – with their current payloads – cannot compete with fixed wing aircraft in terms of the time it takes to move cargo and can only compete with the CC-130J on total payload. Even then, the CC-130J can move material six times faster (flight hours) than the most efficient current airship, the LMH-1. This is a major concern if we consider the value of having a responsive and agile supply chain. Being responsive to changes in demand for supplies will require a rapid re-allocation of transport and movements resources. The time required using currently available airships will severely limit the agility of the supply chain, when compared to existing air platforms. While airships may be the most efficient platforms (and this is not yet confirmed) they cannot compete with the effectiveness of fixed wing aircraft, when measuring lift and time to delivery.

For moving supplies from 3rd line to 2nd line facilities, airships are currently competing primarily with the CH-47. Figure 56 below shows a similar comparison of airships to aircraft as represented in Table 8 above, but for transport to 2nd line facilities. The CH-47 is much faster that either airships, though the LMH-1 carries almost twice the payload, and the Airlander 10 carries almost the same payload. This means the CH-47's advantages are in speed and time to delivery; both of which are vital in threat environment where time is a factor for success. This shows that for 2nd line delivery the currently available airships show some promise as potential platforms for CSS, if time is less vital as a success factor.



Moving 1M lbs. of supply	
# of round trips	Hrs of flight time (round trips)
42 trips	80 hrs
22 trips	119 hrs
45 trips	182hrs

Figure 56: Comparison of airships to aircraft for 2nd line resupply

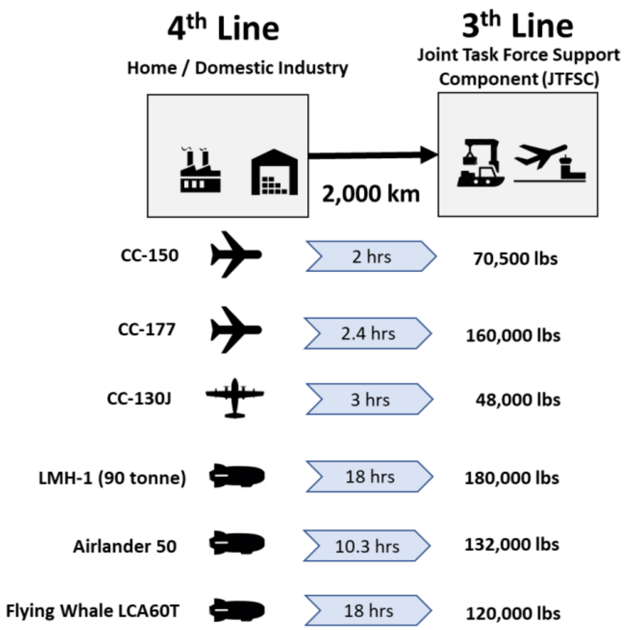
The threat environment and the landing space still present challenges for airship delivery to 2nd line facilities. Airships are clearly vulnerable to ground fire due to their size, their limited maneuverability, and the fact they are in effect a balloon and therefore vulnerable to small arms fire. A CH-47 can maneuver aggressively to avoid threat areas and has weapons to provide local self-defence. An airship could be armed; however, this would not prevent the airbags from presenting large, attractive targets, with limited ability to maneuver to avoid targets. Another challenge for airships, especially in urban environments, is finding sufficient space for a safe landing. Though they require very limited infrastructure on the ground to enable them to land and offload supplies, both the LMH-1 and Airlander 10 are 80+ metres long and require about 150m to land. Unlike at CH-47 that can carry a slung load, airships will take more time to unload and will need to spend longer on the ground. However, operating in low-threat environments with sufficient landing space airships are a viable option, and are reputed to be a lower-cost option than traditional aircraft.

There are airships under development that are claiming larger payload than any other airships, seeking to compete with strategic lift aircraft. Lockheed Martin is claiming a future design based on the LMH-1 with a 90-ton payload that could be in service by 2019 [194], representing a more than three-fold increase from the current 24-ton maximum. Airlander is also claiming that it will extend the Airlander 10 concept to an Airlander 50, capable of carrying 132,300lbs (66-ton) and could be in service by the 2020s [230]. Airlander also claims the Airlander 50 will be capable of carrying 50 passengers and 6 ISO containers [230]. This is an interesting claim, given the total weight of most ISO containers is over 60,000lbs (see Table 5 for specifications), meaning each of those six containers can weigh no more than 22,000lbs, meaning slightly more than one third of maximum capacity. The claim of 6 containers is likely meant to showcase volume capacity, not payload. Another experimental airship design is the Flying Whale LCA60T, made by a French / Chinese consortium and is claiming their airship will be capable of lifting 120,000lbs, cruising at a speed of 60kts [231]. The Flying Whale appears to be a drawing at this stage, with no operational prototype available. The same is true of the LMH-1 and Airlander 50 concepts: there is no material available on experimental airframes available.

Table 8: Comparison of aircraft to airships for 2nd line resupply

System	Country of Origin	Cost	Range	Payload	Speed	Other
Lockheed Martin LMH-1 – 90 tonne (concept)	US	N/A	N/A	180,000lbs [194]	Max: 60kt (assumption)	
Airlander 50 (concept)	UK	N/A	3,500km [230]	132,0000lbs [230]	Cruise: 105kt [230]	Still a concept
Flying Whale LCA60T	France / China	N/A	N/A	120,000lbs [231]	60kt [231]	

If we compare the airships that are still a concept with existing fixed wing platforms (as we did in Table 8) we see that increased payload significantly reduces the number of trips required and therefore also reduces the number flight hours required to move 1 million pounds of cargo. In fact, the increased cargo capacity means that the airship concepts are competing with the CC-177 for the heaviest hauler. When the LMH-1 increases payload from 24 tonnes to 90 tonnes we see a reduction from 792hrs to 216hrs to move 1 million pound of cargo, a 73% reduction in the number of flight hours required. For the Airlander, when payload increases from 10 tonnes to 66 tonnes, and speed increases by 20kt the number of flight hours required to move 1 million pounds of cargo is reduced from 1,215hrs to 164.5hrs, an 86% time savings.



Moving 1M lbs. of supply	
# of round trips	Hrs of flight time (round trips)
15 trips	61 hrs
7 trips	33.5 hrs
21 trips	128 hrs
6 trips	216 hrs
8 trips	164.5 hrs
9 trips	324 hrs

Figure 57: Comparison of airship concepts in development to aircraft for 3rd line resupply

This is a signification observation, in terms of future potential. Based on the comparisons in Figure 57 we see that as payload increases the number of trips required is significantly reduced along with the total flight hours required to move 1 million pounds of cargo. The reduced operating costs that airships will allegedly provide may be worth the trade-off in time, *if the future payloads are realized*. The previous concerns about the capability of flying airships compared to in-service aircraft are reduced somewhat if the payloads envisioned can be realized. The initial concerns about landing space and survivability in high-threat environments remain.

Notwithstanding the promise of larger payloads, there are still some concerns about the durability of airships, including those in service. An Airlander 10 had a very hard landing (or possibly a crash) during a test flight [232] in 2016. More recently in 2017, an airship broke free from its ground moorings resulting in the skin being punctured, deflating the airships and injuring two people [233]. These concerns have more to do with operator safety than payload capacity and should be rectified before taking any airship platform into service.

In terms of sustaining airships through their life cycle, there is concern about the global supply of helium available. According to some, the helium shortage is often over-stated, however it remains a non-renewable resource, and perhaps the remaining supply will find more demand in the medicine and research sector than transport [196]. Hydrogen is the other obvious option, and we know from the Hindenburg disaster that this is not viable for the future as an alternative gas to helium in airships. If there is, in fact, a helium shortage now or anticipated in the future, this presents a major obstacle to the sustainability of airships.

To summarize: airships are not likely to replace existing tactical and strategic airlifters in the near future for 3rd line resupply. Their payload is too small and speed to slow to compete with the rate of supply that can be delivered by airships. As payloads for airships increase they may present a viable alternative to fixed wing aircraft. In terms of 2nd line supply, the payloads are sufficient to provide re-supply, however there are major concerns about survivability of airships in the urban environment or any high threat environment. The nature of airships means this challenge is not likely to be overcome. The greatest valued-added that current airships can provide is for resupply to forces in a low-threat environment where there is limited infrastructure. Operations far from built up areas (desert, arctic, low-density littoral, etc.) are good candidates for airship resupply, especially domestic arctic operations with limited airfield infrastructure. As technology advances and payloads increase, the comparative value of airships over fixed wing aircraft should be reconsidered. If possible, cost-per-hour and cost-for-payload comparisons between airships and fixed wing aircraft should be conducted to determine exactly how much cost savings can be realized from airship re-supply operations.

6.4 Large UAS for Bulk Delivery

There are three basic types of large UAS for bulk delivery: removing the human pilot from the cockpit of existing helicopters (making them, in effect, converted platforms), experimental technologies for new UAS (consisting of the ARES and BlackKnight Transformer), and a precision parachute delivery system (JPADS). Each of them will allow for resupply to happen without a human operator on board the system delivering supply. A summary of the estimated costs, range, payload and speed is provided for each system in
Table 9 below. Figure 58 below also shows the payload comparison for all the large UAS systems mentioned in this section.

Table 9: Summary of large UAS for bulk delivery technology under development

System	Country of Origin	Cost	Range	Payload	Speed
K-MAX	US	~$8m per unit [234] ~$1300 per hour [61]	396km with load 494km without load [235]	6,000lbs at sea level 4,000lbs at 15,000 ft [235]	80kt with load, 100kt without load [235]
AACUS (UH-1)	US	AACUS can be used for any aircraft (the largest cost)	455km [74]	4,800 lbs [74]	106kt [74]
AACUS (Bell 206)	US		602km [236]	2,119lbs [236]	109kt [236]
AACUS (H-6)	US		6 hours endurance [73]	1,000 lbs unmanned 1,200 lbs manned [73]	145kt [73]
OPBH	US		592km [71]	9,000 lbs [71]	150kt [71]
Black Knight Transformer	US	TBD -still experimental	TBD – still experimental	1,500 lbs (fly only) 1,000 lbs (driving) – projected [76]	70mph driving [76] – No flight experiments beyond hovering
ARES [78]	US	TBD – still concept	TBD – still concept	3,000 lbs – claims. Still concept	TBD – still concept
JPADS [81]	US	2,000lbs kit cots ~$30,000 (USD) 200-750lb kit costs ~$18,000 (USD)	25,000ft droppable, with plans for 35,000ft. [82], with 25km standoff range [81]	2,000 lbs, 10,000 lbs, with plans for 30,000lbs and 60,000 lbs [82]	N/A – dropped from aircraft.

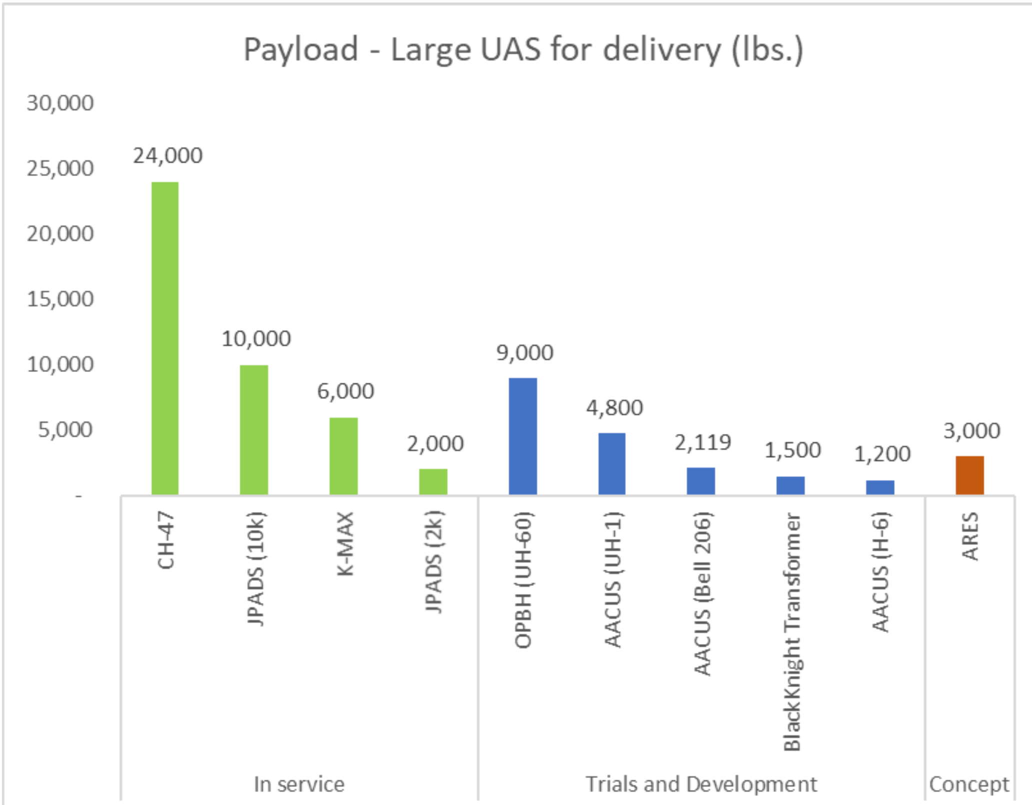


Figure 58: Maximum Payloads for Air-Delivery Options

The technology improvement of the converted helicopters rests primarily with the reduced risk of injury for personnel in the removal of the pilot, the increased endurance of the aircraft due to lack of crew rest, and overall reduced complexity in planning and briefing a human crew that does not exist.

In terms of improvement over existing systems, for retrofitted helicopters there is no change in maximum payload, less the weight of the pilot. The K-MAX is the most notable of the unmanned helicopter retrofits. It is a retrofit of a single seat helicopter with a narrow fuselage and contra-rotating blades that give is an exceptional lift-to-weight ratio. It is capable of carrying 6,000lbs in a sling load (it has no internal capacity), though only weighs 5,000lbs empty itself. Three K-MAX were evaluated operationally in Afghanistan over a three-year period and showed positive results. Testament to the fact that an unmanned aircraft can exceed human endurance (due to lack of pilot), the K-MAX conducted 5 resupply missions to a FOB in Afghanistan in one day, delivering a total of 30,000lbs, all without a pilot [237] in the aircraft. The K-MAX uses inertial navigation – like other unmanned platforms – and relies on a mobile device to program waypoints for the aircraft while flying, using line of sight (LOS) and beyond line of sight (BLOS) technology to dynamically re-task the aircraft while in flight [238]. It is not clear if a pilot can take manual control of the K-MAX. The K-MAX is not intended to serve any additional purpose: it is purpose designed for heavy lift and can operate during the day or night with equal performance [239].

One K-MAX reportedly crashed because of heavy tailwinds that the flight computer could not adequately compensate, resulting in the loss of the aircraft and load [240]. The mission commander reportedly could not recover from the loss [63], raising questions about how the balance between autonomy and human input. The fact that a mission commander intervened directly in the use of the K-MAX implies the potential for more direct contact than with the other autonomous helicopters below, all of which imply that mission control for the K-MAX includes more than just mobile device inputs, if required. Notwithstanding the crash, the driver for the continued use of the K-MAX stems from mission success in Afghanistan, the dedicated nature of the platform, and the high lift-to-weight ratio. The K-MAX is designed solely for heavy lift, so there is no competition from other mission sets: it has a dedicated purpose. The payload is higher than the other unmanned helicopters and has proven its ability to deliver supplies in an active theatre. This is the most advanced of autonomous helicopters in general, and specifically compared to the other aircraft in this section.

The AACUS and the OPBH variants are configured to be pilotless aircraft, however typically with the AACUS system there are no pilots, and with OPBH there is only one flying pilot on board. The core of the technology is in removing helicopter pilots from the aircraft. Nothing else about the aircraft changes. The AACUS system has the proven versatility to be installed in multiple existing rotary wing platforms. Different airframes lead to wide variability in payload potential, based on the performance parameters of the aircraft. For example, in the AACUS H-6 allows for only 1,000lbs of cargo in the manned configuration and 1,200lbs without a pilot in the aircraft [73]. The UH-1 and Bell 206 can clearly carry far more, as we see in Figure 58.

The larger the aircraft the greater the payload benefits based on reduced crew weight. Aircraft like the UH-60 (OPBH) require flight engineers and crew chiefs to do things like spot landing zones, check landing zones for debris, and guide pilots to landing. With a system like OPBH developed by Sikorsky, the only person that may be required is one pilot, and this is optional. The crew chief(s) / flight engineer (s) are not required because the OPBH system uses sensors to scan landing zones and ensure a safe landing. Making the conversion from a traditionally piloted aircraft requires very few modifications, and typically only requires installing the flight management system to be compatible with the remotely piloted capability and establishing a UAV-standard datalink [241]. Sikorsky claims these modifications are simple enough that the same aircraft can be switched from the piloted to remotely piloted configuration if the mission requirement changes on a given day.

Retrofitted aircraft gives air power employers the ability to rely on one airframe and change the piloting requirement based on the task type and threat environment. For example, a transport or resupply mission in a low threat environment could be accomplished using K-MAX, OPBH or AACUS, and the same aircraft could later be flown with a human pilot if the threat environment or mission type changes. This provides air commanders with additional flexibility to manage crew and crew rest requirements [242] to meet land commanders operational and sustainment requirements. Large-scale introduction of these systems provides greater benefit than just the crew rest of an individual crew: it will allow the helicopter fleet to fly more mission that don't require aircrews. For un-crewed logistics and supply missions, un-crewed or partially crewed aircraft can serve to accelerate the overall tempo of air re-supply missions and therefore to volume of supply that can be moved from 3rd to 2nd line, or even delivered to the 1st line. In the Canadian context, this means there is potential for technologies like OPBH or AACUS to be used in the CH-47 and CH-146 fleet for land-based re-supply missions. It should be noted that these aircraft are operated by the Royal Canadian Air Force (RCAF) and not the Canadian Army and would therefore need to be a directive at the joint level.

