Canadian Space Agency Agence spatiale canadienne

Evaluation of the Canadian Space Agency Satellite Communications Business Line

For the period from April 2012 to March 2017

Project # 16/17 – 02-04

Prepared by the Audit and Evaluation Directorate

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Acronyms used in the report

AIS	Automatic Identification System
ARTES	Advanced Research in Telecommunications Systems programme
BLOS	Beyond Line-of-Sight
CBSA	Canadian Border Services Agency
CCG	Canadian Coast Guard
CIARS	Center for Intelligent Antenna and Radio System
CSA	Canadian Space Agency
DDCM	Dielectric Deep Charge Monitor
DFO	Department of Fisheries and Oceans
DND	Department of National Defence and Canadian Armed Forces
DRDC	Defence Research and Development Canada
ePOP	Enhanced Polar Outflow Probe
ECCC	Environment and Climate Change Canada
ESCP-P	Enhanced Satellite Communication Project – Polar
FAST	Flight and Fieldwork for the Advancement of Science and Technology
FGCB	Federal Global Navigation Satellite Systems Coordination Board
FTE	Full Time Equivalent
GBA	Gender-based analysis
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
HTS	High Throughput Satellite
IMO	International Maritime Organization
ISED	Innovation, Science and Economic Development Canada
ISRO	Indian Space Research Organization
ISS	International Space Station
ITU	International Telecommunication Union

JPO	Joint Project Office
LDRS	Low Data Rate System
LEO	Low Earth Orbit
MDA	MacDonald Dettwiler and Associates Ltd.
MMMB	Multi-Mission Microsatellite Bus
MOU	Memorandum of Understanding
MSOC	Marine Security Operations Centres
O&M	Operation and maintenance
PCW	Polar Communication and Weather mission
PC	Parks Canada
PNTB	Positioning, Navigation and Timing Board
PSPC	Public Services and Procurement Canada
PSLV	Polar Satellite Launch Vehicle
QEYSSat	Quantum Encryption and Science Satellite
RCM	RADARSAT Constellation Mission
RCMP	Royal Canadian Mounted Police
R&D	Research and Development
SAAS	SAR-AIS Association System
SAR	Synthetic Aperture Radar
SCBL	Satellite Communications Business Lines
SSGP	Space for Smarter Government Programme
STDP	Space Technologies Development Program
TDP	Technology demonstration project
TC	Transport Canada
TRL	Technology Readiness Level
UKSA	U.K. Space Agency

Executive Summary

This report presents the findings of the evaluation of the Canadian Space Agency (CSA)'s Satellite Communications Business Line (SCBL). The SCBL's fundamental purpose is to enhance, where applicable, the capacity of federal departments and agencies to deliver their programs and services by implementing space-based solutions. It also includes communications and outreach activities that are expected to enhance the awareness and understanding, among departments and agencies, of the potential of space-based solutions in supporting their mandate and programming. Finally, the SCBL is expected to enhance the capacity of the space industry in the area of satellite communications, through its direct participations in various phases of mission cycles. The evaluation covers a five-year period, from April 1, 2012 to March 31, 2017, and examines the Sub-Program's relevance and performance. While focussed on activities carried-out during the targeted period, the evaluation also addressed the overall needs of federal departments and agencies in the field of satellite communications.

The evaluation was conducted by PRA Inc., on behalf of the Canadian Space Agency (CSA)'s Audit and Evaluation Directorate, between April 2017 and March 2018. The evaluation is a requirement of the CSA's five-year evaluation plan and was conducted in accordance with the Treasury Board of Canada's *Policy on Results (2016).*

Relevance

In terms of relevance, the evaluation found that the expertise and involvement of the CSA is necessary to ensure that federal departments and agencies can effectively integrate satellite-based communications solutions to support the delivery of their programs and mandates. While many federal departments and agencies could benefit from the growing range of space-based communications solutions that are emerging in the New Space environment, there is limited expertise within these departments and agencies to confidently assess and act upon these potential solutions. As the centre of expertise on space-related issues, the CSA is uniquely positioned to support these departments and agencies as they consider space-based communications options. During the period covered by the evaluation, the CSA has only collaborated on targeted initiatives, mostly related to the monitoring of Automatic Identification System (AIS) signals. Expanding more broadly the support role that the CSA could play in facilitating the adoption of space-based communications solutions within the federal government would respond to a need identified in this evaluation. It would also align with the overall priority of the CSA to facilitate the involvement of federal departments and agencies in space-based solutions that can improve their ability to serve Canadians. Consequently, the evaluation recommends that:

> *The Space Utilization branch should explore options with regards to the role the CSA could play concerning the use of space-based communications solutions by federal departments and agencies in order to enhance their ability to deliver their programs and activities.*

The CSA also plays a pivotal role in enhancing the capacity of the Canadian space industry to commercially engage in satellite communications activities, particularly through Research and Development (R&D) and demonstration activities. Some of these activities, however, fall outside the scope of the SCBL. As such, the evaluation found that the business line model may not be the most efficient structure to apply. At the time of this report, the CSA was implementing its new Departmental Results Framework, which will support a more integrated approach to all CSA activities related to satellite communications. Finally, the evaluation noted the important contribution that the CSA can make in supporting government-wide procurement practices that can strategically support the Canadian space-industry.

Performance

The predominant initiative undertaken during the evaluation period was the full implementation of the technology demonstration mission M3MSat. While the mission was initiated in 2006, the satellite was launched in June 2016, with the full commissioning completed in May 2017. The mission achieved its demonstration objectives, with all three payloads on board having been successfully tested. The Automatic Identification System (AIS) payload has since been in operation, while the other two payloads, namely the Dielectric Deep Charge Monitor (DDCM) and the Low Data Rate System (LDRS), have not been commercialized and, as such, were not in operation. The Multi-Mission Microsatellite Bus (MMMB) used to host the three payloads was also successfully tested, but in the absence of repeated microsatellite missions, its ability to minimize non-recurring expenses is limited.

The most significant challenges faced by the M3MSat mission were the delays in completing all phases leading up to the operation of the satellite and its payloads. Some of these delays were triggered by shifts in instrument design, particularly for the AIS antenna, while other delays were associated with the launch of the satellite. As a result, additional financial resources had to be invested in the mission.

Overall, the M3MSat mission allowed the Canadian industry to enhance its expertise and confidence in the potential market for space-based AIS services and to successfully engage in this field. In addition, through commercially available AIS data and services, a number of federal departments and agencies have successfully integrated this type of space-based communications solutions to their operations.

During the evaluation period, the CSA also supported the demonstration of the Cascade payload, which has not been commercialized, but has nonetheless provided benefits for the space industry, which have since been applied to other related communications technologies. Finally, the PCW mission, as initially conceived, was not pursued. However through the ESCP-P initiative, the Department of National Defence (DND), the CSA and other federal departments and agencies are now collaborating to explore how to address both military and non-military communications needs in the Arctic.

Finally, to enhance internal efficiencies, the CSA has implemented a project closure process that, in the case of M3MSat, has provided detailed insights and lessons learned on the mission, particularly from a technical and internal management perspective. The closure report plays a highly complementary role to the findings included in this evaluation report.

1 Introduction

This document constitutes the final report of the evaluation of the Canadian Space Agency (CSA)'s Satellite Communications Business Lines (hereafter the SCBL). It covers a range of activities that primarily aim to enhance the capacity of federal departments and agencies to deliver their programs and services by implementing space-based communications solutions. The SCBL is also expected to enhance Canadian expertise in satellite communications and the competitiveness of the Canadian space industry in this particular field. As with most activities in which the CSA is engaged, the SCBL is not operating in isolation and, as such, other CSA programs and activities may play a complementary role in achieving these expected outcomes.

The evaluation covers a five-year period, from April 1, 2012 to March 31, 2017, and examines the relevance, design, and performance of the SCBL. It is a requirement of the CSA's five-year evaluation plan and was conducted in accordance with the Treasury Board of Canada's *Policy on Results.* It constitutes the first evaluation being conducted of the SCBL.

The evaluation was conducted by PRA Inc. on behalf of the CSA Audit and Evaluation Directorate, between April 2017 and March 2018.

2 Description of the SCBL

This section of the report includes a brief description of the SCBL and the broader context in which it operates. It covers the SCBL's key components, governance model, resource allocation, and expected outcomes.

2.1 The broader context of satellite communications

2.1.1 Communications as an enabler

Satellite systems are one option used by industrialized societies to facilitate the transfer of data or information. The exceptional coverage they afford – which, in the case of constellations of satellites, may include the entire planet – is a feature of satellite technologies that sets them apart from other forms of communications. Because they act as a means to transfer information or data, satellite communications are always developed to serve larger purposes and, as technology continues to evolve, the range of activities or initiatives they may support appears almost limitless. Using but a few illustrative examples, satellite communications may be implemented to:

- Provide internet or phone services, connecting individuals, communities, or entities, particularly in remote locations;
- Access entertainment content, such as satellite radio or television;
- Manage or monitor fleets of vehicles or ships;
- Facilitate access to distance learning or telemedicine;
- Support search and rescue operations, through enhance localisation capabilities;
- Support public safety and national security operations, and;

- Support environmental monitoring and national resource management activities.