The experimental aircraft in the large UAS category (the Black Knight Transformer and the ARES) present different type of improvement over existing capabilities. The Transformer was designed to be driven like a vehicle and flown like a helicopter, carrying a payload of 1,500lbs at a maximum altitude of 10,000ft [76]. The experimental videos show the transformer driving and flying at a hover, though without payload or personnel on board [243]. It does not represent an improvement over existing technology at this stage in its development: it is not flying beyond a hover, and its payload is only slightly greater than an AACUS H-6 (a converted light scout helicopter).

The Aerial Reconfigurable Embedded System (ARES) concept is built around a core flying wing without fuselage that includes two electrically driven lift / thrust fans, transitions between hovering and straight-ahead flight using a tilt-rotor concept like the MV-22 Osprey. The ARES is designed to carry a wide array of modular payloads under the tilt-wing, including cargo, casualty evacuation, a light vehicle, or an ISR platform [78]. It has a maximum payload capacity of 3,000lbs, has flight performance similar to other light aircraft, and can take off vertically like a helicopter, and is designed as an unmanned aircraft [78]. For urban operations, the ARES is well suited for small landing zones, with a smaller landing footprint than conventional helicopters, and can be controlled with ruggedized mobile devices [77].

The modular approach of ARES provides the opportunity to simplify maintenance and repair of the actual ARES aircraft, and the modular payload approach will allow for a single standard for containers. The ARES flight platform can be used for supply, casualty evacuation, delivering vehicles, or ISR mission systems and meaning that enterprise-level management of the flight platforms is possible. Similar to the versatility the AACUS and OPBH provides air employers, a single flight platform will allow for surges to be planned to support high-tempo operations (i.e.: surge supply missions, vehicle deliveries, etc.) as required to meet operational needs.

The ARES payload is smaller than many of the existing rotary wing platforms (UH-60 Blackhawk can carry 9,000lbs [71] and CH-47 Chinook can carry 24,000lbs [75]), and was conceptualized specifically to support smaller, more distributed combat units [77], aligning it with the adaptive dispersed operations concepts (ADO). The relatively small payload runs on the assumption that future supply requirements will involve less total weight per drop and rely on greater mobility. The assumption for the future concept is that dropping 10,000lbs of supplies on unit renders them immobile because they need to guard supplies [244]. Changing the approach for the future force to one that is resupplied more often with less weight with each supply drop will represent a shift in the approach. The ARES concept also relies on a modular approach similar to the container concept discussed in Section 6.2, which as we discussed has benefits in terms of standardization of packaging and container use.

There are two potential challenges to realizing the ARES concept. Firstly, despite development effort the ARES remains a concept (i.e.: drawings) not an operational aircraft. Though there were stated plans for experimental fights by autumn of 2017 [244] there is no update on the Defence Advanced Research Projects Agency (DARPA) website on those flights, and there are no videos in the open source that indicate a test flight has taken place. The second challenge is that the success of the future concept relies on the notion of greater mobility of combat forces, and a change in the resupply model to rely on more frequent resupply drops with less payload in each drop. The concept prioritizes mobility, meaning that fewer supplies are carried with the expectation that aerial resupply will provided just-in-time delivery. For this concept to be successful it will demand a sizeable fleet of ARES vehicles to perform the additional drops, and redundancy measures to ensure that units get the necessary supply in case of emergency.

The general challenge presented by the K-MAX, AACUS, OPBH, ARES, or any unmanned system is for operations in complex environments, including the networked urban littoral. The current state of AACUS shows aircraft flying autonomously to select a landing zone in an open field [67]. The ability for an aircraft to fly autonomously and select and landing zone autonomously is an impressive technical feat. However, the time required to survey potential landing zones, and the gentle rate of descent creates challenges for the urban environment, high-threat environments, or both. In the urban environment the complex geography and geometry – buildings of different heights, traffic lines, hydro poles and wires, ‘urban tunnels’ of road surrounded by buildings – will create significant challenges for an autonomous system that needs to survey its landing zone before. In testing in a simple built-up area, an AACUS-enabled helicopter performed a very gentle landing with a slow and steady descent [245]. This kind of landing makes a helicopter very vulnerable to ground fire, whether piloted or not. In urban environments where there is a threat of ground fire helicopter pilots tend to fly more aggressively, specifically to avoid the threat of ground fire, the source of which may be difficult to locate in complex urban terrain. Traditional helicopters also have flight engineers / door gunners / crew chiefs to scan for ground threats and operate machine guns to return fire if required. The current iteration of the AACUS is not capable of flying in this manner and present a relatively easy target for ground fire. AACUS has not carried flight engineers / door gunners / crew chiefs as part of its experimental flights, meaning that if it comes under fire it will not be able to return fire in self-defence. This applies not only to AACUS, but to OPBH and any other autonomous platform, especially those that are unarmed. The outcome of an autonomous platform being shot down does not require a combat search and rescue to save the downed crew; though it does result in a loss of supplies and the need to send another supply mission to the supported unit in need.

The Joint Precision Air Drop System (JPADS) applies the GPS precision-guidance concept to drop up to 500, 2,000 or 10,000lbs of cargo from up to 25,000ft on a target 100m across with a stand-off distance of 30km from the aircraft to the target [246]. There are plans to expand that payload capability to 30,000lb and 60,000lb modules, and to increase maximum drop altitude to 35,000ft [247]. An increase in altitude will likely result in an increase in the stand-off distance of the aircraft from the target. The JPADS is primarily a 2nd line and 1st line delivery system. The employment model calls for aircraft (tactical airlifter like the CC-130J or strategic airlifter like the CC-177 Globemaster) to fly within range of the drop-zone (within 30km) and releases as many JPADS bundles as the supported unit requires. Though it is an air-dropped system, and not an aircraft like the other UAS in this category, it is placed in this category because it is a precision delivery system that requires no input after it is programmed for delivery. This is a common characteristic to all the other large UAS evaluated in this section. Table 10 shows the maximum payload for each air delivery system discussed in this section, including the JPADS to show payload comparison.

There are many advantages to relying the JPADS system over the existing land (trucks) and air-based (free-fall parachute air-drops, helicopters, or future-concept UAS) options: the use of JPADS presents less personnel risk, can delivery greater payload than any of the existing options for 2nd and 1st line, can deliver with higher precision that conventional free-fall parachute air-drops, and allows for a much greater supply range between 3rd line (presumed location of airfield) and 2nd line or 1st line supply areas.

JPADS is safer than any land or air-based alternative because of the altitude at which the aircraft flies puts it out of range of the vast majority of anti-aircraft artillery systems (AAA) and man-portable air-defence systems (MANPADS). It is also much more precise than traditional free-fall unguided air-drops. 100m accuracy is sufficient to drop supplies on deployed units in the field, with greater payloads than the ARES for ADO. This is a significant advantage over land-based systems like truck convoys that rely on exist routes and are more vulnerable to small arms fire, IEDs, and ambushes than aircraft. While aircraft like helicopters are less susceptible to ground fire than truck convoys, there is still a risk of being shot down by large calibre automatic weapons, RPGs or MANPADS. JPADS bundles can be dropped from 25,000ft, an altitude at which aircraft can barely be heard or visually identified, and in low-light or low-visibility conditions neither the aircraft of the JPADS bundles being dropped will be visually identifiable [247].

The second major advantage of the JPADS over other large UAS is the total payload that can be delivered. While the 10,000lbs maximum weight of a single JPADS drop exceeds the capacity of everything but the CH-47 for air-dropping, a fixed wing aircraft like the CC-130J or the CC-177 can carry multiple JPADS kits for air drop on a single mission. A fixed wing aircraft can carry multiple JPADS bundles for drops on multiple locations during a single sortie. This is a major advantage that the payload of a fixed wing aircraft provides; the ability to resupply multiple units in a single sortie, where the equivalent using trucks or helicopters would require multiple sorties.

The maximum cargo capacity of any fixed wing aircraft is a function of payload and volume, so we cannot assume that fixed wing aircraft can necessarily carry the maximum payload (48,000lbs for the CC-130J [56], and 160,000lbs for the CC-177 [58]) in JPADS due to the volume they take up in the aircraft. However, based only the payload (without considering volume) the following table shows how many of the 2,000 JPADS bundles and how many of the 10,000lbs JPADS bundles can be dropped in a single sortie. This is important because it shows much cargo can be delivered to a single target, or how much can be split between multiple targets in a single sortie.

Table 10: Number of JPADS bundles delivered (payload), per sortie, by aircraft

	Payload (lbs.)	% Of Max Payload	2,000lb JPADS bundles	10,000lbs JPADS bundles
CC-130J	48,000	100	24	4
	36,000	75	16	3
	24,000	50	12	2
	12,000	25	6	1
CC-177	160,000	100	80	16
	120,000	75	60	12
	80,000	50	40	8
	40,000	25	20	4

The other major advantage that the JPADS delivers over other large UAS is that it can deliver supplies to the 2nd line forward operating bases or given the accuracy of the system could be used for 1st line resupply also, in a sufficiently permissive threat environment. Given the maximum payload of a fixed wing aircraft, it can also deliver more supply to the 2nd and 1st line than any other air-drop system and can do so with less risk to personnel due to the altitude of the aircraft. This applies equally to combat missions and non-combat missions, domestic and expeditionary.

There have also been experiments with smaller aircraft to determine if the JPADS solution is viable. The CC-130 and CC-177 are the aircraft currently in service most likely to drop JPADS and other cargo. Experimenting with different aircraft as platforms for dropping JPADS bundles is underway in the United States. The United States Marine Corps has experimented with JPADS drops using the CH-53 Super Stallion heavy lift helicopter to drop the 900lbs and 2,000lbs variant from an altitude of 10,000ft [248], and conducted tests using the MV-22 Osprey tilt-rotor aircraft [249]. Both were deemed successful, showing that not only fixed wing airlifters are suitable for this equipment. The only solution for the CH-47 and JPADS publicly available is a slung rack from which JPADS bundles could be dropped [90]. The same concept has been experimented with the UH-60 Blackhawk and the UH-72 Lakota [250], to determine if the system is viable for smaller aircraft. However, for all externally mounted JPADS solutions, this somewhat defeats the purpose of a high-altitude and stand-off range, and slung loads will less stable in flight than cargo carried internally. It is also notionally possible that airships could be used to drop JPADS bundles. The airships described in Section 6.3 have sufficient payload and altitude capability to carry JPADS bundles.

The JPADS has the ability to deliver a huge payload compared to other systems, however the system is not without its drawbacks. Unlike the other large UAS listed above, the JPADS cannot deliver itself: it requires an aircraft to do so, likely a fixed wing aircraft in the Canadian context. This means employing a tactical or strategic airlifter to deliver supplies to the 2nd or 1st line location. The potential benefit is that it could free up helicopters that would otherwise fill this function and could potentially reduce the truck volume required to support the 2nd and 1st line. There will, however, be significant cost implications in using large aircraft for this task; which when balanced against the potential for casualties with road moves, the cost implication will be worth it. The challenge with fixed wing aircraft reliance therefore becomes a challenge of managing the daily air tasking order (ATO) to ensure that when fixed wing aircraft are assigned for JPADS missions that other missions can also be performed.

In terms of technical challenges, the JPADS system uses a parachute, GPS guidance and navigation system, a system to physically steer loads onto target, and a battery to power each JPADS load. For each JPADS drop a full system will be left in the drop zone. This means that in 2nd line facilities parachutes, batteries and systems will start accumulating. For support to the 1st line, this means that mobile units will need to either bring the parachute, batteries and systems with them to avoid them falling into the hands of the adversary or destroy them. In either case, it forces units to do some processing of the JPADS kits after they are delivered.

In the urban environment the JPADS faces similar challenges to the other large UAS in this category: precision of the drop and vulnerability to enemy fire. The claimed accuracy of JPADS is roughly 100m. This is well within the margin of acceptability for forward operating locations, or a space with a large dedicated helicopter landing zone. However, this level of precision may be a challenge in complex urban terrain. In a dynamic situation with 1st line units moving through the urban environment a margin of error of 100m could be the difference between a JPADS drop hitting its target on a roadway or falling on the roof of a nearby building. In terms of enemy fire, JPADS is after all a parachute system. Its rate of decent is sufficiently slow that it could present a target for enemy fire. Enemy fire could destroy the package or destroy the guidance system such that it becomes an unguided free-fall parachute system. Additionally, an adversary watching the drop of many JPADS systems could reasonably easily ascertain where a 1st line unit is operating based on the request for supply drop. This may represent an operational security risk to a unit under already in contact, so for units attempting to maintain operational security JPADS drops are not advised. In high threat environments JPADS should be perhaps not be used during daylight hours for 1st line support, given the potentially adverse outcomes. For 2nd line facilities, daylight drops are likely not an issue, given that their location is typically well known by the local population including potential adversaries.

The maturity for large UAS in general varies across platform. K-MAX and JPADS, for example, have been used operationally in Afghanistan. Though there is room for technological improvement, this is also true for all in-service platforms. These technologies can be considered mature. For the other large UAS (AACUS, OPBH, BlackKnight Transformer), the technology still does not replicate the human-piloted and crewed aircraft they seek to replace in the supply role. The challenges for autonomous aircraft landing in urban areas is the complex geometry of buildings, wires, etc., and performing landings to avoid ground fire. The current state of technology shows that autonomous helicopters are capable of landing in wide open spaces using only their sensors; however, these technologies do not *yet* show the sophistication for urban operations. The technology cannot yet compete with human crews sensing the environment, flying to minimize the likelihood of enemy contact, selecting landing zones and landing quickly.

All large UAS – including JPADS – rely on GPS navigation and guidance to understand the current position of the platform, and then navigate to the final destination. As we know, GPS systems are vulnerable to jamming. This can be simple commercially available jammers that block satellite signals from all GPS devices within a range of few hundred metres [251], or it can be large-scale military-driven GPS jamming. Norway and Finland have both complained that Russian military exercises near their borders have included GPS jamming and has affected civilian aviation navigation [252]. Russia also stands accused of jamming US drones flying in Syria by disrupting the GPS signal – even those with anti-jam technology and with encrypted communications – a move that is “seriously affecting” American drone operations in Syria [253]. North Korea also was allegedly jamming GPS signals, impacting dozens of South Korean civil airliners, fishing trawlers, using devices believed to have been imported from Russia [254].

The US military is preparing for this challenge and has conducted exercises to test its ability to defeat GPS jamming. At China Lake, California, the US military conducted GPS jamming tests affecting aircraft operating at altitudes up to 25,000ft [255]. GPS satellite typically broadcast a weak signal because of the distance from the satellite to the ground equipment receiving it, and the exercise was meant to jam GPS reception from the ground up to operating altitude. Civil airlines continued with back-up measures like high-frequency radios for navigation, so flight can still take place in a GPS jammed environment [255], however this example involved human pilots with back-up systems. The same back-ups will not be available to autonomous UAS, especially when they are not designed to allow a human using a remote station to take control of the aircraft.

Alternatives to GPS are currently under development to address this shortcoming, with varying degrees of likely success. Satellite Time and Location (STL) provides an encrypted signal 1000 times stronger than the Global Navigation Satellite System (GNSS) that GPS currently relies on [256] and is designed for global shipping. The STL is only accurate to between 30 and 50 metres, however, which is probably too little precision to replace GPS/GNSS for aircraft navigation for large UAS. DAPRA has been working on a solution to GPS jamming by building a PNT network that relies on multiple sources to give location data. This could include things like television broadcast towers, cellular telephone towers, lightning strikes, and cross-referencing imagery to determine position, navigation and timing (PNT) [257]. In essence, the DARPA system will use multiple data source to provide the PNT rather than only one type of source (satellites) to determine PNT. Whatever the solution – whether countering jamming or developing a new means of PNT – the GPS jamming issue will be addressed in order to ensure the reliability of autonomous systems.

The last challenge is for supplying 1st line units that may be in contact. The use of JPADS or other large UAS will put additional aircraft in the operating environment, and will need to be deconflicted with things flying through the air, such as: other aircraft, air-dropped munitions, artillery or mortar ammunition in flight, etc. This is known as battlespace deconfliction. This is currently being done already, and this challenge is known. The addition of new entities (i.e.: JPADS and other large UAS) does not represent a new technical challenge, but it does increase the number of entities to be deconflicted.

If the threat to GPS navigation can be addressed or mitigated, large UAS will present the opportunity to reduce the number of personnel required to delivery supply, extend the number of flying hours per platform per day due to the lack of crew rest required, and likely improve the timeliness, simplicity and capacity for resupply, under the right conditions (i.e.: high threat environments may not be feasible). As technology advances, operations in higher threat environments may become viable. However, at present this represents a limitation on all large UAS applications. In the Canadian context, large UAS would fall under the purview of the RCAF not the Army; meaning that any implementation model will need to be a joint effort, as is the case today with helicopters and fixed wing aircraft.

6.5 Small and Medium Autonomous Helicopters

There are two main types of small and medium autonomous helicopters: those that were retrofitted from existing designs (the MQ-8B and MQ-8C Fire Scots series) and those that were purpose designed (including all other in Table 11 below). The main difference between the helicopters listed in this section and the helicopters listed in 6.4 is that those listed here are permanently unmanned: that is, they cannot be converted back to manned flight, and cannot have a single pilot on board as part of a reduced crew. Due to their size and payload, the platforms discussed here are most applicable to resupply to 1st line units in the field. They are notionally capable of providing resupply delivery from 3rd line to 2nd line, though there are many other platforms with a larger payload that would be more efficient. Therefore, we will limit the analysis in this section to 1st line resupply. To avoid re-stating the challenges to navigation and autonomous flight presented by GPS navigation it is assumed that small and medium autonomous helicopters are also vulnerable to jamming the GPS signals on which they are reliant for PNT.

The main driver for all small and medium autonomous helicopters is to reduce the need for humans – and therefore the risk to humans – in executing resupply missions. Some of these technologies began as military platforms for ISR (the Fire Scout series) and others like the Ehang 184 are designed as air-taxis for a single passenger. This section will evaluate the viability of each technology for military application in CSS.

Table 11: Summary of small and medium autonomous helicopter technology under development

System	Country of Origin	Cost	Range	Payload	Speed
MQ-8B Fire Scout	US	~$27.5m per unit [258	1,100 km max (lower at max payload) [98]	300lbs [98]	85kt [98]
MQ-8C Fire Scout ([99] for all data)	US	~$10.8m per unit [259	2,2275 km max (lower at max payload) [99]	500lbs internally and 2,650lbs sling load [99]	135kt
MMIST Snowgoose	Canada	$500,000 - $650,00 USD each, with $300 hourly operating cost [260]	600km [102]	575 lbs [102]	120km/h [102]
JTARV	US	N/A	Up to 125 miles (future) [105]	300 lbs with plan for 800lbs (future) [105]	60mph [105]
Ehang 184	China	$200,000 - $300,000 [261]	25-minute duration [109]	100kg [109]	100km/h [109]
AirMule / Cormorant	Israel	$14m [262]	50km [112]	1,100lbs [112]	N/A
DP-14	US	N/A	150km [115]	430lbs [115]	130km/h [115]

The MQ-8B and MQ-8C Fire Scout helicopters began as traditional, manned aircraft and were retrofitted for autonomous or remote piloting for application by the US Navy. The MQ-8B was designed as an ISR platform with limited ability to deliver weapons on target [263]. The MQ-8B flies autonomously, meaning that a pilot does not need to maintain hands on control from a control station; it flies missions based on waypoints identified by the mission leaders, and the flight control system then flies the aircraft accordingly [263]. Because of its initial purpose – ISR and light attack – it does not have much space in the fuselage for resupply and has a maximum payload of only 300lbs [98]. The MQ-8C Fire Scout has a similar operating concept as the MQ-8B, though it is based on a larger helicopter and therefore has a larger payload, up to 500lbs internally or 2,650lbs externally [99]. The purpose for which the MQ-8C was designed was ISR missions using EO/IR sensors, with the ability to do resupply.

The Fire Scouts do not represent an improvement over existing helicopters in terms of payload they can deliver. As we can see in Figure 59, the MQ-8B carries less than even the H-6, and the MQ-8C carries less than the comparably sized helicopters in the Large UAS category. The MQ-8C is, however, capable of carrying approximately the same payload as the ARES concept, which was designed based on the understanding that deployed field unit would rely on ARES to deliver supplies to distributed units. The bulk of the payload carried by the MQ-8C will be in a slung load underneath the aircraft, similar to the approach of the K-MAX. However, the K-MAX can carry almost twice the load that the MQ-8C can carry externally. This makes the K-MAX much more efficient for resupply, however the MQ-8C provides the added benefit of being able to conduct ISR missions in addition to resupply. It is possible that the K-MAX could be configured for ISR missions, however at present it is not.

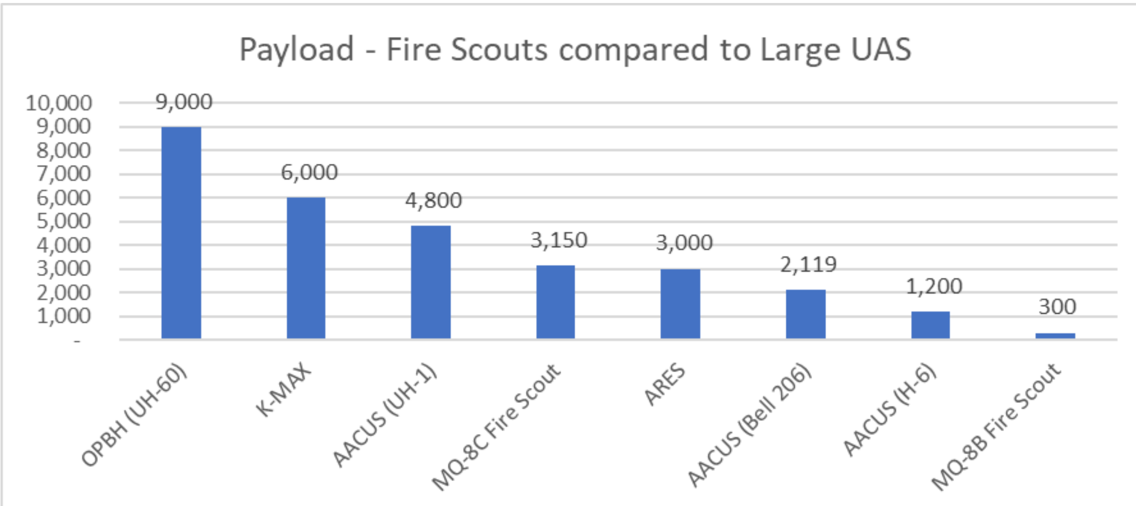


Figure 59: Fire Scout Payload compared to other helicopters (Large UAS category)

For operations in the urban environment both Fire Scout variants are limited by the same shortcomings as the autonomous helicopters in the large UAS class: their landings are very deliberate making them vulnerable to enemy fire. The MQ-8B and MQ-8C are both capable of taking off from ship's decks and landing on the ground, though the landings for the MQ-8B [264] and MQ-8C [265] appear to require a lengthy hover. During hovering both autonomous platforms would be very vulnerable to ground fire, a vulnerability already discussed earlier with reference to large UAS. In a low threat environment, the MQ-8C could be useful for delivering supplies, though the other unmanned helicopter platforms like the OPBH, K-MAX and AACUS (UH-1) are capable of carrying greater payload.

Determining if the Snowgoose, JTARV, Ehang 184, AirMule / Cormorant, or DP-14 represents an operational improvement over existing technology is a challenge because these vehicles represent a new operating concept for CSS. There are currently no comparable small, flying platforms – manned or unmanned – to serve as a baseline. In terms of payload, the most comparable platforms for 1st line support are the M-Gator from John Deere and the M-Razr from Polaris. The M-Gator is capable of carrying a maximum payload of 1,650lbs [266] and the M-Razr from Polaris claims a maximum payload capacity of 1,500lbs [267]. The small and medium autonomous helicopters all carry less payload than the M-Gator and M-Razr (with the exception on the MQ-8C Fire Scout), meaning more trips from small and medium autonomous helicopters to fulfill the same supply need.

However, payload is not the only variable that should be considered. Small and medium autonomous helicopters present less risk to personnel in two ways: they are not vulnerable to the IED threat that has been so lethal in Iraq and Afghanistan because they are flying, and though they will be vulnerable to ground fire on landing the destruction of the platform will not result in a loss of life from the aircrew (because there is none). This is a concern worth noting: in June 2007 three Canadian soldiers were killed when the M-Gator they were travelling in struck an IED [268]. This concern does not exist for the small and medium autonomous helicopters.

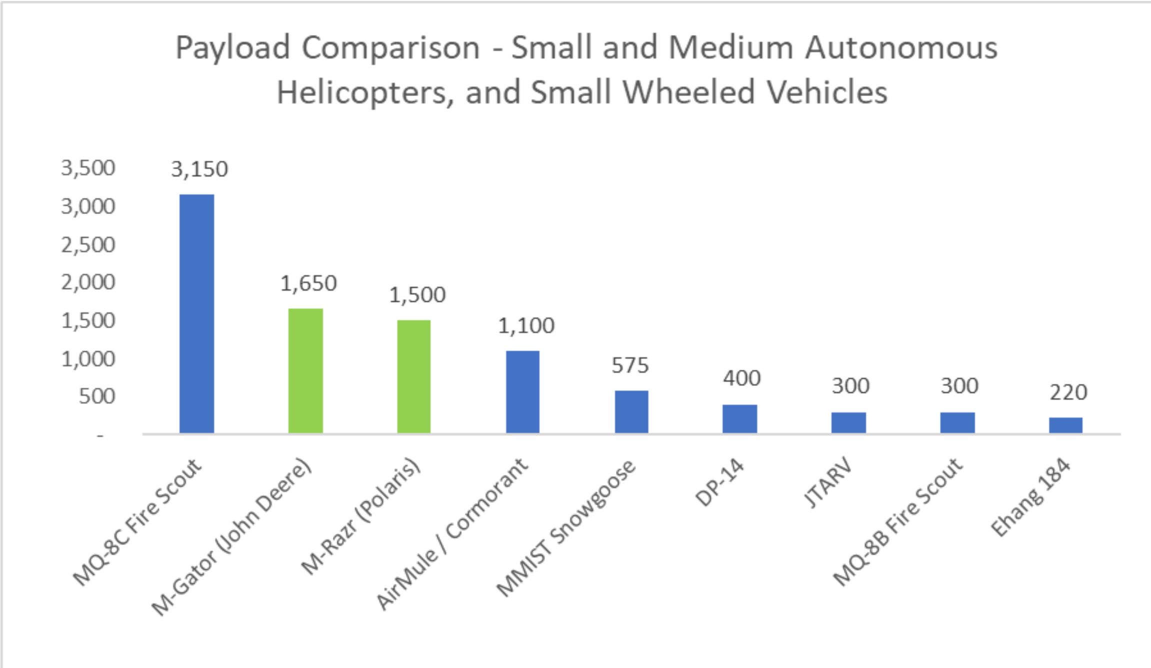


Figure 60: Payload Comparison - small and medium autonomous helicopters, and small wheeled vehicles

The MMIST Snowgoose is an autonomous helicopter that uses a pusher propeller to generate speed, with the main body slung under an open parachute that generates lift. The Snowgoose is capable of carrying 575lbs to a maximum range of 600km [102]. The test video shows that the Snowgoose is not capable of taking off on its own and needs a truck and trailer to accelerate the Snowgoose to take-off speed, after which it begins its mission [102]. This also means that once the Snowgoose lands at its target, it will require a truck and trailer to accelerate the Snowgoose in order to take off and return to base. In terms of suppling 1st line units, this is very impractical. In order to take delivery from a Snowgoose, a unit will need a truck and trailer – and the personnel to operate them – to re-launch the Snowgoose so it can return to base.

To avoid landing, the Snowgoose can drop cargo packages from its six containers. However, as the test video shows, the packages are dropped from the Snowgoose using free-fall parachutes [269]. As observed with the JPADS in section 5.4.2 free-fall air dropping presents challenges for accuracy. This is not a major concern when dropping supplies in a rural environment, however unguided supply drops in an urban environment or dense jungle or forest terrain, raises the risk of supply drops missing their target (i.e.: falling into the hands of adversary, or civilians). There is a gyrocopter variant of the Snowgoose in development that will eliminate the parachute in favour of a spinning rotor to provide lift the same way a helicopter does [102]. However, there is little evidence that the gyrocopter concept has progressed beyond the concept phase, meaning the parachute / parafoil model is the most developed technology available. The Snowgoose technology faces many challenges to becoming a viable technology, chiefly that it cannot take off on its own after landing.

The JTARV (Joint Tactical Aerial Resupply Vehicle) is designed to be an autonomous helicopter platform for delivering supplies to 1st line units. It uses four shielded rotors to hover and fly forward with the stated purpose of reducing the volume of casualties associated with convoy resupply [270], and capable of carrying 300lbs of equipment and supplies [105]. Experimental flights have been conducted without using any load, in order to validate the flight characteristics of the JTARV [105]. The US Marine Corps Forces Special Operations Command recently tested the JTARV, testing a 2km mission to bring medical supplies and equipment to notional special operations teams [271]. Though the payload the JTARV was carrying for this test is unknown, the test was declared a success.

Like other autonomous helicopters, the take-off and landing of the JTARV is deliberate and includes a relatively slow transition from hovering to level flight [105]. This means it too will be vulnerable to ground fire during this transition. However, the JTARV has a very slim, flat visual profile meaning that compared to other small and medium autonomous helicopters it presents a smaller target. This offers and advantage over other similar vehicles, though the JTARV will still be vulnerable during the transition flight: but less so than other aircraft. The JTARV also make a very distinctive sound, which could alert enemies to it, enabling them to follow the sound to the where the 1st line unit awaiting resupply is located. This applies to any aircraft flying low to the ground, however the distinctive sound could allow adversaries to detect the JTARV specifically and understand that it is a supply drop.

The main drawback facing the JTARV is the relatively small payload. With 300lbs as the target payload, multiple JTARVs or multiple JTARV sorties will be required. There are future plans for an 800lb payload [105], which would almost triple the delivery capacity of the JTARV or a group of JTARVs. This technology currently shows promise, and if the target payload can be realized this technology could be useful for 1st line resupply.

The AirMule / Cormorant (it is marketed under both product names) is an autonomous helicopter that uses shielded fans to take off vertically and to propel itself straight ahead. It is roughly the size of a station wagon, making it much larger than the other autonomous helicopters, though still smaller than traditional helicopters. The AirMule / Cormorant can land in confined spaces such as in the urban environment with little difficulty and provides an advantage over traditional helicopters in that regard. With a payload of 1,100lbs [112] it is capable of carrying significantly more equipment and supplies than the other autonomous helicopters. This is a differentiator for the AirMule because – other than the MQ-8C Fire Scout - it can delivery almost twice as much as its nearest competitor (the Snowgoose) and up five times as much as the smaller autonomous platforms.

Like other autonomous helicopters, the platform is vulnerable during its transition from hovering to level flight [113]. This is a common characteristic of autonomous helicopters. However, the AirMule is capable of being tele-operated – that is, flown by a human pilot in a remote location [272] similar to most medium-altitude long endurance fixed wing drones. This will help overcome the relative sluggishness performance that autonomous helicopters tend to show when maneuvering in urban areas, or other spaces of complex geometry. This is a major differentiator compared to the other autonomous helicopters. The AirMule faces endurance and range challenges that could limit its utility. The maximum range of 50km [112] presents a challenge for distributed operations. The ADO concept and the AoT concept both envision a future in which small groups operate independently, often far away from each other. It is quite conceivable that mechanized forces could be 50km – or more – away from a resupply base. This challenge will need to be overcome to exploit the maximum versatility of the platform.

The DP-14 is a unique autonomous helicopter design that relies on two main rotors in a similar layout to the CH-47. It is capable of carrying 430lbs [115] of cargo, and more than sufficient to carry a soldier with weapons and equipment. The DP-14 faces all the normal challenges that autonomous helicopters face (hover before landing, susceptibility to enemy fire, etc.), however the manufacturer claims to have overcome the challenge of relying on GPS for navigation. He also claims that the DP-14 will [115] use its LIDAR system to navigate even when operating in a GPS-denied environment. Though the information does not elaborate on how this is done, it is possible that the DP-14 uses a pre-loaded terrain data model that is cross referenced with real-time LIDAR data collection to navigate. If this is the case, it would represent a potential solution to the challenge of GPS denial.

However, the DP-14 as an airframe faces a major structural flaw. The aircraft photos and tests show a dummy loaded in the vehicle to simulate how the DP-14 could be employed. These photos do not show the aircraft with the rotors operating. The rotors of the aircraft spin at roughly throat height. This means that for humans to interact with the DP-14, either the aircraft needs to shut down to prevent the rotors from injuring personnel, or personnel need to crawl below the spinning rotors to load casualties or unload supplies. This creates significant complications for using the aircraft in a real situation. While the aircraft could still be used to delivery supplies if shutting down is standard operating procedure, there are other autonomous and human-piloted aircraft that can carry more payload and don’t present the same personnel safety challenges. For this reason, the DP-14 is not a reasonable option for CSS.

The Ehang 184 was designed as a passenger drone to fly a single passenger through an urban environment to replace taxis. It consists of a main passenger compartment and has four arms that hold two rotors each. The passenger enters the vehicle and selects their destination using a tablet device, similar to the interface for ride-sharing applications like Uber or Lyft. The Dubai Roads and Transports Authority approved the Ehang 184 for trials along pre-determined air routes [273]. This vehicle was clearly designed to operate in complex urban terrain and is unlikely to face challenges in landing at the designated spot. The Ehang 184 is an electric aircraft, capable of carrying a maximum payload of 220lbs for a flight distance of 31 miles on a single charge at an operating speed of 100km/h (62mph) [109] at low altitude. As payload increases, range decreases, with claims of 264lbs payload with a range of 10 miles [108]. Like the DP-14 the Ehang 184 needs to shut down while a passenger gets in or out of the aircraft; however, because it is electric it takes seconds to stop the rotors, making it safe for passengers to get in or out.

This vehicle was developed to meet single-passenger transportation needs to replace taxis. It is clearly marketing itself as a luxury good for wealthy individuals to travel relatively short distances. This represents a significant challenge for military application, especially with respect to payload. The payload is sufficient for an individual carrying a briefcase, however for casualty evacuation a soldier carrying weapons, equipment, and wearing armour plates and helmet may exceed the maximum stated payload of 264lbs. With all aircraft as payload increases range decreases, and at maximum payload the range is only 10 miles. This is insufficient for distributed operations, whether domestic or expeditionary. For delivering supplies the maximum payload and range still falls well below other autonomous helicopters and well below the maximum payload of traditional helicopters capable of carrying thousands of pounds of supplies. The Ehang 184 is an interesting technology for personal transportation, but its limited payload and range mean this technology is not currently viable for military application in CSS.

For all of the small and medium helicopters, the implementation model could include the Army having responsibility for the platforms or the RCAF. This will likely be a function of the size, payload, and range of a small or medium helicopter. For example, the Fire Scout series are retrofitted from aircraft that would likely be the RCAF's purview – if they were manned – while smaller devices may be the responsibility of the Army. This issue would need to be revisited in the case of a future procurement.

6.6 Small Unmanned Fixed Wing Aircraft

The small unmanned fixed wing aircraft discussed in this section were all designed as unarmed ISR platforms, with a specific focus on providing persistent airborne surveillance using electro-optical / infrared (EO/IR) sensors. Though the larger small unmanned fixed wing aircraft are capable of carrying a maximum payload of up to 40lbs, this payload was intended to comprise sensor suites, not air-dropped cargo. A summary of the range and payload for each system is shown below in Table 12.