Satellite communications technologies are also bound to play a predominant role in supporting the ever expanding Internet of Things, along with a myriad of other technologies.

There are various interpretations as to the range of technologies that, in fact, fall within the realm of communications technologies. When considered through the purposes for which they are used, all technologies that allow individuals to speak on the phone (such as mobile or satellite phones), hold videoconferences, exchange emails, or share pictures, data or videos would undeniably be considered communications technologies. But what about global navigation satellite systems (GNSS), such as the Global Positioning System (GPS)? While it is enabled through satellite technologies, its core purpose is to facilitate navigation, not communication. Another example, particularly relevant in the context of this evaluation, is the Automatic Identification System (AIS), which is used for tracking moving objects, notably commercial ships. In this scenario, a transceiver, placed on a ship, broadcasts radio waves containing key information, such as the vessel's name, position, speed, and navigational status. Transceivers located on other ships, or receivers placed on land based or satellite based systems, can then be used to scan, receive and relay the information contained in these signals. As such, is AIS to be considered communications technology?

For the purpose of this report, satellite communications technologies are defined in the broader sense, to include traditional forms of communications, as well as navigation and monitoring technologies such as AIS. This is done to reflect the views expressed by key stakeholders involved in the SCBL, as well as the fact that these navigation and monitoring technologies are not covered by other business lines of the CSA.

2.1.2 Satellite communications: publically or privately driven?

While private industry is heavily involved in commercializing satellite communications services, public spending – most particularly military spending – has historically been a driving force behind the expansion in the range of satellite communications technologies being deployed and their civil, military and commercial applications. The GPS stands as a stellar example of this dual dynamic. Owned by the United States government and operated by the United States Air Force since 1974, the GPS has received considerable public support[1] for its development, improvement and expansion and yet, it continues to be "delivered free of direct user fees for peaceful civil, commercial, and scientific uses worldwide" (US Department of Defense, 2008). Countless civil and commercial applications now rely on access to GPS signals.

Military requirements continue to drive public investments in satellite communications technologies. It is estimated that 80% of worldwide government spending for satellite communications is spent on military

[1] It appears challenging to assess the precise level of spending that the U.S. government has allocated to the GPS. A study conducted in 2005 estimated that, up to that point in time, the US government had already invested over $14 billion in the GPS (Pace et al., 2005).

projects and activities (Euroconsult, 2013a, pp. 37–38, 42). However, governments have also used public investments to enhance the capacity of their own space industry to compete in commercial satellite communications markets (Euroconsult, 2013a, p. 42). Through funding for Research and Development (R&D) and demonstration activities, governments have helped to reduce the risks of exploring new technologies and of transitioning successful innovations to the market. This dimension is further explored in sub-section 4.1.3 of this report.

The vast space-based communications infrastructure that has emerged from public and private investments now supports a significant sector of Canada's economy. In 2014, $4.5 billion in revenues derived from satellite communications activities (CSA, 2017b, p. 21). Of that amount, $2.7 billion was linked to broadcasting services, which largely target non-government customers, while an additional $1.3 billion derived from satellite operations and the development of applications and products, which are also primarily led by private industries. And the sector could experience further growth. Among other things, the current race to expand broadband connectivity through geostationary and low earth orbit (LEO) high throughput satellite (HTS) systems, including LEO microsatellite constellations such as those being developed by Telesat (involving over a 100 satellites) and One-Web (involving 900 satellites), are triggering further investments that are expected to yield significant revenues (Telesat, 2018; OneWeb, 2018).

The maturity gained by the satellite communications sector, combined with large revenue streams and ever-expanding infrastructures, have led many countries, including Canada, to reduce its public investment in support of the sector (Euroconsult, 2013a, p. 46).[2] In particular, as part of an internal review of its expenditure in 2012, the CSA placed a moratorium on any new satellite communications mission, ceased to fund technology development activities related to satellite communications under its Space Technologies Development Program (STDP) now referred to as Space Technologies Development (STD) initiative, and reduced its investment in satellite communications related programs offered through the European Space Agency (CSA, 2015a, p. 14, 2016b, p. 4).

2.2 Business line activities

2.2.1 SCBL overview and objectives

The CSA uses the concept of "business lines" to structure the various space missions it undertakes or participates in. This applies to satellite communications missions, as well as to earth observation or scientific missions. At the time of the evaluation, these various missions were grouped under the "Space Data, Information and Services" Program 1.1 of the CSA (CSA, 2017a), which is now referred to as the

2 Important exceptions to this rule are Russia, China and India that "consider their satellite communication network as a national strategic asset and maintain government control over the development, funding, and operations of the systems through the involvement of the treasury, space agency, and dedicated state-owned satellite enterprises (SOSE)" (Euroconsult, 2013b, p. 46).

Space Utilization Program.[3] While each type of mission pursues its own specific goals, they do share common characteristics:

- Each mission must first be defined and designed, and the required technology must be developed. In some cases, it involves the creation of an entire satellite system, whereas in other instances, it involves the development of sub-systems, payloads or instruments placed on domestic or foreign satellites. As illustrated in Figure 1, these activities fall within the "Earth orbit satellite mission and technology" Sub-Program 1.1.1.
- Each satellite or sub-component also requires ground operating infrastructures and data handling capacity, which are part of the Sub-Program 1.1.2.
- Finally, each mission is expected to facilitate the access and use of the space data acquired through its implementation, which falls under the Sub-Program 1.1.3.

The concept of a "business line" serves to bridge the nature of missions undertaken and these various operational dimensions that any satellite mission would typically include. For the purpose of this evaluation, the emphasis is placed on satellite communications missions, considered through the three sub-programs included in Figure 1 (see highlighted cells). It should be noted that, while the Sub-Sub Programs 1.1.1.2 and 1.1.3.2 are unique to communications missions, Sub-Sub Programs 1.1.2.1 and 1.1.2.2 are shared among the three types of missions that the CSA undertakes (earth observation, communications, and scientific).

CSA Program 1.1: Space data, information and services							
Sub-Program 1.1.1 Earth orbit satellite mission and technology			**Sub-Program 1.1.2 Ground infrastructure**		**Sub-Program 1.1.3 Space data, imagery and services utilization development**		
SSP 1.1.1.1 Earth observation missions	**SSP 1.1.1.2 Communications missions**	SSP 1.1.1.3 Scientific missions	**SSP 1.1.2.1 Satellite operations (shared)**	**SSP 1.1.2.2 Data handling (shared)**	SSP 1.1.3.1 Earth observation data and imagery utilization	**SSP 1.1.3.2 Communications services utilization**	SSP 1.1.3.3 Scientific data utilization

Figure 1

In this context, the SCBL's fundamental goal is to enhance, where applicable, the capacity of federal departments and agencies to deliver their programs and services by implementing space-based solutions. Based on the identified needs of targeted departments and agencies, the CSA, through the SCBL, oversees

[3] At the time of the evaluation, the other two programs of the CSA were Space Exploration and Future Canadian Space Capacity. As of December 2017, the CSA structures its activities in three main programs: Space utilization Program, Space Exploration Program and Space Capacity Development Program.

the implementation of satellite communication missions, covering all applicable cycles (CSA, 2016b, p. 16):

- The development of the initial concept (Phase 0)
- The required feasibility studies (Phase A)
- The design, development and implementation activities (Phases B/C/D)
- The ongoing mission operations and data use (Phase E)

Communications and outreach activities are also expected to be undertaken to enhance the awareness and understanding, among applicable departments and agencies, of the potential of space-based solutions in supporting their mandate and programming.

While responding to the needs of federal departments and agencies remains its primary focus, the SCBL is also expected to enhance the capacity of the space industry in the area of satellite communications, through its direct participations in various phases of mission cycles (building and operating satellite components, payloads, instruments, and ground infrastructure, designing new data applications, etc.).

2.2.2 Activities undertaken during the evaluation period

During the period covered by this evaluation (April 2012 to March 2017), CSA's activities related to satellite communications focussed on three missions:

- Maritime Monitoring and Messaging Micro-Satellite (M3MSat): Launched in 2016 as part of a joint project between the CSA and Defence Research and Development Canada (DRDC), M3MSat is a microsatellite that carries three payloads for demonstration purposes: an Automatic Identification System (AIS) that supports the monitoring and management of maritime traffic; a Low Data Rate System (LDRS) that ensures data continuity when AIS receivers cannot provide real-time coverage; and a Dielectric Deep Charge Monitor (DDCM) that supports the ongoing monitoring of static energy accumulated in satellites and improve their overall performance and lifespan (CSA, 2017c).
- Cascade: Integrated as a communication technology demonstration payload on the CASSIOPE satellite (launched in 2013), Cascade is a "proof of concept" design for a high volume store-and-forward data communications operational concept, involving the upload of large data files that can be delivered to almost any destinations in the world (CSA, 2015c).
- Polar Communication and Weather (PCW) mission: Only limited activities related to the PCW mission occurred during the period covered by the evaluation (the bulk of these activities occurred prior to the evaluation period). The mission's primary goal was to provide reliable 24/7 high data rate communication services in the High Arctic, to better monitor weather in that region, and to enhance the monitoring of space weather. This was to be achieved through a system of two satellites operating in highly eliptical orbit (CSA, 2014c).

These three missions illustrate the range of space-based solutions that were supported to respond to the needs of federal departments and agencies. In proceeding with the evaluation of the SCBL, the following considerations guided the treatment given to each of these three missions:

- During the period covered by the evaluation, a large proportion of activities related to satellite communications missions were directed to M3MSat. As such, this mission is the predominant focus of the evaluation.
- The CSA completed an evaluation of the CASSIOPE satellite mission in 2014, which includes the Cascade payload. A summary of the findings from this evaluation served as the primary data source for documenting the activities undertaken through Cascade that are relevant for the purpose of the evaluation (see sub-section 2.3 for further details), while complementary findings were also gathered as part of this evaluation.
- While the CSA did not pursue the PCW mission beyond its initial design concept, this mission is included in the scope of the evaluation to provide further illustration of the range of satellite communications missions that may be required to meet the information needs of federal departments and agencies, as well as to explore the CSA's role in providing technical support to other government departments, such as Department of National Defence and Canadian Armed Forces (DND), in the form of expertise.

The CSA also engaged in preliminary work (mission concept and feasibility study) on advanced encryption technology in space for secure online communications. This initial work, undertaken as part of the SCBL, has evolved into the Quantum Encryption and Science Satellite (QEYSSat) technology demonstration mission, which was officially announced in 2017-18. This mission will be undertaken as part of the Space Capacity Development Program and, as a result, is minimally addressed through this evaluation.

Finally, CSA activities under the SCBL have included spectrum management, which is undertaken to secure the proper frequency spectrum necessary to monitor and control CSA satellites, to make use of the instruments and payloads on CSA satellites, to retrieve satellite data, and to minimize potential interferences from frequency transmissions of other terrestrial or space systems that use frequency spectrum similar to the ones used by CSA.

2.2.3 Program resources

Expenditures related to the SCBL are made up of operation and maintenance (O&M) costs. More specifically, they include costs associated to contracts signed in support of communications missions, and internal expenditures (salaries and operations).

As indicated in Table 1, the CSA invested a total of $36.3 million in SCBL activities over the five years covered by the evaluation. The following assumptions apply to these numbers:

- As previously noted, Sub-Sub Programs 1.1.2.1 (satellite operations) and 1.1.2.2 (data handling) are shared among the three types of satellite missions undertaken by the CSA (earth observation, communications, and scientific). As a result, a third of the total expenses allocated by the CSA to these two Sub-Sub-Programs is allocated to each type of missions. As these are generic costs, they are not included in Table 1.
- In addition to costs included in Table 1, a third of the expenses related to the overall management of the Space Utilization branch is allocated to the SCBL. As these activities fall beyond the scope of the evaluation, their associated expenses are not included in Table 1.
- Finally, while other programs of the CSA, such as Space Science and Technology, provide matrix support for the implementation of SCBL activities, these resources are not included in Table 1.

Table 1: Summary of resources allocated to the SCBL ('000$)

Activities	2012-13	2013-14	2014-15	2015-16	2016-17	Total
Mission development (1.1.1.2)						
Number of FTEs*	18.6	14.0	9.3	7.8	2.2	
Contracts	$300	$1,767	$4,074	$2,094	$3,292	$11,527
Salaries	$2,072	$1,379	$1,027	$757	$609	$5,844
O&M (excluding contracts)	$577	$1,016	$197	$229	$203	$2,221
Sub-total	$2,949	$4,162	$5,297	$3,080	$4,103	$19,592
Service/data utilization (1.1.3.2)						
Number of FTEs	2.0	0.9	1.0	1.3	1.5	
Contracts	$359	$870	$3,976	$8,030	$0	$13,236
Salaries	$249	$97	$114	$154	$190	$804
O&M (excluding contracts)	$652	$705	$336	$290	$698	$2,681
Sub-total	$1,260	$1,672	$4,427	$8,474	$889	$16,721
TOTAL	$4,210	$5,834	$9,724	$11,554	$4,992	$36,314
* FTE: Full Time Equivalent						

Source: Financial data provided by the CSA

As previously noted, no new missions were undertaken during the period covered by the evaluation. As a result, expenditures in Table 1 are associated with missions and activities that had already been approved, and for the purchase of AIS data and services on behalf of the federal government.

2.2.4 Management structures

The Director General of the Space Utilization Branch holds the overall responsibility for activities carried out under the SCBL. In doing so, he operates within the set of applicable policies from the Treasury Board of Canada Secretariat (CSA, 2016b, p. 9), as well as the *Project Management Policy* and the *Integrated Governance and Monitoring Framework Directive* adopted by the CSA. This latter policy includes a Project

Complexity and Risk Assessment tool that supports the assessment of the nature and complexity of each project being considered by the Space Utilization Branch, including satellite communications missions.

To support the ongoing coordination of activities related to all satellite missions within the Space Utilization Program (earth observations, communications or scientific), the Director General of the Space Utilization Program chairs the Space Utilization Management Committee. It is the responsibility of each director to implement the decision of this Committee as applicable.

Each individual project related to the SCBL is assigned a Project Team that includes a Program Manager and a Systems Engineer. Matrix support is provided, either within the Branch or from the Space Science and Technology Branch. As required, external contracts are managed by the CSA contract group, with the assistance of Public Services and Procurement Canada (PSPC). The SCBL does not use grants and contributions to carry out its activities.

2.2.5 Program logic

The logic of the SCBL is described in its Performance Measurement Strategy (CSA, 2016b, p. 15). The logic model, which illustrates the SCBL's results chain, is presented in Figure 2, while a more detailed description of each component of the logic model is included in Appendix A.

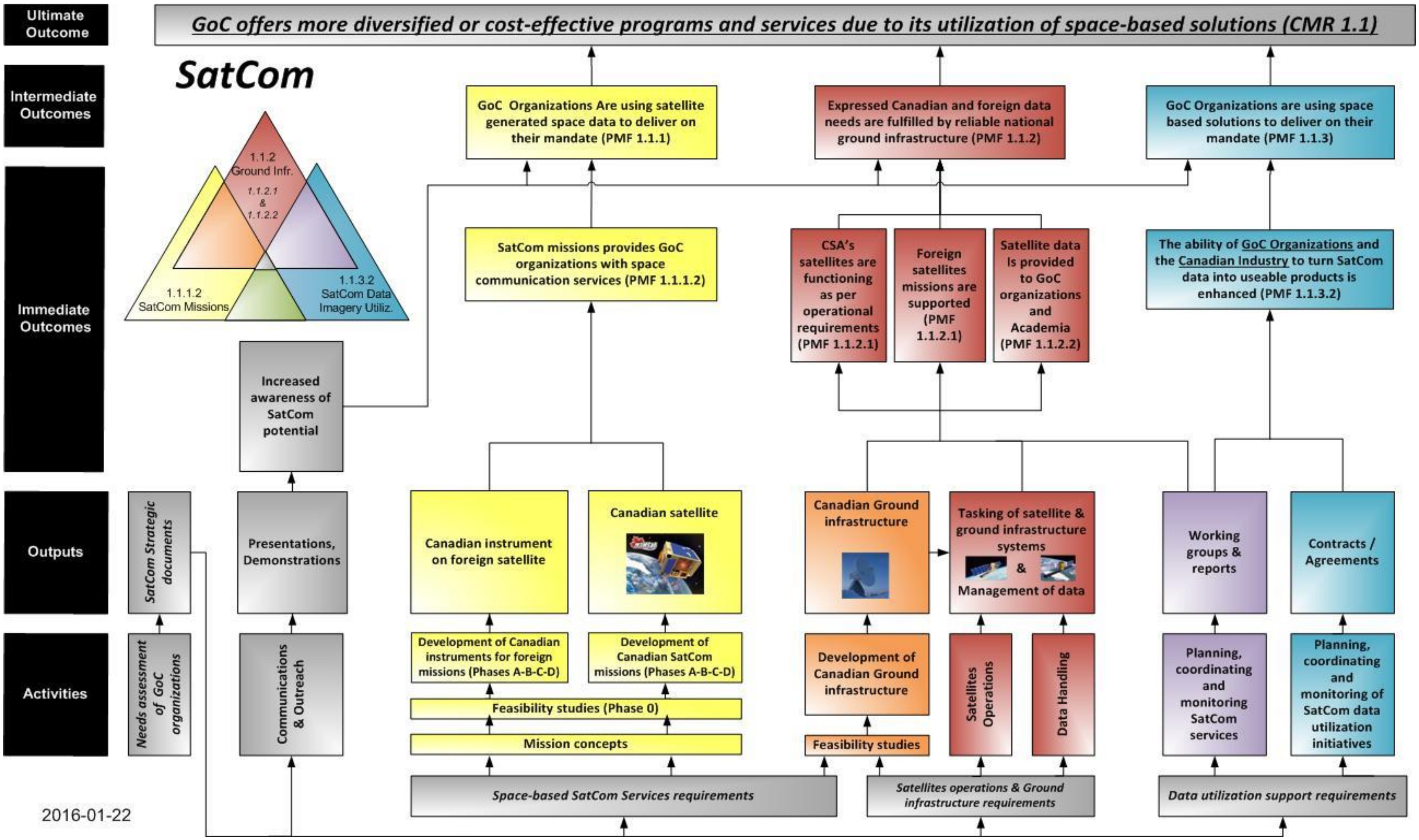
Ultimate Outcome
GoC offers more diversified or cost-effective programs and services due to its utilization of space-based solutions (CMR 1.1)
Intermediate Outcomes
SatCom
1.1.2 Ground Infr.
1.1.2.1 & 1.1.2.2
1.1.1.2 SatCom Missions
1.1.3.2 SatCom Data Imagery Utiliz.
GoC Organizations Are using satellite generated space data to deliver on their mandate (PMF 1.1.1)
Expressed Canadian and foreign data needs are fulfilled by reliable national ground infrastructure (PMF 1.1.2)
GoC Organizations are using space based solutions to deliver on their mandate (PMF 1.1.3)
Immediate Outcomes
SatCom missions provides GoC organizations with space communication services (PMF 1.1.1.2)
CSA's satellites are functioning as per operational requirements (PMF 1.1.2.1)
Foreign satellites missions are supported (PMF 1.1.2.1)
Satellite data Is provided to GoC organizations and Academia (PMF 1.1.2.2)
The ability of GoC Organizations and the Canadian Industry to turn SatCom data into useable products is enhanced (PMF 1.1.3.2)
Increased awareness of SatCom potential
Outputs
SatCom Strategic documents
Presentations, Demonstrations
Canadian instrument on foreign satellite
Canadian satellite
Canadian Ground infrastructure
Tasking of satellite & ground infrastructure systems & Management of data
Working groups & reports
Contracts / Agreements
Activities
Needs assessment of GoC organizations
Communications & Outreach
Development of Canadian instruments for foreign missions (Phases A-B-C-D)
Development of Canadian SatCom missions (Phases A-B-C-D)
Feasibility studies (Phase 0)
Mission concepts
Development of Canadian Ground infrastructure
Feasibility studies
Satellites Operations
Data Handling
Planning, coordinating and monitoring SatCom services
Planning, coordinating and monitoring of SatCom data utilization initiatives
Space-based SatCom Services requirements
Satellites operations & Ground infrastructure requirements
Data utilization support requirements
2016-01-22