Table 12: Summary of unmanned fixed wing aircraft technology under development

System	Country of Origin	Cost	Range	Payload	Speed
Shadow	US	~$15m, including support equipment [274]	200km radius [274]	25.3kg	60kt cruise [274]
Scan Eagle	US	~$100,000 for aircraft only (no support systems) [275]	24+ hrs endurance [120]	7.7 lbs [276]	60kt cruise [120]
RQ-21A Blackjack	US	$13m including support equipment [277]	16+hrs endurance [121]	39lbs [121]	60kt cruise [121]
Integrator	US	N/A – similar to RQ-21A (similar aircraft from same manufacturer)	24+ hrs endurance [122]	40lbs [122]	55kt cruise [122]

Fixed wing UAVs were never intended for resupply, so this comparison is somewhat problematic, because the payload they were intended to carry was never meant to be jettisoned midflight. If this class of UAV could land to deliver supplies, it would still require the infrastructure to launch again. The Shadow [278], Scan Eagle [279], Blackjack and Integrator [280] all require ground infrastructure to take off and land, include catapults to launch and arresting cables to perform what is essentially a controlled-crash landing. Even if fixed wing UAVs could land and take-off without the need for infrastructure, the maximum payload of 40lbs is much less than the average soldier carries as personal equipment, making it an inefficient means of providing resupply. Air-dropping loads presents the same challenge – the payload is simply too small. The relatively small payload and the need for ground infrastructure for take-off and landing make fixed wing UAVs currently unsuitable for CSS missions. These aircraft were purpose designed for ISR missions and provide unrivaled endurance over target areas and should continue to be employed as such.

6.7 Last Mile Logistics / Small UAVs

Last mile logistics is a concept that originated with commercial shippers, addressing the final phase of delivery of a package to a customer's home address. The last mile assumes that the supporting infrastructure (mailing, processing plants, bulk delivery of package to a final sortation point, etc.) has already been taken care of, and that all that remains is delivering the material to the customer. For this reason, the focus of the discussion on last mile logistics will be on delivering to 1st line units only; this could be from a 2nd line facility like a forward operating base or could be from a vehicle containing supplies.

Table 13: Summary of last mile logistics small UAV technology under development

System	Country of Origin	Cost	Range	Payload	Speed
DHL Parcelcopter (tilt-rotor)	Germany	N/A	At least 8km [125]	4.5lbs [281]	45 mph [281]
UPS Zipline	US	N/A	150km [282]	1.5kg [282]	84km/h [282]
UPS Rooftop delivery drone	US	N/A	30 minutes [283]	N/A	N/A
Amazon Prime Air tilt-rotor	UK	N/A	7.5-mile radius [284]	5 lbs [132]	100km/h [133]
Amazon Airborne Fulfillment Centre	US	N/A	N/A – still a concept	N/A – still a concept	N/A – still a concept

There is currently no equivalent of the small UAV for Army CSS. The devices for commercial delivery are capable of flying small payloads to target areas and then, the case of the DHL Parcelcopter, UPS drone, or Amazon Prime Air, land like a helicopter to drop the package on a point on the ground. The Zipline is currently being used in Rwanda to deliver blood and medicine to patient who cannot be accessed by road by dropping cargo via parachute [285] from a fixed wing drone to the intended target. The small helicopter UAVs have a relatively short range (Table 13) with the exception of the Zipline, capable of flying 150km.

The small UAV industry for last-mile logistics is a commercial enterprise, designed to sustain the logistics and delivery industry. DHL, UPS and Amazon all have their own proprietary technology, either to reduce delivery costs or increase delivery speed. Amazon for example, is claiming 30-minute delivery [133] from the time an order is electronically placed. To make this model sustainable, logistics companies are establishing this kind of system only where the economies of scale make the business profitable. This means operating in cities. This also means that the delivery companies' solutions must comply with civil aviation restrictions around the use of commercial drones. Typically, this means not exceeding a specific altitude ceiling to avoid interference with civil aviation and keeping a safe distance from airports. Amazon's promotional material claims a maximum altitude of 400 ft [133], and the Zipline operates between 40m and 100m altitude [257]. Zipline has also developed a collision avoidance system to identify their own systems and identify any other air vehicle, and using RADAR, LIDAR, sound-locations systems, and central air traffic control data to avoid other aircraft, and to take evasive maneuvers if another aircraft enters the Zipline's flight path [257]. Amazon is also claiming a sense-and-avoid technology to prevent collisions [132] with other aircraft.

In terms of operating in complex urban terrain, the small UAVs for commercial purpose are capable of doing this; it is what they were designed to do. The Amazon Prime Air drone looks for a placard the customer places on the ground [132] and identifies it visually once it is in the area. DHL's Parcelcopter identifies the DHL facility at which to land [124], the UPS copter find the truck from which it was launched automatically [283], and the Zipline finds its target and drops the package once over the area [282]. The current technology is capable of doing this using commercial means. Militaries are increasingly using ruggedized tablet devices to navigate, share information and mark targets and hazards in the field, so it is plausible that such a device could be used to pinpoint the drop location for small UAVs.

The challenges to successfully implementing drones for military application is the small payload and the short range (with the exception of the Zipline). For supply delivery, the largest known payload for a small UAV is 5lbs and is the Amazon Prime Air tilt-rotor [130] [132]. This leaves two potential military applications for small UAVs: using multiple small UAVs to deliver supplies to forces in the field, or using a single drone (likely the Zipline, given range constraints) to deliver urgent medical assistance to wounded personnel.

To give some perspective on what this means for Army CSS: one loaded magazine for a C7 rifle or C8 carbine weighs about 1 lb [286], meaning the largest drone would be capable of delivering 5 magazines only in a single flight. This is the basic load of a single infantry soldier and will be expended quickly during combat. An infantry section has 8 soldiers, and has more diverse supply needs to sustain combat, like light machine gun ammunition, grenades, and grenade gun ammunition. One light machine gun ammunition box weighs 5 lbs [287], and there are two light machine guns per section. A rifle section also needs water, rations and batteries to sustain life, meaning that multiple drones would be required to sustain even the basic functions of a rifle section. A rifle platoon typically has 34 soldiers (3 sections, and a weapons section, the platoon commander, and the platoon second-in-command) and has more complex requirements still, with larger caliber machine guns and larger radios that take larger, heavier batteries. These requirements grow further if the rifle section is mechanized, to sustain the weapons and systems of armoured vehicles.

One approach for making small UAVs more viable could be to shorten the distance between where supplies are stored and where they are delivered. Amazon and UPS are both experimenting with this concept. Amazon Prime is claiming a 30-minute delivery time after the order is placed electronically [133]. This timeline takes into account a customer placing the order, the warehouse receiving the order, the order being loaded into an available drone, and the flight time to deliver the item to the customer. The approach of a central facility storing supplies will not be applicable for future defence concepts, where operations are expected to be widely dispersed. The Amazon Prime Air tilt-rotor can only fly 7.5 miles (~12km) [284] and future operational concepts are not limited to those relatively short ranges.

UPS is experimenting with a solution that could partially address this. UPS is using a small UAV that takes off from the rooftop of the UPS delivery truck to save the driver from making long trips off of main roads – specifically in rural areas – to increase time efficiency and reduce cost of fuel. The driver manually loads the package into the small UAV, selects the destination on a tablet device, and the small UAV flies from the truck to drop off the package and returns to the truck automatically for its next delivery [130]. If with the reduced linear distance, the payload issue remains (i.e.: drones do not carry enough payload to be practical). Amazon is attempting to reduce the linear distance by using vertical height above the service area. Amazon has patented a similar concept, but on a massive scale, called the airborne fulfillment centre (AFC). This concept uses an airship filled with goods that will float at an altitude of 45,000 ft, and individual tilt-rotor small UAVs will then fly up to the airship, collect the package and deliver it to the customer [135]. This concept will necessarily involve hundreds of small UAVs to deliver all the merchandise contained in the airship. The main airship will be refilled by another, smaller airship when it runs low on merchandise. A visual representation of what this could look like for military application is shown below in Figure 61.

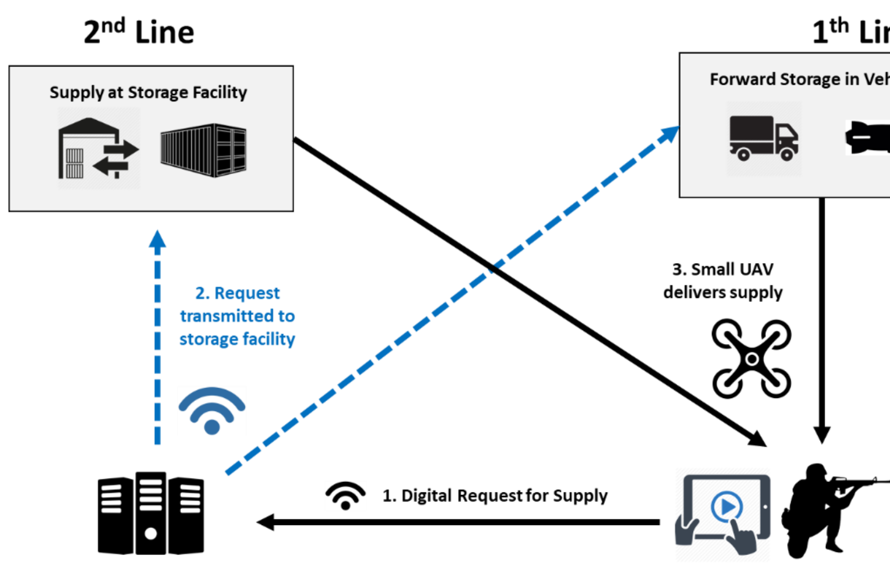


Figure 61: Small UAV distribution model (options)

There are many challenges associated with the idea of a 'mothership' supported by other small UAVs. Multiple UAVs create risks for managing the airspace and for telegraphing friendly positions to enemy forces. With rounds of ammunition flying through the air, the possibility of artillery fire or mortar fire being called in, or the potential for attack helicopters operating in the area, there are concerns about deconflicting the battlespace for small UAVs and all the other things using the airspace. There is less risk involved in the UPS concept, because the 'mothership' is a truck, allowing drones to take off and fly at low altitude before reaching delivery point. There is still the risk of small UAVs interfering with tactical aviation like transport helicopters or attack helicopters. A quick search of the news will show that small UAVs have struck commercial airliners, with serious concerns for aviation safety. The same is true for small UAVs potentially presenting a risk to tactical aviation. In the case of the Amazon AFC, operating an airship at 45,000 would require a restricted operations zone (ROZ) to be established over the supported area; meaning no aviation assets could enter a column of airspace between the ground and the airship operating at 45,000ft. This would severely constrict the options available to ground commanders in terms of requesting air support, artillery support, medical evacuation or other air-supply missions while the AFC is operating. The UPS truck-based option presents some risks, and the Amazon AFC concept is effectively unworkable for military application.

The final concern with small UAVs is the risk that deliveries will give away the position of friendly forces. The buzzing of small UAVs in a combat situation would alert adversary forces to the location of friendly forces. Assuming that multiple drones would be needed to ferry ammunition forward, enemy observers could pinpoint the location of friendly forces based on where small UAVs are landing. This could have disastrous consequences for alerted enemy forces to friendly locations.

The most viable military application for UAVs is not for conventional resupply, but for medical purposes to deliver blood or plasma to the field. Zipline in Rwanda delivers blood to people in hospitals across the country. Orders are sent via SMS text, and the platform launches almost immediately to deliver [288]. Zipline claims that they have delivered over 7,000 units of blood using the system, with 1,100 emergency deliveries where the patient’s life is in danger [285]. The system could notionally be used to deliver other vital equipment, provided it meets the payload requirement. Sensitive electronics or components could be loaded for delivery

6.8 Unmanned Ground System for Distribution

The unmanned ground systems for distribution consist of autonomous driving systems installed on existing heavy and medium logistics trucks. The most notable of these technologies are the AMAS and CAST systems produced by Lockheed Martin and the TerraMax system produced by Oshkosh Defence. These systems are designed to retrofit existing trucks to be driverless for the purposes of reducing the potential for casualties during convoy operations. The primary purpose of the unmanned ground system is therefore moving supplies from 3rd line depots to 2nd line facilities, or 1st line units.

Table 14: Summary of unmanned ground distribution system technology under development

System	Country of Origin	Cost	Range	Payload	Speed
AMAS	US	US	100 miles [140]	Of existing vehicle	50mph [140]
CAST	US	US	100 miles [140]	Of existing vehicle	50mph [140]
TerraMax	US	US	150 miles [289]	Of existing vehicle	N/A

One of the main benefits of this technology is that, just like the AACUS and OPBH systems that retrofitted existing helicopters for autonomous duty, the Oshkosh system can be used on any truck [290]. This means that for Canadian Army procurement or experimentation, purchasing additional vehicles will not be necessary. While purchasing vehicles from the original equipment manufacturer (OEM) may be simpler in terms of integration effort of the automated systems into non-OEM vehicles, the promotional material insists that any vehicle can be converted to the autonomous platform.

The operational effect these systems seek to generate is reducing casualties by removing drivers from vehicles, while continuing to deliver to necessary payload from the 3rd line to sustain 2nd line facilities and 1st line operations. System test videos show that trial operations are successful, in that safe, autonomous convoy operations can be conducted using the AMAS and CAST system [140] [142] [144] [145]. Each system is capable of navigating, accelerating, braking, turning and avoiding obstacles.

The most recent iteration of the TerraMax called the Unmanned Ground Vehicle (UGV) shows a combination of autonomous systems and human-operated systems as part of a single convoy. This system shows a lead autonomous vehicle equipped with mine rollers, followed by two autonomous cargo vehicles, followed by a human-operated vehicle at the rear of the convoy. The system is intended to allow a single operator to control multiple vehicles, while also providing protection against IEDs through the use of a lead vehicle [291]. The lead vehicle will have ISR sensor for monitoring the advance, ground penetrating radar to detect buried IEDs, and electronic counter-IED equipment on board [292]. What is not clear is the response of the system in the case of an IED detected or an IED strike: will the remainder of the convoy carry on with its mission? Will the human operators dismount to scan for other IEDs? Presumably, the human operators in the last vehicle can make these decisions based on the specific scenario. Most concerning, however, is the limited support for the human operators in the TerraMax UGV. Despite the force protection measures offered by the lead vehicle equipped with counter-IED equipment, there is virtually no fire support for the humans involved. In a high-threat environment, this raises the possibility of an adversary targeting the only humans in the UGV convoy *because they know there are no other humans to shoot back at them.* In low or medium threat environments this will not likely represent a challenge, however it is not clear how this would be addressed in a high-threat environment.

An important iteration of the TerraMax technology is that it claims to be capable of operating in a GPS-denied environment. This is an important point, because as we discussed previously with autonomous helicopters and devices that rely on GPS for navigation, GPS jamming can render the PNT data that systems rely on to be autonomous useless. It is not clear how long the TerraMax can operate in a GPS denied environment, but this is an important development in the state of the art for unmanned ground systems.

The main shortcoming of the AMAS, CAST and TerraMax trials is that the test conditions do not show realistic urban conditions, meaning the technology may not yet be sufficiently sophisticated to fully replace human drivers and operators. For decision-making, the test terrain shows an over-simplified test environment. While travelling in convoy the systems shows that the lead vehicle is capable of avoiding obstacles, yielding to other traffic, give the right of way, and navigate urban terrain, all using its sensor suite to detect its environment and obstacles [293] [145]. The test conditions for these vehicles do not reflect the complexity of the urban environment. The most notable thing is the absence of pedestrians in the trial. This is a major factor to consider in any urban setting, whether domestic or overseas. That the AMAS and CAST systems can avoid a single pedestrian does not accurately reflect the possibility of thousands of people that a truck may pass during an urban convoy, whether standing still, crossing the street, running market stall, getting on and off buses or other vehicles, etc. The simulation of traffic is also limited to single vehicles, either meeting the convoy or passing the convoy. This is not representative of the type of traffic that will be faced in the typical operating environment, either domestically or overseas.

The most worrisome part is that the videos show the vehicles stopping when another vehicle is obstructing the path forward. This means that an adversary could pull a vehicle in front of the convoy in order to halt the whole convoy, and then loot the contents of the convoy. Equally, a vehicle borne IED could be placed in the path of the convoy the whole convoy would halt. The demonstration videos also make no mention of what happens if the lead vehicle is disabled, or if a vehicle midway through the convoy is disabled. The concern over looting and IEDs applies to the expeditionary context more than domestically, though in the case of disaster relief domestically when people are desperate, theft from convoys is a possibility.

There is also an issue concern with the maximum range of the autonomous ground systems. The Oshkosh HEMTT A4, FMTV, and MTVR trucks – the trucks used for the AMAS, CAST and TerraMax programs – claim to have a 300 mile (483km) maximum range in its normal configuration (i.e.: human drivers) [294] [295] [296]. With human drivers all three trucks are capable of travelling between two and three times further than when equipped with autonomous driving systems (see Table 14) represents a significant reduction in range using the autonomous system over human drivers. While the 100-mile range may be sufficient for adaptive dispersed operations, it imposes a different standard on autonomous capability than with human drivers. This could lead to a preference for human drivers to extend the maximum range, negating the benefits of the autonomous concept. It is not clear if the limits on autonomous range is because of the limits of the navigation system from the vehicle's home base, or if the vehicle carries less fuel. In either case, the relatively limited range presents a significant obstacle.

The payload of the vehicle appears to be unaffected by the use of autonomous systems, though that will depend on the type of truck into which the system is fitted. The Oshkosh HEMTT A4 can carry a maximum payload of 21,561 lbs [294] and the FMTV can carry a maximum payload of 10,000lbs or a towed load of 21,000 lbs [297]. The maximum loads for these vehicles is still well below the maximum that an ISO container can carry and is slightly less than the maximum payload of 24,000lbs that a CH-47 can deliver. The obvious benefit of the unmanned ground systems for distribution is that truck convoys are not comprised of a single truck, meaning the total payload of 6 to 10 trucks is far greater than the payload of a single helicopter.