Figure 2

2.3 Prior and related evaluations

This is the first time that the SCBL is evaluated. One recent evaluation that has a direct link to the SCBL is the evaluation of the CASSIOPE Contribution Program that the CSA conducted in 2014 (CSA, 2014b). As already noted in sub-section 2.2.2, the CSA used the CASSIOPE mission to develop and demonstrate the Cascade payload. In addition, this mission was used to launch and operate the Enhanced Polar Outflow Probe (ePOP) payload that uses a suite of instruments to observes the Earth's ionosphere, collecting data on the effects of solar storms and their potential impacts on space-based and ground infrastructures (CSA, 2015c). Finally, the CASSIOPE mission was used to develop a generic Canadian satellite bus and to demonstrate its capacity to host multiple payloads.

The CASSIOPE evaluation indicates that, at the time of the report, MacDonald Dettwiler and Associates Ltd. (MDA) had delivered all components and sub-components required for the assembly of the Cascade payload, and the technology had been successfully demonstrated (CSA, 2014b, p. vi, 20). The remaining challenge for MDA was to successfully commercialize the Cascade technology. Between the time the mission was first envisioned in 2003, and the launch of the CASSIOPE satellite in 2013, technological advancements in the field of communications were perceived as having reduced the range of commercial applications that a secure digital store-and-forward file delivery service such as Cascade could offer (CSA, 2014b, pp. 22–23).

The evaluation report also indicates that the CASSIOPE mission successfully deployed the ePOP payload, providing researchers with relevant data, in addition to confirming the capacity of the small satellite bus to host multiple payload (CSA, 2014b, p. 21).

3 Evaluation approach and methods

This section of the report provides a brief description of the methodology used to conduct the evaluation of the SCBL. It clarifies the purpose and scope of the evaluation, describes the key evaluation issues being addressed, and the methods used to gather evaluation findings. It also identifies the limitations that the evaluation faced, along with the strategies used to mitigate these limitations.

3.1 Purpose and scope

This report fulfills the commitment included in the CSA's Departmental Evaluation Plan (2016–17 to 2020–21) to conduct the evaluation of the SCBL. It covers a five-year period, from 2012–13 to 2016–17.

The evaluation covers the relevance and performance of the SCBL. The following eight evaluation questions are addressed:

Relevance	1. Does the SCBL continue to address a demonstrable need? 2. Are the SCBL and the M3MSat project aligned with federal government, CSA, and the Canadian space sector priorities? 3. To what extent do activities undertaken through the SCBL reflect an appropriate distribution of roles and responsibilities related to satellite communications missions, management, and solutions?
Performance (effectiveness)	1. Has M3MSat been implemented effectively? 2. Has M3MSAT demonstrated Canadian expertise in innovative ways to effectively respond to the priorities of the Government of Canada? 3. Has the SCBL achieved its immediate and intermediate outcomes? 4. To what extent has the SCBL contributed to the achievement of its ultimate outcome? 5. What processes has the CSA implemented, if any, to enhance the efficiency of SCBL activities?

3.2 Methods

Evaluation data were collected through a number of research methods, which are briefly described in this sub-section.

3.2.1 Overall approach

In light of the proposed scope of the evaluation, and of the limited activities that had been carried out over the evaluation period, the evaluation approach included a number of qualitative methods that allowed for an appropriate triangulation of findings, particularly as it related to the relevance of the SCBL. The goal was to document the actual needs of targeted stakeholders, while also documenting and describing the broader context for satellite communications missions carried out for public purposes (as opposed to private or commercial purposes) in Canada and in other jurisdictions as applicable. The proposed approach also included quantitative methods to ensure an effective integration of performance and financial data on activities undertaken.

Throughout the implementation of the methodology, including the design of data collection instruments and the analysis of evaluation findings, a particular focus was placed on ensuring that the M3MSat mission could be appropriately assessed and reported on. The goal was to provide mission-specific analysis, while also ensuring that it be linked to the analysis of the SCBL as a whole.

3.2.2 Document and literature review

The document and literature review informed all evaluation questions. It included both information provided by the CSA on the SCBL, including documents that are specific to M3MSat, as well as documents provided by other stakeholders, including federal departments and agencies in relation to their involvement in satellite communications missions, or their needs for space-borne data.

As it relates more specifically to performance data, the CSA approved the SCBL's Performance Measurement Strategy in March 2016. As such, some but not all performance indicators had been documented at the time of the evaluation. The performance information included a variety of operational documents, administrative data, and financial information.

The literature review portion of this task focussed on the relevance of the SCBL. It covered both the Canadian context and the activities of other jurisdictions, as applicable. An international scan of government funded satellite communications activities by the other space-faring nations was conducted to obtain a better understanding of how these nations are investing in satellite communications solutions (data, information and services).

3.2.3 Key Informant Interviews

Key informant interviews contributed to the in-depth understanding of the SCBL, including results achieved and challenges faced by key stakeholders. These interviews also corroborated, explained, or further elaborated on findings from other data sources and provided important input into whether outcomes have or have not been achieved, and why they have or have not been achieved.

A total of 45 interviews of approximately one hour each were conducted, which involved 58 individuals (some were group interviews) from five different stakeholder groups. Federal departments and agencies (other than the CSA) were sub-divided based on the level of involvement they have had in satellite communications. While some departments, such as DND, have used space-based communications solutions quite extensively, other departments, such as Transport Canada, have more recently engaged in this field. As for academia, while they were not a predominant stakeholder group, interviews were conducted with professors who have been engaged in satellite communications missions. The distribution of these interviews is included in ***Table 2***.

Table 2: Distribution of interviews conducted as part of the evaluation

Key informant groups	# of interviews	# of individuals interviewed
CSA representatives	15	15
Other federal departments (emerging users)	11	13
Other federal departments (established users)	5	5
Industry representatives	12	23
Academia	2	2
Total	45	58

3.2.4 Limitations

This section describes the limitations encountered in the evaluation and how they were addressed.

Limited scope of activities

As previously noted, the CSA undertook a limited range of activities on satellite communications during the period covered by the evaluation. Using the SCBL's logic model as a reference, this would particularly apply to activities that the CSA is expected to carry out to assess the needs of federal departments and agencies, to communicate and do outreach activities to increase the awareness of departments and agencies on satellite communications, or to coordinate satellite communications data utilization. This was partially addressed by having the evaluation focus on the current needs for such activities.

Performance measurement strategy development

The SCBL's performance measurement strategy was developed and approved in 2016. Consequently, the data collected to date address a number but not all associated performance indicators. The strategy also provides an updated description of the SCBL and includes relevant information regarding how the business line intends to collect data and the nature of the data to be collected.

Challenges in identifying stakeholders who could address evaluation issues and questions

Largely as a result of the limited scope of activities undertaken by the SCBL, a number of individuals contacted to participate in an interview declined the invitation on the basis that they did not have sufficient experience or knowledge of the SCBL to provide informed opinions. This was particularly the case among federal departments and agencies. This was partly addressed by having some questions that focussed on the perceived needs for space-based communications solutions, rather than actual experience with the CSA's missions, such as M3MSat or CASSIOPE (for the Cascade payload).

Most interviewees have a vested interest in the Sub-Program

This limitation was mitigated by requiring interviewees to explain their perspectives and provide examples where appropriate. In terms of the overall report, the findings from the key informant interviews were triangulated with findings from other data sources (document review, administrative data, financial data, and case studies).

4 Evaluation findings

This section of the report describes the evaluation findings. It first explores the relevance of the SCBL, before turning to the performance of the SCBL, with a particular focus on the M3MSat mission.

4.1 Relevance

The evaluation indicates that activities undertaken through the SCBL, along with other complementary activities of the CSA, address an important need in ensuring that federal departments and agencies can engage with and benefit from satellite communications solutions. In accordance with its established mandate, the CSA also has a role to support the Canadian space industry in this rapidly evolving market. This vision reflects the broader goals of the federal government in promoting innovation and digital skills.

4.1.1 Level of engagement in satellite communications

Finding: A range of federal departments and agencies already benefit from space-based communications solutions. DND is engaged in a number of space activities and projects, and is planning to expand this involvement. Other federal departments and agencies already collaborate on the use of AIS data to support marine monitoring and tracking. **(Evaluation question: Relevance #1)**

With some exceptions, which are further discussed in this report, each federal department and agency determines the extent to which it will use satellite communications technologies to support the delivery of its activities and program. As such, there has been no systematic and government-wide efforts to coordinate or facilitate the adoption of space-based communications solutions within departments and agencies.

In this context, the evaluation provided an opportunity to better understand how satellite communications technologies are currently integrated in the operations of federal departments and agencies. However, the evaluation cannot claim to offer a comprehensive listing of all instances in which these technologies manifest themselves within the federal government as it falls well beyond the scope and purpose of the evaluation.

The evaluation found that satellite communications cannot always be considered in isolation from other forms of satellite-based technologies, particularly when it comes to radar imaging capabilities such as those found on RADARSAT-2. For many representatives from federal departments and agencies who were interviewed, the actual or potential benefits derived from satellite-based technologies, such as being able to monitor ships, are their prime area of interest, rather than any technological distinctions between navigation, communications, or imaging technologies.

Keeping these considerations in mind, the following sections summarize evaluation insights that speak to the level of engagement in satellite communications by federal departments and agencies.

4.1.1.1 The Department of National Defence and Canadian Armed Forces

When it comes to space utilization, DND plays a rather unique role, which could arguably be positioned between the CSA and other federal departments and agencies. This comes, in part, from the fact that it not only uses space-based solutions quite extensively, but it also owns and operates satellites (or components thereof), a role that is otherwise limited to the CSA.

In 2017, DND released an updated version of Canada's defence policy. Among other things, the policy notes that "satellite communications are essential for the command and control of military operations, both in remote regions in Canada, and around the world" (DND, 2017, p. 71). As a result, the department intends to "invest and employ a range of space capabilities, including space situational awareness, space-based earth observation and maritime domain awareness, and satellite communications that achieve global coverage, including the Arctic" (DND, 2017, p. 72). The Department is also committed to enhancing its tactical narrowband and wideband communications capability globally, including the Arctic region (DND, 2017, p. 39). The systematic reference to the Arctic region reflects the federal government's priority of ensuring proper surveillance and control of this portion of Canada's territory (Government of Canada, 2015).

During the period covered by the evaluation, DND was involved in a number of satellite communications missions and activities. A focus has been placed on enhancing DND's wideband and tactical narrowband capabilities in support of its military operations. This has been done through collaborative efforts with allied countries through the Mercury Global SATCOM System (operational since March 2017) (DND, 2012, 2015; Pugliese, 2017), as well as through the mission design activities related to the Enhanced Satellite Communication Project – Polar (ESCP-P), which focusses more specifically on narrowband and wideband communications in the Arctic region, between 65^0 and 90^0 N latitudes (DND, 2016a, 2016b; PSPC, 2017). At the time of this report, DND, in collaboration with the CSA, Innovation, Science and Economic Development Canada (ISED) and Public Services and Procurement Canada (PSPC), was seeking input from industry on the various options available for ESCP-P. The goal is to have the new system operational no later than 2029 (PSPC, 2017, p. 13), and to make the new technology available to other departments and agencies (PSPC, 2017, p. 3).

An additional priority area for DND has been the use of AIS data to support greater marine situational awareness capability. Ever since the International Maritime Organization (IMO) implemented, in 2004, its AIS requirements for certain categories of ships (International Marine Organization, 2018), organizations involved in national security have explored how AIS technology could be used to not only track ships and avoid collisions, but also ensure greater control and surveillance over maritime traffic in certain strategic zones, including the Arctic. Not long after, in 2006, DRDC, in collaboration with the CSA, proceeded with the initial design (Phase A) of the M3MSat mission (CSA & DRDC, 2007). As Canada proceeded with the design and implementation of its AIS-focussed mission, other countries were also engaging in this technology. For instance, during the same period, the Norwegian Defense Research Establishment carried out initial work on space-based AIS technologies, which led to the launch of its AISSat-1 in 2010, followed by ASISat-2 in 2014 (Norwegian Space Centre, 2018)[4]. Even the International Space Station (ISS) has supported the development of AIS technologies, through a demonstration project (the Columbus AIS experiment) carried out in 2010, with the support of the European Space Agency (ESA) (ESA, 2010). The development of these new technologies was supported by the space industry, which promptly initiated the design and launch of commercial AIS satellites. In addition to COM DEV and exactEarth, companies such as LuxSpace, SpaceQuest, and ORBCOMM launched their first AIS satellite services around 2009 and 2010 (Euroconsult, 2010, p. 53).

Moving forward, and building on the experience gained to date with the Polar Epsilon Project and the SAR-AIS Association System (SAAS) (DND, 2013; Vachon, Kabatoff, & Quinn, 2014), DND is aiming to combine AIS data with synthetic aperture radar (SAR) imaging technology to enhance the monitoring and tracking of ships. The Polar Epsilon 2 project, which was initiated in 2013 with a full implementation scheduled for 2023 (Government of Canada, 2017b) will combine the SAR imaging and AIS technologies that are to be included on the RADARSAT Constellation Mission (RCM), set to be launched in 2018, to track in near-real-time “vessels of interest in Canada’s maritime areas, the Arctic Region, and in support of expeditionary operations around the world” (Government of Canada, 2016a).[5]

These different projects and activities illustrate the complementary role between the CSA and DND when it comes to satellite communications. Whereas CSA focusses on supporting R&D and demonstration activities, which reflects the legislative mandate of the CSA and Canada’s Space Policy Framework (CSA, 2014a, p. 11), DND is acquiring the satellite communications capabilities that are required to support its operations.

4.1.1.2 Other federal departments and agencies

Arguably, all federal departments and agencies benefit, directly or indirectly, from space-based communications solutions, particularly if one is to include navigation technologies, such as GPS. There is, however, a sub-group of these departments and agencies that makes a relatively more intense use of satellite communications technologies. For the purpose of this evaluation, and excluding DND that has already been covered, the following entities are included in that sub-list:

- Canadian Border Services Agency (CBSA)

[4] Of interest is the fact that the satellite platforms of the Norwegian IAS satellites were built in Canada (Norwegian Space Centre, 2018).

[5] While outside the field of satellite communications, another illustration of DND’s involvement in space is the Sapphire satellite mission (DND, 2014). Based on a Memorandum of Understanding (MOU) signed between DND and the U.S. Air Force, this satellite provides data that are integrated into the U.S. Space Surveillance Network to monitor space debris and other objects that may jeopardize the operations of space assets.