The challenges that face the unmanned ground systems are similar to those facing the autonomous helicopters: humans have the ability to rapidly assess a situation and make decisions in a way that autonomous technology cannot yet replicate. We discussed slow landings from autonomous helicopters and their vulnerability to ground fire as a result, especially in the urban environment. Unmanned ground systems face similar challenges in terms of navigating complex urban terrain. Test videos show the ability to navigate simulated urban environments, however the test conditions do not reflect a living city with people, vendors, overhead wires, vehicle and motorcycle traffic, etc. This represents a major challenge. From a civil-military-co-operation (CIMIC) and information operations perspective, an unmanned vehicle system colliding with a civilian vehicle already presents challenges in terms of hearts-and-minds and gaining support from the local population during expeditionary operations. If such a collision were to happen with an automated system, there were likely be major frustration from the victims and local authorities investigating the incident.

This is not to say that unmanned ground systems do not show some promise. The ability for a group of trucks to delivery tens of thousands of pounds of cargo, all without human crews, is an impressive technological accomplishment. However, the application of the current state of technology should be limited to either domestic operations where there is limited threat along the transit route, or to expeditionary operations where there is limited threat along the transit route. These systems could be used to transit open spaces (desert) and deliver supplies to a unit in leaguer. However, until further testing can be done to improve the ability to navigate in urban terrain, these systems should not be implemented for movements in complex urban terrain. This restricts the number of scenarios from the AoT where unmanned ground systems will be applicable.

6.9 Dismounted Load Carriage

The concept of dismounted load carriage systems is that a small wheeled or legged vehicle will carry payload for a dismounted infantry section. These systems are intended to sustain soldiers at the 1st line, with some capability to return to the 2nd line to collect more supplies to bring forward. With soldiers often carrying more than 100lbs of equipment on their bodies, dismounted load carriage systems would allow soldiers to carry less equipment on their backs. This would improve a soldier’s individual agility, improve a soldier’s endurance, reduce physical and mental fatigue, and reduce the likelihood of injury resulting from carrying heavy loads. At the section level, a dismounted load carriage system means that an infantry section can operate independently for extended periods of time without needing resupply or contact with other units. The SMSS, MUTT and Big Dog will fit in a large helicopter, and the SMSS has been slung under the K-MAX autonomous helicopter. Based on their size, all systems are presumably air-mobile for helicopter transport and air-droppable from fixed wing aircraft if they are appropriately rigged. There has been no mention of whether or not these systems are amphibious.

Table 15: Summary of dismounted load carried technology under development

System	Country of Origin	Cost	Range	Payload	Speed
Squad Mission Support System (SMSS)	US	N/A	60 miles radius [147]	1,500 lbs [147]	N/A
Multifunctional Utility / Logistics and Equipment Vehicle (MULE)	US	N/A	30 miles [298]	2,000 lbs [152]	60 mph [152]
Multipurpose Unmanned Tactical Vehicle (MUTT)	US	N/A	15 miles [299]	600 lbs [154]	N/A
Big Dog	US	N/A	N/A	45kg [156]	5 mph [156]

In terms of operational effect, there is a wide variability in the payload and range potential for the dismounted load carriage systems in development. The two wheeled systems are the SMSS and the MUTT, and the legged system is the Big Dog. The SMSS is produced by Lockheed Martin and is the most capable, with a range and payload exceeding all of the others. However, it is also the largest of all the active systems, limiting the kind of terrain the infantry section can cross. The MULE has a larger payload overall, however this system was cancelled due to challenges with the autonomous navigation system that could not be overcome [151]. The MUTT is produced by General Dynamics and carries a smaller payload than the SMSS and has a shorter range, and it is also a smaller vehicle, meaning it imposes fewer mobility restriction on an infantry section. The Big Dog is a legged system that walks like an animal. Its payload is much less than either of the wheeled system, and based on that would only be capable of carrying the equipment of one soldier, not the whole section. While the Big Dog can climb stairs inside buildings, its payload presents a serious obstacle. Even if this was overcome the Big Dog operates using a gasoline engine and is *very* loud. This obstacle prevents the Big Dog from being fielded, due to obvious operational security challenges. This project has been abandoned by the US military for that reason [300].

The SMSS has the greatest apparent potential for Army CSS applications. 1,500lbs is the stated payload, however there is indication that under combat conditions in Afghanistan, the SMSS was capable of carrying a larger payload, though no figure was stated [301]. Even if we assume a maximum payload of 1,500lbs, that is sufficient payload to carry all of the rucksacks of an infantry section (8 soldiers X 100lbs per rucksack = 800lbs) and 700lbs of additional equipment, weapons and supplies. This means that 700lbs of rations, water, ammunition, fuel, crew served weapons, communications equipment or other mission equipment can be carried by the SMSS to maximum range of 60 miles [145]. The maximum range of 60 miles for the SMSS far exceeds the distance an infantry section is likely to cover on foot in one operation. With that extended range comes the potential to extend the range of light infantry operations using the SMSS. The SMSS can also travel to a resupply point – autonomously – to collect more supplies and bring them back to the infantry section’s bivouac area [149] [150]. This means that the 1,500lb payload can be replenished autonomously if required. The SMSS is controlled by a soldier in the section and can be driven manually (i.e.: with the user using a hand-held controller to direct the vehicle) or can be programmed by waypoints, or to follow the infantry section as it moves.

The MUTT in 4X4 configuration is a smaller vehicle than the SMSS, and correspondingly carries a smaller payload. The MUTT can be controlled either by a tether that is physically attached to a soldier (i.e.: when the soldier moves the MUTT moves with the soldier [154]) or using a hand-held controller with a screen to select waypoints and follow mode [302], similar to the control method for the SMSS. The MUTT is capable of doing most of the things the SMSS is capable of doing (minus autonomous travel to add more supplies) though does so with less payload. With a maximum payload of 600lbs, this can take the rucksacks off of soldiers’ backs, however those rucksacks will need to be no more than 75lbs each to accommodate 8 infantry soldiers if a single MUTT is used. Alternatively, two MUTTS can be assigned per infantry section [303] and can be tied to each other in a trailer configuration [154] raising the maximum payload to 1,200lbs for the section, allowing for more supplies to be carried. There are 6X6 and 8X8 variants available, with 900 and 1,200lbs payloads respectively and according to the manufacturer using the same control systems [303]. However, it is not clear if the 6X6 or 8X8 versions have been tested for unmanned cargo missions. The only demonstration material available shows the 4X4 variant.

The SMSS and MUTT are both available in different variants. The SMSS can be configured for unmanned ISR tasks, counter-mine / counter-IED, with armed versions for either mortars or direct fire weapons like machine guns [150]. Likewise, the MUTT can be mounted with a variety of direct fire weapons systems like machine guns or grenade guns [299]. Though this has little to do with CSS, the point is that the procurement of the SMSS or MUTT platform does not limit the Army to a single mission. Each system can be configured according to the mission set. This means that procurement of the SMSS or MUTT could address land ISR needs, direct fire needs and CSS needs through a common platform. A common platform streamlines maintenance, and CSS for unmanned systems through common parts and components.

The challenge associated with both the SMSS and the MUTT for light infantry is that despite the value of taking the load off of soldier's backs, these are fundamentally vehicles that will accompany soldiers. This means the SMSS and MUTT will not be capable of moving through forest, or jungle, or capable of following soldiers indoors: they are simply too wide and cannot enter that kind of terrain. This is an important point because these vehicles are not intended to resupply the 1st line; they are embedded in the 1st line to carry supplies and equipment used on the mission. This will limit the terrain through which soldiers can transit and will tie them to roads and trails. This is an important point for urban operations where infantry soldiers will often enter buildings, courtyard, alleys, and will use alleys and stairs to cross floors. The vehicles will not be capable of following them during this time and will need to wait outside. Leaving a vehicle full of ammunition and supplies is unacceptable, meaning that soldiers will need to remain on guard duty for the SMSS or MUTT if the remainder of the section enters a building.

Like all vehicles, they are vulnerable to enemy fire, and given that there is no driver to respond to enemy fire (i.e.: a person to maneuver the vehicle to cover) there is a risk of the vehicle being destroyed under fire. There is also a concern for noise. The SMSS uses a diesel engine and the MUTT uses and hybrid diesel engine. The MUTT claims that it generates less than 50db of noise at 7m due the sound deadening technology [303]. This makes them less suitable for reconnaissance missions, due to the noise generated. Like the observations for autonomous helicopters and unmanned ground distribution systems, where GPS guidance is required these systems are likely vulnerable to jamming. When the operator is located near the system and is entering waypoints or manually directing the system there is no concern to navigation. The challenge for operating in a GPS denied environment is that any autonomous functionality will be negated. This means an increased driving / commanding workload for the soldier tasked with directing the autonomous system. This effectively removes one soldier from an infantry section, for practical purposes, because they are directing the vehicle.

The SMSS and the MUTT are the most viable of the dismounted load carriage systems available. They show great promise for lightening the carried load for infantry soldiers. The main drawback is that some stealth is lost due to the fact that a section is moving with a vehicle and not on foot. Additionally, some of the agility of the infantry section is limited by having a vehicle as part of the section. However, for domestic operations and for operations in low to medium threat environments, humanitarian operations, or any operation where extended endurance is expected, the SMSS and MUTT should be further examined to reduce the burden of equipment carried by soldiers.

6.10 Automated Systems for Material Handling

Autonomous systems for material handling were intended to reduce the felt burden carried by a soldier or technician in the performance of their duties. There are two main solutions under evaluation: the FORTIS system from Lockheed Martin, and the TALOS system being built by the US Special Forces. The main difference between the two systems is that FORTIS system is only intended to serve as an exoskeleton, while the TALOS system is intended to be an integrated situational awareness system for special operators that also includes an exoskeleton.

Table 16: Summary of autonomous systems for material handling under development

System	Country of Origin	Cost	Payload
FORTIS	US	$23,320 [304]	36lb tool, and feels weightless to operator [163]
TALOS	US	$80M for full program R&D [305]	75lbs unpowered, 150lbs powered [166]

In terms of operational effect, both FORTIS and TALOS systems represent an improvement over existing conditions, due mostly to the fact that no comparable systems are in service. The FORTIS was initially designed as an unpowered system to reduce the physical strain on the shoulders and back for industrial workers [306], not military personnel. The FORTIS system is reportedly awkward to wear and limits the mobility of the wearer [307]. This is not ideal for a combat situation, though is not an obstacle to implementation for warehousing, or vehicle and aircraft maintenance. This point was further emphasized during testing of a battery powered system from Lockheed Martin called the Human Universal Load Carrier, or HULC. This powered system used the same concept as FORTIS but allowed for 200lbs of load to be carried. The system appears to have been cancelled. Initial testing showed reduced fatigue to back and shoulders; however, it also showed that operators burned more calories when wearing the suit than not, experienced heart rates 26% higher than not wearing the suit and consumed 39% more oxygen [308]. This was largely attributed to the fact that the suit was bulky and did now allow for a natural gate when walking; effectively, the wearer was wrestling with the system [308]. This extension of the FORTIS concept illustrates that if the system is awkward to wear, it will not deliver the benefits expected.

The initial driver of the FORTIS system for Lockheed Martin was to ease the strain on their own workforce, building C-130 Hercules aircraft. Building aircraft requires significant manual construction (riveting components, for example) and doing so required heavy hand-held tools. Lockheed Martin developed the system for its own workforce, and then marketed the technology to other heavy industry companies with human workforces [306].

The TALOS (tactical light operator suit) is more than just an exoskeleton, though there is one built into the core of the suit to help the operator carry the weight of the fluid-based armour, communications systems, electro-optical systems [309]. There is traditional plate armour on this suit, and also tube system filled with fluid that pumps fluid to the specific point on the person’s body where they are about to be shot. This system is intended to integrate all the elements of the modern combat load – weapons, communications, computers, armour – into a single system. TALOS is heavy, and for that reason an exoskeleton is integrated into the system. This system does not have any immediate CSS implications, aside from possibly increasing the volume of batteries required for units that wear the TALOS system. Unlike the FORTIS, TALOS is powered and will require batteries to power the exoskeleton, the dynamic armour system, communications systems, and sensors. The driver for the development of this suit was for Special Operations Command (SOCOM) to attempt to develop technology that will give operators an additional technological advantage, and increased survivability in the operating environment, according to the Commander of SOCOM in 2015 [310]

The implications for CSS for each system are in reducing fatigue and increasing supply requirements. The FORTIS could be used in 3rd line and 2nd line facilities to reduce the strain on warehousing personnel, building maintenance and vehicle and aircraft maintenance by allowing personnel to use heavy tools with reduced strain on their bodies. This could reduce the need for rest for maintainers by extending the number of continuous hours they can work, due to reduced load strain. TALOS is a very impressive technology, however it will require batteries to sustain it. For this reason, the impact on CSS is likely a negative impact. This is probably offset by the improvement in operational effects that can be generated, though further evaluation would be required to make this determination.

6.11 Power and Energy

Power and energy continues to present a challenge for military operations. Electronic devices are mission critical – radios, GPS, networked devices – and are part of a modern soldier's battle load. They all rely on batteries, and devices will go through multiple batteries on a single mission. This makes the soldier's personal load heavier, and therefore impacts soldiers' endurance. The need for batteries also generates strain on CSS capacity, because batteries need to be moved to the 1st line where they will be used. Mechanized operations require significant volumes of diesel fuel, especially during combat operations, generating a logistical challenge for keeping the mechanized brigade group supported and supplied with fuel. 2nd line facilities like FOBs also have significant energy needs including energy for communications systems, ISR systems, and energy for living facilities, food storage, exercise spaces, and lights. Operating in far-flung regions including combat zones, failed states, the site of natural disasters, or simply operating far from electricity infrastructure and networks means that the power grid cannot be taken for granted. This often means diesel generators to sustain FOBs, which adds to the amount of fuel transported to 2nd line facilities.

In short; whether to sustain the electronics worn by infantry soldiers, mechanized organizations, or supporting 3rd line and 2nd line facilities, energy and power challenges are ubiquitous. This section discusses emerging power and energy technologies, and their potential application for military use, for facilities, vehicles, and soldiers. The most prominent emerging technologies are batteries, fuel cells, energy harvesting technologies, and solar power generation.

6.11.1 Facilities

Significant energy is required to sustain computers, operations centres, communications networks, and water infrastructure. The technology for facilities is very different from vehicle and personnel-mounted devices in size and storage, in that dedicated generators are often used for extended period of time. Emerging battery technology provides the potential to store generated power to optimized use, and ideally reduce reliance on diesel fuel generators, or improve the efficiency of the use of diesel fuel generators. Large batteries provide some promise for local power storage.

Sodium-ion batteries operate on the same concept as traditional lithium-ion batteries, but operate at a lower energy potential, meaning there are most useful for grid storage [311], and are therefore suitable for facilities. The lower energy potential makes sodium ion batteries impractical for vehicle or personnel application due to the relatively rapid rate at which vehicle and personal devices deplete power. The attractiveness of sodium-ion batteries is that they have projected cost less than 20% of what a lithium-ion solution would cost to deliver the same storage capacity [312]. Much of the cost differential is due to the fact that lithium costs roughly $15,000 per ton to mine, while sodium costs just $150 [313] meaning the costs of production for sodium-ion are a fraction of those for lithium-ion. Sodium-ion batteries could allow 3rd line and 2nd line facilities to better manage their energy storage, though their lower energy potential means other technologies could be more effective for facilities.

Another technology that appears viable is actually an old technology that is being modernized: redox flow batteries. Redox flow batteries were initially developed by the National Aeronautics and Space Administration (NASA) for aerospace applications and are now being explored for storing energy generated by renewable sources. The name ‘redox’ comes from the reduction and oxidation reactions that come from the flow of electrolytes through electrochemical cells during charge and discharge [314]. Commercial renewable energy companies see redox flow batteries as offering a viable solution for storage of energy from a source (wind, solar) that does not generate energy at a steady rate [315]. In test application a redox flow battery system (the largest in the world, ever) was found to be capable of storing 200 MwHs in tests, a massive amount of energy [316]. This would not be the normal application, though indicates there is significant energy storage potential. Redox flow batteries are more expensive that lithium ion batteries at initial purchase, however they have much cheaper sustainment costs over the 10-year period, making them a potential for storing power at installations [316]. This allows the user to store energy generated by renewable means and to use it a time of their choosing. Redox-flow batteries do not appear to be as viable for mobile use (vehicles or by dismounted soldiers) though does offer potential for 2nd line and 3rd line facilities.

Fuel cell technologies show some promise for facilities where they can store power generated locally in order to optimize power use over the course of a day to improve efficiency (i.e.: running generators when less power is needed and storing the energy for surge periods). There are three types of promising technologies: solid oxide fuel cells (SOFC), proton exchange membrane fuel cells (PEMFC), and hydrogen cells.

SOFC function by using a fuel to generate power – ranging from hydrogen, natural gas, coal gas, reformed gasoline or diesel, and gasified carbonaceous solids (solid waste or biomass) [317] – and a solid electrolyte to store power. These batteries are large and can store significant amounts of energy, making the primary drivers to the use of these technologies are residential, commercial, industrial, with additional grid support to provide supplementary power generation locally [318].

There are two key advantages to using SOFC over other types of fuel cell: they have greater tolerance over impurities in the source fuel than other fuel cells meaning a greater diversity of fuel options [319]. When used in conjunction with gas turbine engines, they have the potential to realize up to 85% energy efficiency, a significant increase over other engines and modern thermal plants that generate roughly 30% [317]. The cost of buying an SOFC system is expensive, and the greatest cost savings are realized when an SOFC system is used to supplement an existing power grid [320]. Realizing cost reduction is essential to making SOFCs competitive, because at present natural gas turbines are more cost-effective than SOFCs for power generation [321]. The driver for military application will be determining if SOFC is a more cost-effective solution that relying on either existing power grids while on operations or relying on other means of local power generation (i.e.: diesel-fired generators).