- Canadian Coast Guard (CCG)
- Department of Fisheries and Oceans (DFO)
- Environment and Climate Change Canada (ECCC)
- Parks Canada (PC)
- Royal Canadian Mounted Police (RCMP)
- Transport Canada (TC)

During the period covered by the evaluation, these departments have engaged, along with DND, in the direct use of space-based AIS data. A needs assessment study conducted by the CSA in 2015 indicates that these departments and agencies have used commercially available AIS data (acquired jointly by the CSA and DND) to support their respective activities and mandate, particularly in the following areas (CSA, 2015b, p. 15):

- Safety, such as marine domain awareness, monitoring of ships, collision avoidance and warning;
- Defence and security, such as border control, smuggling and trafficking, non-reporting vessel detection;
- Fisheries management, such as commercial fish fleet monitoring, illegal fishing, seal hunting monitoring, and marine mammal management;
- Environmental protection, such as ice and iceberg mapping, monitoring of protected areas, and regulation compliance;
- Search and rescue operations; and,
- Disaster management.

The three Marine Security Operations Centres (MSOC) located in Halifax, Niagara and Victoria are responsible for receiving and sharing ground-based and space-based AIS data (CCG, 2017; CSA, 2015b, p. 14). Led by DND and the RCMP, these centres are mandated to collect and analyze data and information from the marine environment to identify security threats. They are staffed by individuals from DND, RCMP, CBSA, TC, DFO and CCG (the CSA is not involved in the operations of these MSOC).

As noted during interviews conducted as part of this evaluation, the increasing capability to combine AIS data and SAR images is a particularly promising development, which will be further advanced through the RCM. The enhanced synchronization of these two technologies through the RCM has been qualified as a "game changer", as it will enhance the reliability of the information provided, and expand the range of potential applications.

Other than the AIS (and SAR) technology, interviews indicate that the use of other space-based communications solutions appears quite limited among federal departments and agencies. In some cases, such as Parks Canada, commercial satellite phone services are used to support the work of its employees located or operating in remote locations. In the case of Transport Canada, satellite broadband services are used to stream video images to first responders involved in marine navigation surveillance or environmental spills.[6]

In sum, the involvement of federal departments and agencies in satellite communications technologies varies quite substantially. DND considers these technologies as being vital for its operations, particularly in the Arctic or other remote locations; departments and agencies focussing on marine monitoring and tracking have integrated AIS technologies and will continue to expand these capabilities with the RCM; and other departments continue to explore ways to effectively implement more traditional solutions around voice and data transfer through satellite broadband services. On that latter point, the anticipated deployment of LEO microsatellite constellations offering planet-wide broadband connectivity is expected to open-up a number of opportunities for federal departments and agencies to integrate more satellite communications solutions into the delivery of their programs and activities.[7] While the CSA may provide some technical expertise, the agency is not systematically involved in supporting federal departments and agencies as they navigate these various space-based solutions.

4.1.2 The participation of departments and agencies

Finding: While some coordination of activities among federal departments and agencies have occurred, there is a need to more systematically support the federal government's awareness and use of space-based communications solutions. The experience of the UKSA offers relevant insights in that regard. **(Evaluation question: Relevance #1)**

4.1.2.1 The experience to date

Evaluation findings indicate that the rapid expansion of satellite communications solutions makes it increasingly difficult for federal departments and agencies to maintain a corporate level of technical knowledge that would allow them to make sound and fully informed decisions on the most effective and efficient solutions to adopt. One representative from a federal agency summed-up particularly well the general trend that emerged from interviews conducted as part of this evaluation, when he stated:

> "We don't have a great idea what's out there; we pick it up based on what we see in articles or by luck. (…) There are a lot of different programs but we learn about them haphazardly. I don't know what's out there, who to talk to, or what things may cost."

6 In 2014, the aerial imaging technology installed on Transport Canada's surveillance aircraft, which relies on satellites to provide live video streaming, played a pivotal role in planning and executing the arrest of an individual involved in a high profile homicide case that cost the lives of three RCMP officers in Moncton (Friesen, 2014).

7 The 2018 federal budget allocated $100 million in funding support, through the Strategic Innovation Fund, to support projects related to LEO microsatellite constellations, to expand access to broadband connectivity in remote areas (Government of Canada, 2018, p. 120).

The emergence of the New Space economy has a multiplier effect on this dynamic. With more options entering the market, in a largely uncoordinated commercial environment, departments and agencies have access to a larger set of space-based solutions that may well improve the delivery of their programs and activities, as long as they have the capacity to navigate through these commercial options. At this point, evaluation findings indicate that such capacity is not firmly established within the federal government.

In this context, the evaluation found that there is a need for knowledge-sharing and advisory support of activities among federal departments and agencies in relation to satellite communications options and solutions. Practically all representatives of federal departments and agencies that were interviewed as part of this evaluation emphasize the strategic role that the CSA could play in that regard.

During the period covered by the evaluation, some coordination did occur, particularly in the area of space-based AIS technologies. As previously noted, the cooperation and collaboration that has been operationalized through the three MSOC has allowed for a common approach among participating departments and agencies for the acquisition and use of AIS data among key user departments and agencies. Along the same lines, the 2015 consultations that the CSA held as part of its AIS study (CSA, 2015b) provided an opportunity to better understand how this technology could be integrated in the operations of federal departments and agencies. The CSA also funded feasibility studies in 2011 and 2016 that explored the range of potential applications of space-based AIS data within the federal government, including options for combining this data with SAR imaging technologies. Finally, discussions held at the Interdepartmental Marine Security Working Group has also allowed key departments and agencies, including the CSA, to maintain a dialogue on AIS developments and options.[8]

In the area of global navigation, Public Safety Canada established in 2011 the Positioning, Navigation and Timing Board (PNTB), formally known as the Federal Global Navigation Satellite Systems Coordination Board (FGCB), to coordinate federal efforts in the areas of detection, reporting and mitigation of interference with these systems, as well as future investments and opportunities for integrating this technology. The PNTB includes the CSA, as well as ISED, Public Safety Canada, DFO, Global Affairs Canada, Natural Resources Canada, DND and TC (Government of Canada, 2014).

Despite these efforts, evaluation findings point to significant unmet needs for support, particularly as it relates to non-AIS technologies. During interviews, key informants described the current approach as being disjointed or largely absent. As a result, departments and agencies are exposed to a myriad of options, without being clear on their actual needs and those of other departments and agencies with whom they could potentially collaborate. As one key informant put it, the CSA is needed to act as the

[8] The Interdepartmental Marine Security Working Group, established in 2001 and chaired by Transport Canada, includes 17 departments and agencies, including the CSA, that are involved or have an interest in marine security issues (Transport Canada, 2012).

"honest broker" for satellite communications solutions. Moreover, there is limited ability to engage industry and academia in a dialogue on emerging solutions that may apply in the federal context.

4.1.2.2 Lessons learned in other jurisdictions

The evaluation provided an opportunity to explore how other countries are managing satellite communications technologies, particularly as it relates to the coordination of these technologies to support departments and agencies. In doing so, one initiative clearly stood out: the U.K. Space for Smarter Government Programme (SSGP).

Established in 2014 and led by the UK Space Agency (UKSA), the SSGP aims to achieve three specific outcomes (UK Space Agency, 2017):

- "Increased awareness and number of public sector bodies using space-enabled services and applications by 2020;
- Accelerate the public sector uptake of space-enabled services and applications to make Government policy delivery and operations more efficient;
- Government use of space services and applications positively contributes to the wider UK space sector growth target by 2030."

To support the implementation of this program, the UKSA collaborates with Satellite Applications Catapult, a not-for-profit entity established in 2013 by the U.K. government (through its Innovate UK agency) that specializes in accelerating the take-up of emerging technologies. It offers advanced facilities and expertise in a range of space-related areas, including satellite communications. According to the SSGP's Program Manager, the fundamental strength of the program comes from the combination of technical knowledge and linkages to the industry and academia that Catapult offers, and the access to government departments that the UK Space Agency can facilitate (SSGP, 2016).

The activities of the SSGP focus on the following three areas (UK Space Agency, 2017):

- *Raising awareness of space and satellite enabled services*. This is to be achieved through "long-term relationship with government departments to understand their priorities and needs". The goal is also to facilitate an ongoing dialogue involving government, industry and academia. Finally, there is an element of training to "inspire and educate potential new users and dispel the myths over costs and technical aspects".
- *Improving access to data, information and services*. This is to be achieved by identifying the current barriers that limit the government's access to satellite data and services. There is also a commitment to establish and maintain centralized catalogues of space data and training available.

- *Enhancing industry and government capability*. This is to be achieved by running regular competitions that can "identify innovative technology solutions to meet public sector requirements".

While the focus is on national departments and agencies, the SSPG is also reaching out to local government to enhance their own capacity to integrate space-based solutions (Trendall, 2017). In a report tabled in June 2016, the U.K. Parliamentary Committee on Science and Technology recommended that the mandate and budget of the SSPG be expanded given the program's success to date (Parliamentary Committee on Science and Technology, 2016).

No other systematic approach to engaging government departments in space-based solutions has been identified in reviewing the experience of jurisdictions comparable to Canada.

4.1.3 Supporting the space industry

Finding: Governments continue to play an important role of supporting space industries engaged in satellite communications. The commercially-driven New Space environment is expanding the range of applications for space-based communications technologies, and the CSA has a critical role to play in supporting innovation in that field. **(Evaluation questions: Relevance #1, #2, #3)**

4.1.3.1 The mandate to support the space industry

The *Canadian Space Agency Act* mandates the CSA to take measures that will "ensure that space science and technology provide social and economic benefits to Canadians" (Section 4). In doing so, and among other things, the CSA is expected to (Sub-section 5 (2)):

- "plan, direct, manage and implement programs and projects relating to scientific or industrial space research and development and the application of space technology;
- promote the transfer and diffusion of space technology to and throughout Canadian industry;
- encourage commercial exploitation of space capabilities, technology, facilities and systems."

As already noted in the sub-section 2.1.2 of this report, the federal government's level of engagement in supporting the development of satellite communications technologies and market growth has declined over the period covered by the evaluation. This trend, however, must be properly contextualized. Canada has historically been engaged in supporting the development and commercialization of satellite communications technologies, motivated in part by the desire to connect communities distributed throughout a uniquely vast territory (CSA, 2014a; Gainor, 2012). During interviews conducted as part of this evaluation, the case of Anik F2 was regularly used to illustrate the strategic role played by the CSA. Owned and operated by Telesat, the Anik F2 satellite has been in service since 2004 and offers wireless broadband Internet that supports voice, data and broadcast services in North America, including a portion of Canada's North. It is "the first satellite to fully commercialize the Ka-frequency band" (BCE Inc., 2005).

The CSA provided funding for the demonstration of two payloads (including the SpaceMux on-board processor) and, in return, the CSA secured an agreed upon level of access to broadband services.

Another example noted during interviews is the current involvement of MDA in providing communication antenna subsystems for the planned OneWeb LEO Constellation. In June 2016, MDA announced that it would provide 3,600 of these subsystems to OneWeb, to be built in its Montreal facility (MDA, 2016b). The CSA provided financial support to MDA in the early stages of development of this technology, through its participation in the ESA ARTES program.

Evaluation findings point to a large consensus among individuals interviewed that government support, particularly for the development and demonstration of emerging satellite communications technologies, is required to favourably position the Canadian space industry in this segment of the space market. As noted during interviews, satellite communications is a fast-pace industry requiring significant investments. In this context, industries tend to invest to incrementally improve existing technologies, but are far more hesitant to venture into radically new solutions.

4.1.3.2 Experiences in other jurisdictions

Recognizing the significant economic and social benefits that may derive from successful satellite communications projects, governments around the world are providing support to lessen the risks that are necessarily associated with innovation. The ambitious UK Space Innovation and Growth Strategy (IGS) illustrates this trend well. Launched in 2010, the IGS has served to mobilize government, academia and space industry in growing the UK space sector. In its update published in 2015, the UK Space Agency reported an average annual growth of 8.6 % in its space industry since the launch of the strategy in 2010, supported through a number of initiative, including investments in commercial missions in a variety of sectors such as space-based communications solutions (UK Space Agency, 2015, p. 4).

The U.S. also has a long history of funding the commercial development of satellite communications technologies. Back in 1989, a report from the National Research Council noted – in reference to research and development activities needed "to yield revolutionary technological advances" – that "satellite providers and satellite manufacturers seldom have the motivation to commit significant financial resources to such investments". This, according to the report, was one of the main drivers behind the public support for the development of commercial satellite communications technologies. The report also emphasized that "every other nation active in space communications provides government support, at least in technology development and export assistance" (National Research Council, 1989, p. xv). To this day, NASA continues to make such investments. In a recent Announcement of Opportunities published in 2017, NASA offered financial assistance in support of its strategic goals of "advancing commercially-developed technologies that can benefit both the commercial and government use of space", by accelerating "the development and availability of these technologies" and reducing "the costs associated with their implementation and use"" (NASA, 2017, p. 1). The field of advanced communications technologies is one of the areas specifically targeted by this initiative (NASA, 2017, p. 29).

Finally, ESA has long recognized the need to support research and development in satellite communications technologies, particularly through its ARTES Advanced Technology programme that is "dedicated to long term development of Satcom industry based on ESA's initiative", which "focuses on research and development of new technologies and techniques in telecom satellite, ground and user equipment for future or evolving systems" (ESA, 2018).

4.1.4 Expectations towards the federal government and the CSA

Finding: Key stakeholders, such as federal departments and agencies, as well as the space industry, expect that the CSA will continue to be actively engaged in satellite communications technologies, by supporting R&D and space demonstration activities, by assisting other departments and agencies, and by contributing to a government-wide procurement approach that is strategically aligned to support the Canadian space sector. **(Evaluation questions: Relevance #2, #3)**

Evaluation findings confirm that the federal government has an important role to play in the field of satellite communications. Any remaining assumption that this largely commercially-driven sector of space activities is sufficiently mature to operate and grow without government support must be set aside in favour of a more balanced perspective that reflects the remarkable transformations that the sector continues to experience. While the agency has a critical role to play in that regard, it is a goal that extends beyond the CSA.

This vision, which emerged from evaluation findings, is also aligned with the work that the Space Advisory Board recently conducted. Tasked by the Minister of Innovation, Science and Economic Development (ISED) to consult with stakeholders on a new space strategy, the Board tabled a report that includes eight key proposals for consideration by the Minister (Space Advisory Board, 2017). The report covers all areas of space activities, including important insights that relate directly to satellite communications.

More specifically, in proposing that space be designated a "national strategic asset", the Board not only emphasized the level of deep integration that space technologies have into all dimensions of Canada's society, but it also noted that, in order to operationalize such an approach, all departments and agencies must "focus and synchronize policies and programs to support the development and growth of a national space capacity capable of meeting national needs and competing in the global market" (Space Advisory Board, 2017, p. 4).

In order to develop and grow this space capacity, the Board addressed both the initial support provided in technology development and the impact of procurement policies when it comes to acquiring data, services or assets: "The government has a wide range of procurement policies and practices that could be leveraged to better promote the development of internationally competitive space companies and world-class science" (Space Advisory Board, 2017, p. 6).

Finally, echoing principles contained in the 2014 Space Policy Framework (CSA, 2014a, p. 11), the Board proposed that the federal government "procure space services (as opposed to owning and operating space system) whenever possible in order to promote private sector investment" (Space Advisory Board, 2017, p. 8).

Promoting the use of satellite communications technologies and growing the Canadian space industry that is contributing to this sector also reflect the priorities of the federal government as defined in Canada's Innovation and Skills Plan, where innovation and technological capacity are identified as key contributors to positioning Canada in the digital economy (Government of Canada, 2017a).

During interviews conducted as part of this evaluation, key informants provided insights that are largely aligned or that build upon this vision. The following key messages emerged from these interviews:

- The New Space environment is transforming the industry, particularly in the field of satellite communications technologies and their applications. In this context, it would be misguided to think of the communications space industry has being a mature sector that is largely operating within a stable and predictable environment.
- The emergence of LEO satellite constellations may arguably redefine the access to broadband Internet, particularly in remote locations, which would both address longstanding concerns with access to proper communications technologies in such locations, and open-up a range of potential applications that have yet to be defined, designed, demonstrated and commercialized.
- The CSA continues to play a critical role in supporting research and development, and demonstration activities in satellite communications technologies, particularly through STDP, the Flight and Fieldwork for the Advancement of Science and Technology (FAST) program, space demonstration activities, and its participation in the ARTES program with ESA.
- In some instances, when the emerging technology primarily (or at least initially) serves a public purpose, where the commercial potential is narrower, and the level of risks remains particularly significant, the need for the federal government to undertake full communications missions may still be required. In such cases, the CSA is expected to play a central role. The QEYSSat technology demonstration mission mentioned in sub-section 2.2.2 illustrates well this principle.
- There is a lack of awareness and organizational capacity within federal departments and agencies (other than DND and the CSA) on how best to integrate satellite communications in support of the delivery of their respective programs and activities. The CSA is perceived as the natural broker of knowledge and the institutional guide that can support decision-making within these departments and agencies when it comes to satellite communications options.
- The federal government as a whole has a pivotal role to play in using its procurement practices to strategically support the Canadian space industry involved in communications technologies. While this challenge extends well beyond the CSA, the agency is expected to inform any government-wide strategy that would support this goal.

These key messages indicate that, in addition to the long-standing role that the CSA has played in supporting R&D and the demonstration of new space-based technologies, there is a need to address a remaining gap in coordinating and enhancing the capacity of federal departments and agencies to engage in new space-based communications solutions. As well, the views around the larger role of procurement to support the Canadian space industry reflect the fact that positioning the industry in this particular field requires a government-wide approach, which extends well beyond the strict mandate of the CSA.

4.2 Performance

The assessment of the SCBL's performance over the period covered by the evaluation is structured along the three key missions or projects in which the CSA was involved, namely the M3MSat mission, the Cascade payload placed on the CASSIOPE satellite, and the PCW mission. In each case, the analysis takes into account the expected role of the CSA in assessing the needs of other federal departments and agencies, in supporting the Canadian space industry, and in managing or supporting these missions and projects.