Proton exchange membrane fuel cells (PEMFC) show considerable promise in terms of limited by-products, rapid response times, and low operating temperature. PEMFC rely on pure hydrogen in a water-based electrolyte and precious metal electrodes to generate power [322]. They have a very low operating temperature, typically between 60 and 80 degrees Celsius when operating with a water solution, which allows for rapid starting times [323]. They can also use a mineral based acid solution, though this increases operating temperature to 200 degrees Celsius and decreases the power density of the unit [322], making the water-based solution an overall better choice.

The main challenges of PEMFC technology is the need for a very pure hydrogen source to limit corrosion of parts, and the need for moisture in the operating environment for maximum efficiency [323]. The requirement for a very pure source of hydrogen creates another fuel commodity that will likely need be transported to the 3rd line and 2nd line, unless it can be manufactured locally to the necessary standard. The need for a high-purity hydrogen source creates a dependency in the supply chain, if power generation becomes dependent on a refined commodity. In terms of environment, the lack of humidity in the surrounding environment can accelerate the production of peroxide radicals (HO) or hydroperoxide (HOO), which contribute to the chemical degradation of the membrane and catalyst in the fuel cell [323], thereby shortening the service life. This represents a challenge for operating in arid environments or in the arctic; in arid environments the dry air will accelerate the production of radicals, and in arctic environment dry air will also accelerate the production of radicals and the low temperature will limit the effectiveness of the PEMFC. In the artic the heat generated will be a benefit, in that it can double as a heat source for facilities, however the dry air means that corrosion will be accelerated compared to temperate environments.

Hydrogen fuel cells are under development primary for the transportation industry, however, they are also under development for the stationary power. Hydrogen fuel cells use a hydrogen input and oxygen input to generate electricity, with heat and water as the only outputs. The basic principle is similar to the stationary options mentioned above, though with almost no emissions. Hydrogen cells are currently used as a back-up power source in the American grid and produce roughly twice the power of natural gas-fired power generator, and even higher if the heat from the hydrogen cells is captured [324].

The biggest challenge for hydrogen power in general is the need for storage of high-pressure tanks for storage, and the consequences of a rupture. Leaks in storage tanks are common, though outright ruptures are rare [325]. At certain pressure and temperature conditions hydrogen can diffuse into metal lattice in a phenomenon called 'hydrogen embrittlement', and there is obvious concern of a destroyed tank leading a massive blast and fireball, with associated fragmentation and debris scattering [325]. For civilian application and for low threat environments, hydrogen fuel cells show some promise; however, for military application there is significant risk that a hydrogen tank rupture could cause significant casualties.

There is a potential for solar generation to provide power for 3rd line and 2nd line facilities instead of relying on other, usually liquid, fuels. Photovoltaic (PV) solar panels are the most common solar power source available today and generate electricity directly from sunlight striking the solar panels. To maximize efficiency the PV panels can be mounted on mechanism that rotates throughout the day to follow the sun, generating maximum energy over the course of a sun cycle [326]. The most common applications of PV panels today is for private homes to generate power locally. However, the US military is already using PV cells at some of its bases. In Hawaii, the US Navy and Marine Corps installed a PV system that generates the equivalent of 54,000 barrels of oil or enough electricity to power 5,000 homes per year [327]. The system can generate 17 megawatts per year and is expected to last for 25 years [327].

Advances are being made in solar technology, specifically with perovskite, polymer cells, and kesterite. Perovskite cells are an improvement of PV cells that use dye-sensitized solar cells, and since 2009 they have gone from 2% efficiency to 18% efficiency in 2014 [328]. They can also be ink-jet printed onto flexible films allowing customized panels to be manufactured to meet specific needs [329]. However, perovskites contain lead, with well-known impacts on human health and on the environment if lead leeches into ground water if the panels are damaged, a reasonably likely outcome for military application [329]. However, research is underway to replace lead in perovskite panel with other metals that are not toxic to human health [330]. Until such a time as the lead issue can be resolved, the energy production gains for perovskites represent too great a danger to human health to be used in a military context.

Polymer cells are a type of PV cells that are made of semiconducting polymers that can be rolled out to custom lengths and generate sufficient energy to viable for further research [331]. The main challenge in developing polymer cells has been using nano-technology in order to improve the efficiency for harvesting energy, and finding suitable material needs to be found for large scale manufacture that will allow devices to operate effectively for longer than 10 years [331]. A Danish firm has done this, finding 10% efficiency in laboratory testing, developing a rollable solution that can be placed virtually anywhere for solar power generation [332]. However, the rollable solution is for power generation at the individual level and does not yet scale to the vehicle or facility level.

Kesterites are another form of PV cells, with researchers attempting new methods to improve efficiency of PV cells. The maximum efficiency with kesterites previously recorded in laboratories is 12.6%, with perovskites showing much greater potential at 22.7% [333]. However, recent research is showing promise, with targets of realizing 18% efficiency by 2020 and 20% efficiency by 2022 using kesterites [333]. However, kesterites still face some challenges before they are viable; like perovskites, some kesterites use materials toxic to humans (cadmium), and the other metals – tellurium and indium – are relatively scarce [333] meaning the costs of mining, and therefore production, are likely to be high. This creates challenges for both development and implementation. If these challenges can be overcome, by using non-toxic material or less scarce materials, the efficiency targets of kesterites could be attractive for military application.

Energy for facilities relies on the assumption that future operations will include the adaptive, distributed environment – with semi-permanent installations from which army operations are launched – or something similar. While it is unlikely that army operations will abandon physical basing (3rd line or 2nd line facilities) the Future Army model clearly anticipates greater mobility and dispersed operations. While energy efficiency can likely be realized with new battery and power generation technologies, the efficiencies at installations may be less impactful if operations are more distributed (i.e.: vehicles and units further away from basing). If this is the case, the model for applying energy will be more localized by necessity with units carrying some mix of liquid fuel and energy production with them.

Currently, solar power generally will face challenges compared the liquid fuels in generators, not least because solar cannot be used at night. The example of Hawaii above is instructive for using renewables at an installation; however, this model may not scale adequately for field units. Fuel cells technology may show more promise for their ability to provide on-demand energy to respond to military necessities, where renewables may not be sufficiently versatile for those uses. Given the sheer volume of liquid fuel that is required to sustain facilities – or to supplement existing sources of power – renewable and alternative power and energy technologies could reduce the sustainment requirements of military installation for domestic and expeditionary operations. The impacts will be most felt in austere conditions, domestically in places like the arctic, or in expeditionary operations in countries where there is limited power infrastructure upon which the Army can rely for some of its power needs.

6.11.2 Vehicles

Military vehicles typically run off liquid fuels, either diesel or gasoline. There has been considerable attention in the civilian vehicle market to develop electric alternatives. To date, these cars have been limited by their maximum range per charge, and long re-charge times. Tesla currently has the greatest range of any electric vehicle, claiming a maximum of 335 miles (539km) for its Model S 100D, surpassing its nearest competitor – the Chevrolet Volt, capable of 238 miles (383km) – by a significant margin [334]. However, the charge times are variable and dependent on the circuitry in the recharge station. On 120V power (standard wall outlet) it takes up to 4 days to recharge the Tesla from empty; on 240V power (larger home outlets for laundry machines, and for industrial uses) the Tesla can recharge in between 6 and 30 hours, and; using the Telsa 'Supercharging' technology with a 480v power source (typically only industrially available) the car can recharge in between 30 minutes and 170 minutes [335]. Currently, the 'superchargers' are Tesla technology and are only available at official Telsa charging stations of which there were only 274 in North America in 2016 [336]. This creates a challenge for the infrastructure: as the number of Teslas (or electric cars in general) are sold, there is an increasing demand for infrastructure, and without increased infrastructure there will be a suppression of demand for vehicle as consumers may not see an electric vehicle as convenient [336].

Tesla has also developed a transport truck for highway use and is claiming a maximum range of 500 miles cruising at 65mph (104km/h), or a range of 400 miles that can be re-charged to 80% power in 30 minutes, with a maximum gross weight of 80,000lbs [337]. While the payload and range parameters are sufficient for military application it is not clear if those figures are transferrable to military vehicles without trailers and if the range estimates are transferrable to rough and uneven terrain. With diesel trucks as a baseline, the figures are not likely transferable, though this remains unknown. The Tesla truck has a very low drag coefficient – 0.36 compared to 0.65 for a standard transport truck – and is being tested in Nevada and California [337]. The lower drag coefficient means the engine doesn't have to work as hard to accelerate and sustain speed. What is not clear is if the battery technology will work as effectively in the colder, damper climates of much of Canada, compared to Nevada and California.

To extend the range of electric cars solid state batteries show some promise and are based on the same concept as liquid electrolyte batteries but using a solid electrolyte instead of a liquid one. Solid-state battery technology is being driven largely by the auto manufacturers, who have faced challenges in extending the range of electric cars to compete with traditional liquid fueled internal combustion engines. Auto manufacturers have two goals with electric car research; the desire to remain competitive with other electric cars manufacturers and extending the range that a car can travel on a single charge to a maximum of 800km by 2030 [338]. In Japan, Toyota, Honda and Nissan have partnered with battery manufacturers Panasonic and GS Yuasa to further development of solid-state batteries [339] in order to realize that goal. Solid state batteries are the path by which they expect to reach their range goals.

The benefits in using a solid electrolyte is there is less space required between single cells, allowing for batteries to be stacked in series with less space, creating a smaller device compared with liquid electrolyte batteries [340]. An evaluation of solid-state technologies showed excellent conductivity and electrochemical stability, translating into high power density, very fast charging, and longer service life than existing liquid electrolyte batteries [340]. Challenges remain with manufacturing techniques and stacking multiple devices, however the overall technology is promising for solid-state batteries [340] for civilian use. These devices are expected to be capable of operating in temperatures ranging from -30 degrees Celsius to 100 degrees Celsius [341]. Solid-state batteries represent the potential for improved range for electric vehicles, but it is not clear if this technology with scale for heavy military vehicles, specifically armoured vehicles and heavy trucks.

The main limitation to electric vehicles, generally and for military use, is that they rely on charging stations to replenish their power. The infrastructure and charging challenges mentioned above for civilian vehicles on paved roads are significant today and would certainly be more complicated for military application where reliable access to an electricity grid cannot be taken for granted. Large batteries for vehicles cannot be practically swapped out in the field, and if they can, cannot be done as easily as pouring diesel fuel into a vehicle that is due for fill-up. With challenges still present for civilian electric vehicles, the challenges for military application will likely prevent the adoption of this technology for the army in the near term.

Hybrid technologies present a potential compromise solution for military application, relying on fossil fuel engines with some electric capture. Hybrid vehicles face unique challenge in the military domain compared to personal use passenger vehicles. The evolving nature of the threat environment, the off-road mobility challenges faced my military vehicles compared to civilian vehicles, and the comparatively long life cycle of military vehicles, and the uncertainty of the reliability of hybrid components over the long-term [342] all create unique challenges. While this is a better solution than electric there are still many unanswered questions. The nature of the threat environment changes the requirements of the vehicle fleet (protection, speed, mobility parameters), and unlike civilian vehicles most military vehicles are expected to stay in service for decades, not years.

Research on the viability of hybrid technology for military application shows mixed results for improved efficiency over fossil fuels. Two important conclusions emerged: the type of duty the vehicle is performing will drive the fuel efficiency gains that can be expected, and small military vehicles tend to realize greater fuel efficiency. The US-made HMMVW (Humvee) realized between 4.3% and 45.2% improvement in fuel efficiency when using hybrid power, the FMTV (a ten-tonne truck) realized between 2% and 32% gains, and the HEMMTT (heavy truck) realized only 0% to 2% improvement in efficiency [342]. We can assume that armoured vehicles would realize similarly small gains, given their payload and fuel expenditure. This is not encouraging for heavier vehicles, though there is promise for lighter vehicles. The slower and more varied the duty of the truck (i.e.: rugged rural terrain with braking and changing slope vs. flat paved highway conditions) the greater the fuel savings, and the flatter the terrain and the most constant the speed the less savings were realized [342]. Further research is required to better understand the capabilities and limitations of hybrid technologies for military vehicles, including which vehicles show the most promise and the ideal use conditions for hybrid technology.

There is an emerging technology that could see a role for heavier logistics vehicles, and not for the heavy vehicle itself. In recent conflicts in Iraq and Afghanistan the notion of ‘front-lines’ became blurred, with logistics vehicles frequently facing enemy contact; in the American context this includes the FMTV and the HEMMTT mentioned above. As a result, non-combat vehicles are often loaded with sensors for communications, jamming adversary electronics like IED detonators, and rely increasingly on command and control systems like blue-force tracking [343]. All of these systems run on electricity, and that electricity is generated by the (typically) diesel engines in the vehicles. As we saw above, in military test applications of hybrid technologies the efficiency was focused on lighter vehicles, with almost no improvement for heavy vehicles. Though, it is possible to run the current the other way and have large vehicles support other units with auxiliary power.

Transmission-Internal Generators (TIG) are a widely available technology that can generate up to 125kW from the engine drive shaft to support the range of systems and sensors on board and can power external systems [343]. Oshkosh Defence has developed a system called ProPulse that is powered off of the vehicle’s engine. Oshkosh claims this system can generate enough energy output to power an airfield of a field hospital [344]. The system appears to be useful only for that purpose when so configured, in that it cannot provide that level of electrical output while also serving as a cargo platform [345]. The Future Army concept centres on dispersed operations, with the potential for significant distances of deployed units from headquarters and facilities. This means a long supply line for batteries and fuel. If vehicles can generate some of that electricity (charging and recharging of batteries for army field equipment) the need for battery resupply is somewhat reduced. However, this will have a (currently unknown) corresponding cost in diesel fuel delivery. Using heavy vehicles as power generation stations will allow for electric devices to be powered from the field with less need for batteries or the grid: however, there will be a need for diesel fuel to power the trucks.

The conflicts in Iraq and Afghanistan relied on massive supplies of diesel to power vehicles and generators. Battery and hybrid technologies show some promise for civilian application, however the transition of this technology to the military domain is not clear. There are limits on the size of vehicle for which hybrid technology provides meaningful savings, and for electric cars the charging infrastructure is the main limiter – both for widespread civilian use and future military use. These technologies should be monitored for future development, however the obstacles in near term are likely to limit their applicability for the Army.

6.11.3 Personnel

Soldiers in the field rely on batteries to power lights, optics, night-vision equipment, communications equipment and command and control systems. Improving the endurance of batteries or reducing the weight of individual batteries will reduce the soldier's overall load, thereby reducing fatigue and improving personnel endurance. New battery technologies are emerging that promise to improve battery life, with many still in development.

The lithium-ion battery is the most common kind of battery carried by soldiers today. There is research effort being applied to improve the application of the basic design. Magnesium-ion batteries function the same way as lithium-ion batteries, however recent research shows they may be capable of improving efficiency of energy transfer, and most cost-effectively than lithium-ion [346]. The research shows that each magnesium ion has the potential to double the charge over lithium [347]. The primary challenge is to develop magnesium-ion solids. It is currently possible; however, the process involves significant effort to achieve the right tuning of the crystal structure and chemistry [347], meaning that mass-manufacture cannot be done cost effectively. This technology is worth tracking, given the number of devices that use lithium-ion batteries. Cellular phones, tablets and other personal electronics – for consumers and military applications – relay on lithium-ion batteries. If magnesium-ion batteries can provide twice the power of a lithium-ion battery it can presumably cut a soldier's battery load in half. For small UAVs or other systems that rely on lithium-ion batteries, some combination of range, payload and speed can likely be improved. At the system level, this could reduce the number of batteries that are supplied forward and/or reduce the rate at which battery stockpiles are replenished in 2nd and 3rd line facilities.

Sodium-magnesium hybrid batteries attempt to use both elements to improve the efficiency of the concept used in lithium-ion batteries. Experiments using sodium-magnesium hybrids are claiming to store roughly 2.5X as much power as a magnesium-ion battery [348] (itself capable of roughly twice the charge of a traditional lithium-ion battery). The costs for developing sodium-magnesium ion batteries are on par with the cost savings realized by either sodium or magnesium alone when compared to lithium batteries. The similar challenge is the size and scale of battery that can be developed (i.e.: challenges with scaling up to large vehicles) [349] with existing technology. Developments of this technology should be monitoring, with focus on moving toward stability and operationalization.

There is potential for improving the output of basic lithium-ion batteries by modifying the design to improve the output. Modifying the anode of a regular lithium-ion battery by using silicon instead of graphite has the potential to increase the amount of energy story. Silicon is the second most abundant material in the world, and by using silicon instead of graphite recent research shows that the anode capacity can be increased by to four times [350]. Lithium-ion batteries can also be modified by using a pure lithium metal at one electrode (instead of a lithium-containing fluid), allowing for a reaction with the oxygen in air [351]. Tests results indicate the potential for five times the power to be stored in a lithium-air battery compared to a lithium-ion battery [352]. The challenge for operating in a real-world environment with natural air (versus oxygen only) because of carbon dioxide and water vapour in the air that eventually gums up the cathode, coating it and preventing the battery from operating [352]. A potential solution is to coat the lithium anode with a thin layer of lithium carbonate that selectively allows lithium ions to enter the electrolyte while preventing unwanted contents from reaching – and gumming up – the anode [352]. If the technical challenge of gumming up the anode can be effectively overcome, lithium-air batteries may represent even greater potential than magnesium-ion batteries. Lithium-ion batteries are used by soldiers today, and the potential for five times the power storage will significantly reduce the number of batteries a soldier will carry, and therefore reduce the load carried. From a CSS perspective this also significantly reduces the number of batteries that must be shipped forward, and the number that are stockpiled. This technology shows significant potential, if the anode challenge can be overcome.

While systems are under development for personnel-carried PV solar panels to generate power for devices, the electronic power supply capacity is limited, at present [327]. The same is true for thermo-electric generators – devices used to capture wasted heat from other processes – in the industrial space [353], meaning they are certainly insufficient for personnel use to recharge batteries. Local thermo-electric generators are typically only capable of generating enough energy to light one LED [354]. Sound harvesting is also technically possible, however the power generated in miniscule. The sound of a locomotive is about 1/100th (10 milliwatts) of watt per square meter, compared to the sun which gives roughly 680 watts per square meter [355]. This means that even if sound energy can be harvested, the returns are not worth the effort. Likewise, electro-magnetic harvesters are capable of harvesting only between 3 and 5 milliwatts, with targets of reaching 50 milliwatts [356], still far less than other sources can provide. There are experimental concepts, like using spores to generate energy from changes in humidity [357], and on using 'hygroelectricity' to harvest charged water vapour in the air before a lighting storm [358], however these technologies still represent concepts and not currently viable for service.

In sum: modification of existing lithium-ion batteries – whether using another metal or new concepts to enhance the capability of the lithium-ion battery – shows the most promise for personnel-carried batteries. Developments should be monitored to determine which type provides the best overall solution for the Army.

7. DISCUSSION

This section will provide a discussion about the timelines for technology development, the technology considerations for CAF / DND, and the potential force structure implications of implementing any of the technologies discussed in this document. This section is intended to provide discussion on technology implementation. The specific conclusions are included in the next section.

7.1 Timelines for Development and Expectations

Expectations should be measured for all technological development, especially the delay between the initial technology's concept roll-out to the point where it can be operationalized and used effectively. Gartner has developed a concept called the Hype Curve (Figure 62). It shows that when the need for new technology is triggered there is rapid increase in expectations of what the emerging technology is capable of providing. For example, some of the autonomous systems described earlier in this document illustrate this idea. However, some of those devices also have major structural issues that prevent them from every being viable. Those technologies are now likely in the trough of disillusionment, however some of the more viable technologies are likely to climb the slope of enlightenment as they are developed, and the best among them may eventually reach the plateau of productivity. Once a technology has reached the plateau of productivity we can assume that it will either replace an earlier generation of technology or being supplementing functions of the earlier generation.

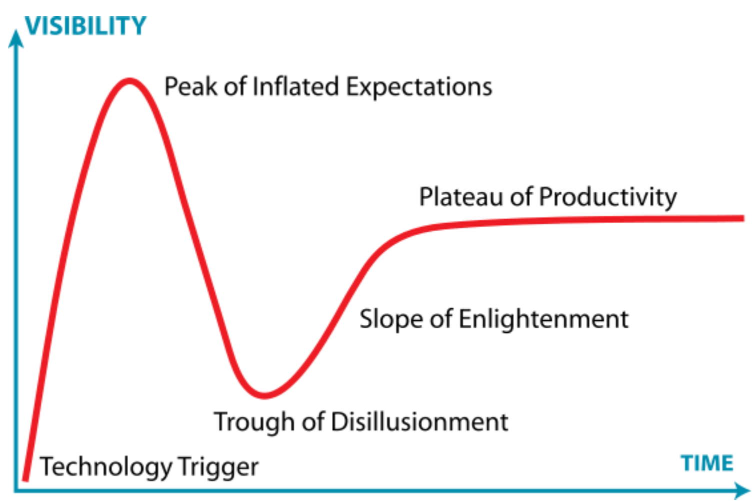


Figure 62: Gartner Hype Curve [359]

The waves in the Hype Curve align somewhat to the Army's concepts of time and future planning, with the Army of Today (0-5 years into the future), the Army of Tomorrow (5-15 years in the future) and the Future Army (20-40 years into the future). Some of the new concepts for which technical and implementation challenges exist may not be sufficient mature for the Army of Tomorrow and may only be viable for the Future Army. If the Hype Curve is accurate, this is an expected part of technology development, and should be expected as part of the process.

A good example is the ARES system. This remains a drawing today, though the concept offers promise. It may be another 20 years before this concept is sufficiently mature to replace existing helicopters for CSS for the Army. Conversely, some of the mature concepts today may be obsolete by then, replaced with a new technology of a significant improvement of the original concept.

Other concepts are likely to be iterative. Intangibles like the IoT concepts are in effect systems-of-systems. Their value is in networking thousands or millions of disparate items into a single network to make sense of the data. The IoT is not a single product and is therefore more likely to be iterated by improvements to individual components in the network (faster transmission, more bandwidth, fewer transmissions required, etc.) than an 'improvement' of all things within the IoT network. This is fundamental difference in networks (or systems) compared to platform and should be understood when viewing timelines for improvements. New platforms can be introduced, and old platforms retired; but for information technology solutions replacement is more likely to be iterative. In effect, the information technology modernization process is endless; it will require constant iteration.

The most important that the Hype Curve shows us is that new technologies, despite the attention they receive, may not turn out to be viable. There is additional complexity associated with introducing new technology into the military, especially if it originated in the civilian world (as many technologies do). A measure of caution should be exercised when considering any of the technologies in this report, and emerging technologies going forward.

7.2 Technology Considerations for CAF / DND

There are many considerations for the technologies being considered. These do not represent observations on specific technologies or products but are intended to provide consideration for the technologies discussed in this document.

IT management within CAF / DND clearly needs to be improved, based on the findings identified in 4.2 on gaps in visibility of the supply chain. Other gaps include a lack of integration between systems, and a tendency toward silos of information. These lessons should be top of mind when discussing an IoT-enabled system for Army CSS. A system that addresses only Army CSS risks creating another silo. An enterprise-wide concept should be used for IoT-enabled systems. There are clear benefits to supply, mobile assets and maintenance optimization; however, there could be other applications for non-CSS components. Designing an IoT-enabled system for the Army should take a CAF / DND wide approach.

Cyber threats are likely to be ubiquitous as net-enabled technology advances. The notion of cyber-attacks is not new, however reliance on net-enabled devices increases, so too does vulnerability to cyber threats. This could have impacts on the CSS systems that rely on net-enabled devices and databases. This concept also applies to electronic counter measures more broadly. All of the autonomous systems mentioned in this document rely on GPS for PNT. While some claim to be capable of operating in a GPS-denied environment, this needs to be investigated in more detail to determine if the challenge of GPS jamming has been addressed. Russia and North Korea are suspected of using large scale GPS jamming operations on their own borders, with allegations that Russia has used GPS jamming in Syria to interfere with coalition UAV navigation. The autonomous systems discussed in this document would presumably be affected by this kind of large-scale GPS jamming operation. Reliable PNT solutions and approaches should be included in any future discussion about autonomous devices.

Unmanned systems offer a reduced risk in making deliveries, and improved endurance of the CSS force in general by off-loading tasks from humans to machines. Caution should be exercised in measuring how many tasks, and under what conditions unmanned systems will be a suitable replacement for human operators. Unmanned aerial and ground systems offer great potential for simplifying CSS operations; however, the limits of this technology – i.e.: reduced performance in complex urban terrain, compared to simpler rural terrain – should be clearly articulated in any discussion about unmanned systems.

The last consideration is with respect to the anticipated operating environments for the AoT and the Future Army, and the connectivity requirements. The networked urban littoral is likely to have significant IT infrastructure available for Army and CAF use. Dispersed operation, perhaps hundreds of kilometers from facilities, may not have the same level of IT infrastructure available. Sophisticated IoT systems require that connectivity is maintained. The network is not a network if not all of the component pieces are connected. While there are operational security concerns with consistently transmitting data, the network also requires updates to present an accurate picture of where units are located and what they are doing. Reliable beyond-line-of-sight (BLOS) solutions will be necessary to enable network connectivity of deployed units, with the applicable network security caveats applied.

7.3 Impacts on Force Structure

New technologies may impact the existing force structure. The notion that a technology should be rejected because it “doesn’t fit our current model” ignores the modifications that have been made over generations to accommodate battlefield technologies that today are essential for battlefield success (UAVs, the most recent example). This section provides a summary of the potential force structure implications of each type of technology examined in this document. It focuses on Army force structure impacts, however there are potential implications for the RCAF and RCN. The RCAF is responsible for delivering air power and air effects, and air delivery vehicles of a certain size and payload are likely to be the responsibility of the RCAF. Likewise, RCN personnel and equipment are likely to be used to support littoral Army operations. The joint nature of large deployments means that beyond the implications for Army CSS, RCAF and RCN personnel are likely be involved in Army-led operations – both in in CSS and in Combat Support roles.

Information Technology Systems and Management*:* the signals corps and Associate Deputy Minister Information Management / Information Technology (ADM IM/IT) will have a significant role to play in any future IT systems. Given the scale and scope of IoT in enabling greater visibility of the supply chain and optimizing supply, mobile assets, and maintenance schedules, IT implications of the force structure could be significant. An IoT system will require the Army to define its requirements for CSS and identify how that fits into an enterprise wide solution. The enterprise-level solution will need input for the broader CAF/DND. Defining the requirements and procuring or building and IoT system will require significant efforts from CAF personnel and DND civilians.

Fielding an IoT-enabled system will require CAF personnel to manage the day to day operations of entering data, querying items, producing reports, and tracking items for deliver. Movements personnel, maintainers, and logisticians will likely be the prime users of this system. While additional personnel are not necessarily required, significant increases in IT infrastructure (servers, RFID tags, transmission equipment, security measures) and mobile devices will be required. The need for a human-in-the-loop for many decisions will generate some labour.

Designing and building an IoT system is likely to require significant personnel and resources; however, once implemented an IoT system will not require any additional effort from the users. The system will likely replace many manual processes and improve the efficiency of decision making and reporting. Designing and building will impact resources.

Containers: containers are not likely to impact the force structure. ISO containers and pallets are already standardized and based on the choice of equipment for the Army, RCAF and RCN to ensure interoperability there may be impacts for materials movements equipment. This will not likely require a change in force structure: only in standardized equipment. Container and pallet standardization choices should be integrated into an IoT-enabled system architecture.

Airships: airships will have a major impact on RCAF force structure, though the impacts for the Army are less clear. Airships are likely to cost at least $40m per airframe and are large aircraft. Airships will likely be life-cycled like any other aircraft or piece of military equipment. This means training pilots and maintainers, airworthiness protocols, and establishing processes and protocols for landing and offloading. It is not clear what additional force will be required for the Army. Airships promise to operate under austere conditions with minimal ground infrastructure. This merits more study, though safe to assume at this stage that the bulk of the force structure impacts will be for the RCAF. The other option for airships is to allow a contractor to provide the service, as one company is doing in Northern Quebec. This will eliminate any force structure impacts on the RCAF or the Army and will generate contracting and administrative effort only.

Large UAS for bulk deliver: similar to airships, large UAS for bulk delivery are likely to be RCAF assets. However, this raises the question of which element ought to employ large UAS, specifically the helicopters: the Army or the RCAF? Regardless of the answer, implementing a large UAS solution will have force structure impacts. Without pilots this effort will be focused on the infrastructure to process orders, the infrastructure that automates flights, and the maintenance time needed to keep the aircraft flightworthy. Recall, many of the large UAS are retrofit helicopters, and therefore will have maintenance requirements like any other helicopter.

For JPADS, the RCAF may not require additional pilots or maintainers, however, as the employer of tactical and strategic airlifters RCAF aircraft will be required to drop JPADS. The implementation of JPADs will almost certainly require more tactical and strategic airlifter sorties. This may generate additional force structure requirements or it may be managed within the daily or weekly ATO, with resulting trade-offs.

Small and autonomous helicopters: small and autonomous helicopters are aircraft; however, they could be small enough to be employed by the Army and not the RCAF. In either case, there will be force implications in terms of managing orders, flights, and maintenance. Given the volume of flights that are possible using small and autonomous helicopters, the total effort required could involve dedicated personnel to manage flight operations. This could also result in the need for new military occupations, however this merits more examination.

Small Unmanned Fixed Wing: these platforms should continue to be employed for ISR tasks and not for CSS, meaning no force structure impacts.

Last Mile Logistics: these platforms are not currently viable for Army CSS, meaning there will be force structure impacts.

Unmanned Ground Systems for Distribution: if the maturity of this technology expands to the point where it is viable for a wider range of operations that is currently possible, there could be a reduced need for drivers. These systems will not require drivers, or far fewer drivers per convoy, depending on the application model. There will be increased need in technicians to implement and manage this technology, similar to the requirements for using large UAS and small and medium autonomous helicopters for operations.

Dismounted Load Carriage: the dismounted load carriage systems do not require a driver; however, they will likely require one infantry soldier to be responsible for the vehicle. The system can be configured for some autonomous tasks, however in high-threat environments the technology may not be capable of making decision as quickly (or as good decisions) as a human operator. Dismounted load carriage systems are not like other resupply vehicles, where they drop supplies and then leave the supported unit; dismounted load carriage systems will be embedded with the infantry section. This will not have an impact on CSS force structure, though could cause re-examination of infantry section processes when the dismounted load carriage systems are used. The dismounted load carriage system is a vehicle and will therefore require maintenance. Because there is currently no equivalent to the dismounted load carriage system, this represents a new capability and therefore will likely impact maintenance force structure requirements.

Automated Systems for Material Handling: implementing automated systems for material handling will likely reduce strain on personnel using these systems, whether in warehouses or doing vehicle maintenance. There are no anticipated force structure impacts.

Power and Energy: improved power and energy solutions could reduce energy requirements in facilities, improve efficiency for vehicles, and reduce the load carried by individual soldiers. For facilities, new systems will require technicians and maintainers to receive new training, though it is not clear if there will be force structure changes required. For vehicles, relying on hybrid or electric power is not likely to impact force structure. More training for safe handling and use of electrical systems will likely be required, though not clear there would be any force structure impacts. For individual soldiers a reduced combat load for lighter batteries, or fewer batteries, will show some improvement in soldier endurance; however, no changes in force structure are anticipated.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Suitability of the Technologies

We can evaluate the technologies examined in this document by using a matrix to show where technologies compare to one another based on the maturity of the technology and the promise that it shows. Maturity indicates the viability of the technology to be implemented in-service in the short term, and promise is a rough estimate of the potential the concept shows. The matrix is shown below in Figure 63, the matrix shows four quadrants, defined below:

- **Track development, identify possible Concepts of Operations (CONOPs):** the technologies in this quadrant show promise for Army CSS, though at present lack sufficient maturity to be implemented. Given the development timelines of technology, it is possible that all the technologies in this quadrant could become viable for Army CSS. For this reason, CONOPs should be developed for how these technologies *would and could* be implemented should they reach the necessary level of maturity. Periodic technology scanning should be done to track the development of these technologies.

- **Evaluate Implementation:** the technologies in this quadrant are those that are either in service in other countries or in service in the private sector and show both the sufficient maturity to be fielded and align to the Army's CSS requirements. These technologies should be evaluated to determine how they would be implemented for the Army. This evaluation should include an examination of how the technologies would be used within current Army processes and structures and identify where processes and structured could be modified to improve the benefits of the technology to Army CSS.

- **Await further developments:** these are technologies that, at present, do not show sufficient maturity or promise to be implemented. These technologies could be revisited in the future if there is a significant advancement of the technology.

- **Identify if potential use case exists:** the technologies in this quadrant show sufficient maturity to be fielded, however doing so would require a change in operational approaches. For this reason, use cases for how the technology would or could be used should be developed to determine if these technologies are viable for the Army today, tomorrow and in the future.

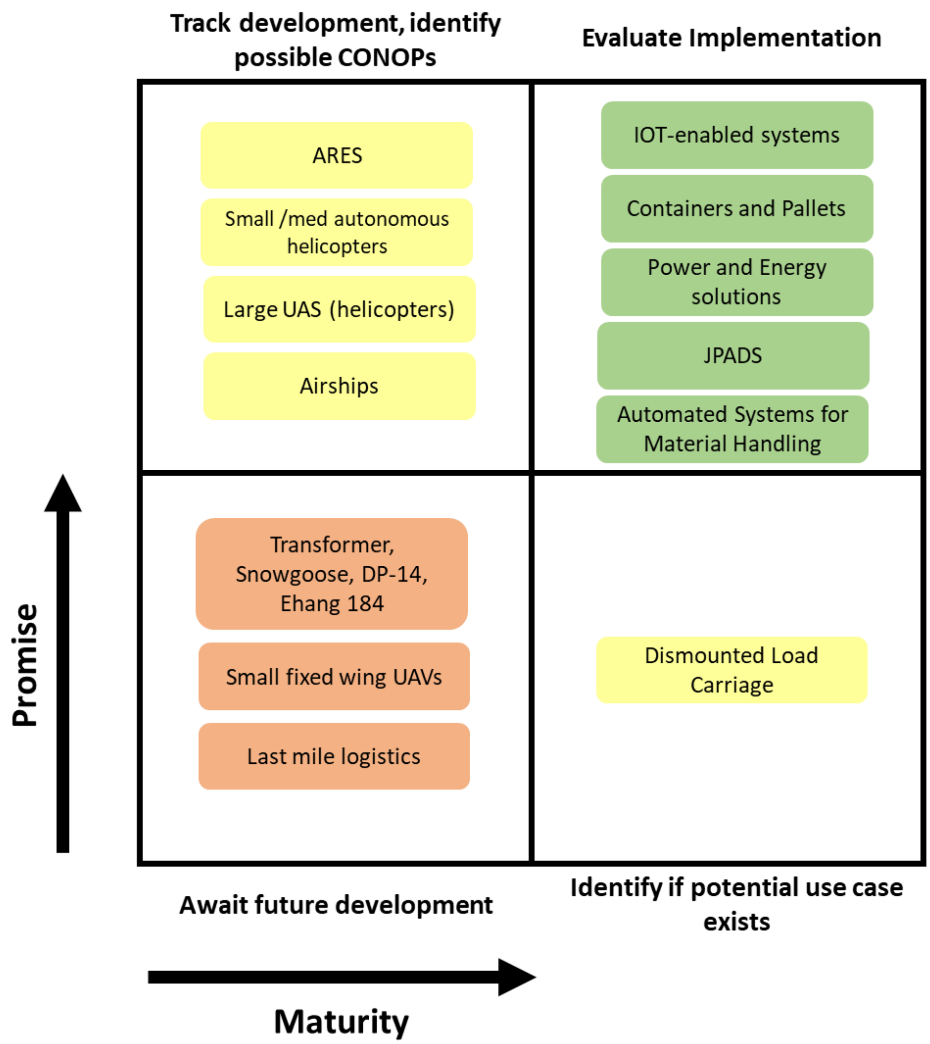


Figure 63: Matrix for Suitability of Existing Technologies

The technologies that are most suitable and ready to be evaluated for implementation are: IoT enabled systems, containers and pallets, power and energy solutions, JPADS, and automated solutions for material handling. IoT enabled systems are under development in the private sector, and the enabling technology like RFID tags, CBM and HUMS technology, and data analytics are also in service. This technology is likely to expand as time goes forward and has the potential to become an industry standard for large organizations, specifically those with complex supply chains. The Army should begin the process of identifying how IoT technology will apply for all Army operations, and specifically for supporting CSS domestically and abroad. Maintenance and asset optimization solutions (CBM, HUMS, MAO) should be given more considering than DT / DTh solutions, for reasons mentioned about R&D and lifecycle. Containers and pallet solutions should also be examined to determine how they can better employed currently, and how the future use of containers and pallets can be integrated into an IoT enabled solution.

Energy and power solutions for facilities, vehicles and personnel should also be explored. Recent experience in Iraq and Afghanistan clearly show the burden on the supply chain of moving fuel to forward areas, and the burden on soldiers carrying sufficient batteries to power electronic devices. Any reduction in the volume of liquid fuel required for facilities and vehicles, and the reduction in battery requirements for soldiers will reduce the volume of material that passes through the supply chain. It is anticipated that long-term efficiency improvements will be materialised through a mixture of improved efficiency of existing system in the near-term and breakthrough technology in the medium and long term. Attention should be paid to the energy requirements that could increase as a result of improved efficiency. Army planners should be mindful of Parkinson's law, that states that work will expand to fill the time available for completion [360]. As efficiencies are realized in power and energy, planners should be mindful not to add technology that consumes more energy (or as much energy) as the efficiencies realized. Power and energy technology for facilities (domestically and on expeditionary operations), for vehicles (hybrids and electric vehicles), and for personnel (improved batteries) should all be evaluated.

JPADS should be evaluated for Canadian applications and will involve both Army CSS and RCAF transport aviation as the supporting organizations, and combat arms units most likely to be supported organizations. This technology has been proven in Iraq and Afghanistan (proving maturity) and shows significant promise for providing resupply in adaptive dispersed operations. Challenges for complex urban terrain should be prioritized, as JPADS appears capable of delivering in all other environments. Automated systems for material handling should be further evaluated for warehousing, material handling, and for vehicles maintenance or any other task involving heavy machinery. These systems are in service and make apparently credible claims about reducing personnel fatigue.

The technologies that show promise but currently lack sufficient maturity, and for which CONOPs should be examined are: the ARES, small and medium autonomous helicopters, large UAS (helicopters), and airships. Airships show promise for moving personnel and equipment to austere environments, and a Canadian mining operation will soon have airships providing resupply and will move ore to a railhead. Airships should be examined further for military application, including the variants currently available, and identifying the implications of concepts that carry heavier payloads.

Large UAS and small and medium autonomous helicopters currently suffer from the same challenge: the lack of maturity for operating in urban and high threat environments. The technology appears suitable for other applications. Both retrofit technologies (i.e.: modifying existing helicopters to fly autonomously) and purpose-designed autonomous helicopters (those designed without a cockpit) should be considered to evaluate if they serve the tactical CSS needs of the Army. Some technologies that fit in these categories were found to be unsuitable, and those technologies should not be revisited. The AirMule, JTARV and retrofit helicopters should be examined to determine if they are suitable to meet Army needs.

ARES is a very interesting concept that proposes a modular tilt-rotor to fulfill CSS and ISR needs. If this concept is viable it could be introduced to fill multiple service roles. However, the technology remains largely a concept. CONOPs of the ARES technology should be examined to determine how such a system would be used for the CAF / DND, with a focus on Army CSS.

The technologies that have sufficient maturity but do not clearly align with the current implementation models are the dismounted load carriage systems. Dismounted load carriage systems show technical maturity in that they are capable of following a dismounted infantry section. One system was even trialed in Afghanistan and exceeded specifications. However, the dismounted load carriage systems add a vehicle to the infantry section, with one rifleman that will likely be responsible for the vehicle. This reduces the overall combat power of the infantry section, though it comes with the potential for reduced fatigue, increased alertness and increased range of operations for the infantry section. The trade-offs and the application model of what integrating dismounted load carriage systems should be examined in greater detail to determine if there is suitable application for this technology within the Canadian Army.

The technologies that currently lack the necessary maturity and do not show great promise are some of the small and medium autonomous helicopters, small fixed wing UAVs, and the last mile logistics UAVs. Some of the small and medium autonomous helicopters have design issues that prevent them from being viable. If those issues are addressed, the technology could be revisited. Small fixed wing UAVs were originally designed for ISR missions and should continue to be employed as such, and not for CSS missions. Last mile logistics UAVs carry too light a payload to be useful individually and using them in swarms to meet payload requirements creates challenges for operational security and battlespace deconfliction. These technologies should not be further examined at this time.

8.2 Recommendations

The recommendations in this section address recommendations for IT implementation, and for platforms. As mentioned in the discussion section, the cycle of procurement and eventual replacement are much more iterative for IT systems than for physical platforms. Also, IT solutions will likely involve the whole CAF / DND, not only the Army. For those reasons IT and platform recommendations are separated.

IT Systems:

1. **CAF / DND should examine how / if other militaries are using IoT solutions:** IoT technology is growing in popularity for the private sector. Implementing any IoT solution will be a major undertaking. The CAF / DND should seek to understand the pitfalls or best practices that other militaries have faced in designing and implementing of IoT technologies. Any future solution will need to be tailored for CAF / DND needs and identifying how other countries have implemented these systems could serve to reduce risk for the CAF / DND.

2. **CAF / DND should identify if other government department are using IoT solutions:** similar to the recommendation above, it would be useful for the CAF / DND to determine if other Government of Canada departments have attempted to implement IoT solutions, and if so identify any pitfalls and best practices that were used. For the purposes of interoperability within the Government of Canada, any data standards that are used by other government departments should be noted.

3. **Start Developing IoT Requirements and Concept of Operations (CONOPs):** an IoT enable solution will be a major undertaking. The Army should start defining what an IoT solution could address for operations and CSS and identify which systems would be replaced by the introduction of an IoT solution. This is an essential step to defining what an IoT will do, and equally importantly identifying how an IoT system would fit into the CAF / DND plans for IT projects. This will be a major undertaking, though will be necessary in order to clearly define what an IoT will do, and to avoid an IoT system becoming a silo, like so many other IT systems.

4. **Re-examine current supply chain:** IoT solutions are driven by the desire for improved efficiency. The concept promises greater efficiency from identifying trends in data. However, an examination of the current supply chain could reveal structural limitations to efficiency, before even considering and IoT solution. Also, given the timelines for designing and implementing an IoT solution there is likely savings and efficiencies that could be realized in the interim.

Platforms

1. **Examine only viable technologies:** there are some technologies in this document that are unlikely to be viable for Army application. Effort should be focused on those technologies that show promise for Army CSS and for CAF CSS more broadly.

2. **Conduct more detailed examination of the most viable technologies:** the technologies that are most viable (i.e.: mature and show promise) should be examined in more detail to determine how they could be implemented for Army CSS. This includes IoT-enabled systems (covered in the IT recommendations), container and pallet solutions, power and energy solutions, automated systems for cargo handling, and JPADS.

3. **Start developing CONOPs and potential employment models for emerging technologies:** the technologies that show promise, but currently lack sufficient maturity, should be examined with notional CONOPs and employment models developed to better understand exactly how these technologies would be implemented for Army CSS. This should be as detailed as possible, understanding that some of these technologies are still concepts. The technologies include the ARES, small and medium autonomous helicopters, large UAS (helicopters only), and airships.

4. **Determine the role of the RCAF in future technologies:** many of the technologies examined in this document are air-delivery technologies. The focus of this work in on supporting Army CSS, though the RCAF will have a role in supporting some air-deliver technologies.

5. **Continue scanning for new technologies:** The Army should maintain awareness of other emerging technologies not covered in this document, and any major improvements to technologies mentioned in this report. Technology will forever advance, and new technologies can overcome previous constraints and limits, providing new opportunity for improvement.

ANNEX A. ACRONYMS

Acronym	Meaning
A2/AD	Anti-Access / Area Denial
AAA	Anti-Aircraft Artillery
AACUS	Autonomous Aerial Cargo Utility System
ADO	Adaptive Dispersed Operations
ADF	Australian Defence Force
ADM IM/IT	Associate Deputy Minister Information Management / Information Technology
AFC	Airborne Fulfillment Centre
ALSS	Advanced Logistics Support Site
AMAS	Autonomous Mobility Applique System
AoT	Army of Tomorrow
APOE / APOD	Aerial Port of Embarkation / Aerial Port of Debarkation
ARES	Aerial Reconfigurable Embedded System
BDE	Brigade
BDE GP	Brigade Group
BLOS	Beyond Line of Sight
BSA	Brigade Support Area
CA	Canadian Army
CAD	Canadian Dollars
CAD	Computer Assisted Design
CAF	Canadian Armed Forces
CANSOFCOM	Canadian Special Operations Forces Command
CAST	Convoy Active Safety Technology
CBM	Condition-Based Maintenance
CBRNE	Chemical, Biological, Radiological, Nuclear, Explosive
CFJP	Canadian Forces Joint Publication
CIMIC	Civil-Military Cooperation
CJOC	Canadian Joint Operations Command
CONOPs	Concept of Operations
CSEC	Communications Security Establishment
CSIS	Canadian Security Intelligence Service
CSS	Combat Service Support
CSS Bn	Combat Service Support Battalion
DARPA	Defence Advanced Research Projects Agency
DHL	Deutsche Post
DOB	Deployed Operating Base

Acronym	Meaning
DOD	Department of Defense (US)
DP	Drop Point
DRDC	Defence Research and Development Canada
DT	Digital Twin
DTh	Digital Thread
ECAT	Empowered Combat Arms Teams
EM	Electro-Magnetic
EO/IR	Electro-Optical / Infrared
EU	European Union
EW	Electronic Warfare
FLS	Forward Logistics Site
FOB	Forward Operating Base
FSA	Forward Support Area
GBAS	Ground Based Augmentation System
GE	General Electric
GN&C	Guidance, Navigation and Time
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GLONASS	Global Navigation Satellite System
HLZ	Helicopter Landing Zone
HRO	Humanitarian Relief Operations
HULC	Human Universal Load Carrier
HUMINT	Human Intelligence
HUMS	Health Usage Monitoring System
IED	Improvised Explosive Device
IoT	Internet of Things
IOT	Initial Operating Capability
IRNSS	Indian Regional Navigation Satellite System
ISO	International Organizations for Standardization
ISR	Intelligence, Surveillance and Reconnaissance
IT	Information Technology
JIMP	Joint, Inter-Agency, Multi-National, Public
JLSA	Joint Logistics Support Area
JLSG	Joint Logistics Support Group
JMIDS	Joint Modular Intermodal Distribution System
JP	Joint Publication
JPADS	Joint Precision Air Drop System
JTARV	Joint Tactical Aerial Resupply Vehicle

Acronym	Meaning
JTF HQ	Joint Task Force Headquarters
JTFSC	Joint Task Force Support Component
LCOP	Land Common Operating Picture
LDS	Laser Direct Structuring
LEE	Land Equipment Engineering
LEMS	Land Equipment Management System
LIDAR	Light Detection and Ranging
LOC	Lines of Communication
LOGIS	Logistics Information System
LOS	Line of Sight
LPWAN	Low-power wide-area network
LS3	Legged Squad Support System
MAO	Mobile Asset Optimization
MANPADS	Man-Portable Air Defence Systems
Med	Medical
MEDEVAC	Medical Evacuation
MURAL	Manned / Unmanned Resupply Aerial Lifter
MULE	Multi-Function Utility / Logistics Vehicle
MUTT	Multi Utility Tactical Transport
NATO	North Atlantic Treaty Organization
NDHQ	National Defence Headquarters
NFC	Near Field Communications
NASA	National Aeronautics and Space Administration
NGO	Non-Governmental Organizations
NSE	National Support Element
OEM	Original Equipment Manufacturer
OGD	Other Government Departments
OPBH	Optionally Piloted Blackhawk
PEMFC	Proton Exchange Membrane Fuel Cells
PNT	Position, Navigation and Time
PSC	Public Safety Canada
PV	Photovoltaic
RCAF	Royal Canadian Air Force
RCMP	Royal Canadian Mounted Police
RLP	Recognized Logistics Picture
RCN	Royal Canadian Navy
RFID	Radio Frequency Identification
ROZ	Restricted Operations Zone

Acronym	Meaning
RSOM	Reception, Staging and Onward Movement
SATCOM	Satellite Communications
SMSS	Squad Mission Support System
SOCOM	Special Operations Command (US)
SOFC	Solid Oxide Fuel Cells
SPOE / SPOD	Sea Port of Entry / Sea Port of Debarkation
SSE	Strong, Secure, Engaged
STL	Satellite Time and Location
SVC BN	Service Battalion
TALOS	Tactical Assault Light Operator Suit
TAV	Total Asset Visibility
TLU	Theatre Logistics Unit
TSB	Theatre Support Base
TTPs	Tactics, Techniques and Procedures
UAS	Unmanned / Uninhabited Air System
UAV	Unmanned / Uninhabited Air Vehicle
UGS	Unmanned / Uninhabited Ground System
UGV	Unmanned / Uninhabited Ground Vehicle
UHARS	Ultra High-Accuracy Reference System
UK	United Kingdom
UPS	United Parcel Service
USD	United States Dollars
USMC	United States Marine Corps
VTOL	Vertical Take Off and Landing
WoG	Whole of Government

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This document provides an overview of the existing Canadian defence policy, concepts about the Army of Tomorrow, Future Army, concepts presented by allies. The document then uses the overview to evaluate how emerging technologies can be useful for Combat Service Support (CSS) for the Future Army. This report discusses and assesses potential novel technologies that could improve CSS to the Canadian Army, specifically to enable modernization and provide an improved tactical sustainment capacity. The report provides summaries of the existing doctrinal concepts for CSS, the current defence policy, and of the concepts about the Army of Tomorrow, the Future Army, and concepts from allies. The report then identifies gaps in current technologies, presents an overview of emerging technologies, a summary of the strengths and limits of each technology, specific observations about how they may be integrated into the future Army concepts, and challenges to implementing the future emerging technologies. The report then presents a discussion on the relationships between the assumptions about the Future Army, the role of technology, and those technologies that can provide maximum value for CSS before presenting conclusions and recommendations.

The report identifies that the technologies that are most suitable and ready to be evaluated for implementation are: Internet of Things enabled systems, containers and pallets, power and energy solutions, Joint Precision Airdrop Systems, and automated solutions for material handling. The technologies that show promise but currently lack sufficient maturity, and for which concept of operations should be examined are: the Aerial Reconfigurable Embedded System, small and medium autonomous helicopters, large UAS (helicopters), and airships. The technologies that have sufficient maturity but do not clearly align with the current implementation models are the dismounted load carriage systems. The technologies that currently lack the necessary maturity and do not show great promise are some of the small and medium autonomous helicopters, small fixed wing UAVs, and the last mile logistics UAVs.

Le présent document donne un aperçu de la politique actuelle de défense du Canada, des concepts relatifs à l'Armée de demain, de l'Armée de l'avenir et des concepts présentés par les alliés. À partir de cet aperçu, on peut évaluer la façon dont les technologies émergentes peuvent être utiles au soutien logistique du combat (SLC) de l'Armée de l'avenir Dans ce rapport, on examine et on évalue également les technologies nouvelles potentielles qui pourraient améliorer le SLC de l'Armée canadienne pour permettre sa modernisation et fournir une meilleure capacité de maintien en puissance tactique. Le rapport contient un résumé des concepts doctrinaux existants pour le SLC, de la politique actuelle de défense, des concepts relatifs à l'Armée de demain, de l'Armée de l'avenir et des concepts présentés par les alliés. De plus, il relève les lacunes des technologies actuelles, fait un survol des technologies émergentes, présente un sommaire des forces et des limites de chacune, fournit des observations particulières sur la façon dont elles peuvent être intégrées aux concepts de l'Armée de l'avenir et indique les défis que pose la mise en œuvre des technologies émergentes futures. Enfin, on analyse les relations entre les hypothèses de l'Armée de l'avenir, le rôle des technologies et celles qui tirent le maximum du SLC, avant de présenter des conclusions et des recommandations.

Selon le rapport, les technologies les plus appropriées et qui sont prêtes à être évaluées aux fins de la mise en œuvre sont : les systèmes avec accès à « l'Internet des objets », les contenants et les palettes, les solutions en matière d'électricité et d'énergie, les dispositifs d'aérolargage de précision et les solutions automatisées de manutention. Les technologies prometteuses mais pas encore assez éprouvées et dont les concepts d'opération devraient être examinés comprennent le système aérien intégré reconfigurable, les hélicoptères autonomes de petite et moyenne taille, les grands UAS (hélicoptères) et les dirigeables. Les technologies suffisamment éprouvées mais qui ne correspondent pas exactement aux modèles de mise en œuvre actuels sont les systèmes de transport de charge. Les technologies insuffisamment éprouvées et pas très prometteuses comprennent certains hélicoptères autonomes de petite et moyenne taille, les petits UAV à voilure fixe et les UAV pour la logistique du dernier kilomètre.