4.2.1 The M3MSat mission

4.2.1.1 Mission overview

The M3MSat mission is a technology demonstration project (TDP) undertaken jointly by DRDC and the CSA. Back in 2001, DND and the CSA signed a Memorandum of Understanding to frame their collaboration in space-related activities. On that basis, the two organizations established, in 2005, a Joint Project Office (JPO) tasked with procuring and delivering a first jointly developed microsatellite, NEOSSat, whose primary purpose is to detect and track asteroids and satellites. A year later, in 2006, the two organizations undertook their second joint microsatellite project, M3MSat.

The M3MSat mission covers four main technologies that are described in Table 3. The AIS and the LDRS payloads relate more directly to satellite communications, while the testing of the multi-mission microsatellite bus (MMMB) and the DDCM payload relate more generally to satellite operations.

Table 3: Key components of M3MSat

Component	Lead	Manufacturer	Description
Multi-Mission Microsatellite Bus (MMMB)	CSA	COM DEV	The multi-mission microsatellite bus is a CSA initiative that supports the development of a microsatellite bus capable of multiple missions with minimal non-recurring expenses. The NEOSSat mission was the first to apply the MMMB requirements.
AIS payload (primary)	DRDC	COM DEV	The AIS payload serves to capture AIS signals emitted by ship equipped with class A AIS transmitters, and to process and transmit the resulting data to support the ongoing monitoring of these ships.

LDRS payload (secondary)	CSA	COM DEV	The LDRS payload provides basic message reporting capability (non-voice) in more sparsely populated regions that have little or no access to terrestrial-based communications systems.
DDCM (tertiary)	CSA	DPL Science	The DDCM payload measures the static charge within a satellite and helps operators take effective measures to preserve the health and safety of the spacecraft.

Source: CSA administrative documents

When the mission was initiated in 2006, DND was expected to be the owner and operator of the satellite, in addition to being the lead on the primary payload for AIS technologies. As such, the M3MSat mission was designed to respond predominantly to the needs of DND. More specifically, DND and DRDC were pursuing the following key objectives:

- Supporting enhanced monitoring and surveillance of Canadian coasts and waters by Canadian Forces, including arctic regions, for domestic defence and security purposes. The AIS data was also expected to be shared with other Canadian enforcement authorities involved in marine security, notably the RCMP, DFO and the Canadian Coast Guard.
- Enhancing the capacity to combine SAR imaging and AIS data, as part of RADARSAT-2 and in preparation for the launch of RCM (risk reduction).
- Enhancing the capacity of DND and DRDC to access space-based AIS directly, without having to rely on other allied countries or data sources, while also allowing collaboration efforts with countries exploring the potential contribution of space-based solutions.
- Testing the capacity of microsatellites to support DND priorities in a more cost-effective manner, when compared to traditional missions using larger spacecraft.

The CSA shares these goals, but has had a particular interest in the following objectives:

- M3MSat was expected to provide an opportunity to further explore how microsatellites could support CSA-led missions. In 2003, the CSA launched its MOST astronomy microsatellite, and has also collaborated with DND on the NEOSSat mission. M3MSat was therefore providing a new opportunity to better inform future decision-making on the use of microsatellite, particularly the MMMB type.
- All three payloads (AIS, LDRS, and DDCM) were expected to position the Canadian space industry in emerging space-based communications solutions that hold a commercial value. In particular, while other countries such as the U.S., the U.K., Norway and Australia were exploring the potential of space-based AIS services, no country had successfully demonstrated this technology using satellites in an environment with a large volume of AIS signals. Supporting the research and development of these three technologies, and their successful demonstration in space would align with the mandate of the CSA to support the Canadian space industry.
- In addition to providing strategic information for DND and other enforcement authorities for security purposes, these three payloads were also expected to support the mandate of other

departments and agencies, such as those involved in marine traffic management, fisheries tracking, port operations, search and rescue operations, and environment and climate change (through, for instance, environmental, weather, acoustic, or biological sensors).

In terms of timeframe, the initial goal was to initiate Phase A activities (mission definition) in 2006 and complete Phase D activities (launch and commissioning) in 2009. The satellite was expected to operate (Phase E) for a minimum of 12 months, with a target period of 24 months.

As for the associated budget, the initial estimate (in 2007) was that Phases A to D could be completed with a budget of $14.4 million. This estimate does not include the costs related to the operations of the satellite (Phase E), which vary depending on the length of operations. It also excludes any costs related to the acquisition of AIS data from other satellites.

4.2.1.2 Mission implementation and results

Finding: The CSA and DND have successfully managed the M3MSat mission, which has provided opportunities to develop and demonstrate emerging communications technologies, including the AIS data that has been successfully commercialized. The mission has, however, encountered challenges that have extended the initial mission timeframe and required additional investments. **(Evaluation question: Performance #1)**

The M3MSat mission achieved its demonstration objectives, but in order to do so, it required more time and investments than initially anticipated.

On June 22, 2016, the Polar Satellite Launch Vehicle (PSLV-C34), owned and operated by the Indian Space Research Organization (ISRO), successfully placed M3MSat in orbit (CSA, 2017c; ISRO, 2016). All three payloads had been integrated in the MMMB platform, and once the commissioning process was completed in May 2017, each had operated and met their technical requirements:

- In the specific case of the AIS payload, the system has met or exceeded expectations. According to representatives from the CSA, industry, and academia who were interviewed as part of this evaluation, the AIS antenna and system placed on M3MSat have provided one of the most advanced and reliable information on ship movements that is currently available. These results further support the current initiative to integrate AIS and SAR imaging technologies on board the RCM.
- In the case of the other two payloads (LDRS and DDCM), they have been successfully tested, but they have not been in operation thereafter. Evaluation findings indicate that there was no direct demand for the ongoing operation of these two payloads, and to minimize any potential interference, the decision was made to not operate them beyond the demonstration stage.

As for the ground operations required to operate M3MSat, the initial plan was that DRDC would undertake these activities, but by the time M3MSat was launched, the decision was made to have the CSA operate the satellite. No new infrastructure investments were required. To this day, M3MSat is operated alongside other satellites. A hybrid team consisting of CSA employees and sub-contractors look after the ongoing operation of M3MSat. Evaluation findings indicate that these activities have been carried out successfully.

Finally, in order to operate M3MSat, the proper radio licence had to be secured in accordance with the broadcasting and telecommunication regulation managed by ISED, a process that also includes international coordination activities required by the International Telecommunication Union (ITU). While the owner of the satellite, in this case DND, is technically responsible for undertaking the required spectrum management activities, the CSA largely managed this process, based on its corporate expertise in the field. This process, while lengthy, was successfully completed in time for M3MSat to transmit frequencies once in orbit.

In addition to supporting federal departments and agencies and the Canadian space industry, the M3MSat mission provided an opportunity for the Center for Intelligent Antenna and Radio System (CIARS) from the University of Waterloo to strengthen its expertise. According to the Director of CIARS, Professor Safieddin (Ali) Safavi-Naeini, this was one of the most challenging antennas ever designed and developed by the Center, and the acquired expertise has already been applied to other space-related projects (CSA, 2016c).

The most significant challenge that the M3MSat mission encountered was a series of delays that considerably lengthened the mission schedule. Figure 3 illustrates the time required to complete each mission phase, and evaluation findings provided the following insights on the main factors that contributed to these delays:

- A number of technical modifications to the MMMB and the AIS payload have expanded the design phase of the mission (phases B and C). As previously noted, the original plan was to have the M3MSat in operation for up to 24 months. However, since the satellite was expected to work in conjunction with other commercial satellites, COM DEV and the CSA agreed to proceed with a higher level of redundancy (also referred to as dual strength), which is typically required for satellite that are expected to operate over a longer period of time. In addition, the original design for the AIS antenna was revised in favour of a more innovative design that could provide better performance. In practical terms, this meant that the mission would no longer proceed with the original antenna included in the project proposal, which had already achieved a certain level of maturity in technological readiness level (TRL). Rather, the team operated with a TRL 1 concept, and built up a new antenna. Both the changes to the MMMB and the AIS antenna delayed the early phases of the mission.
- With the additional time required for the design of M3MSat, its expected launch date was first moved from 2009 to 2011, before being further revised and confirmed for February 2013. Two other Canadian satellites, NEOSSat and Sapphire, were also scheduled for the February 2013 launch to be provided by the ISRO. As available volume on the launch vehicle became an issue, only NEOSSat and Sapphire were included in the launch. At that point, the decision was made to

launch M3MSat using Roscosmos, a Russian launch provider, which had a vehicle scheduled for take-off in June 2014. In early 2014, unforeseen events prevented the launch of the satellite from Russia as planned. After several months of discussions and negotiations, the services of ISRO were retained and, on June 22, 2016, the PSLV-C34 placed 20 payloads in orbit, including M3MSat. Commissioning of the satellite was completed on May 18, 2017, and M3MSat has been in operation ever since.

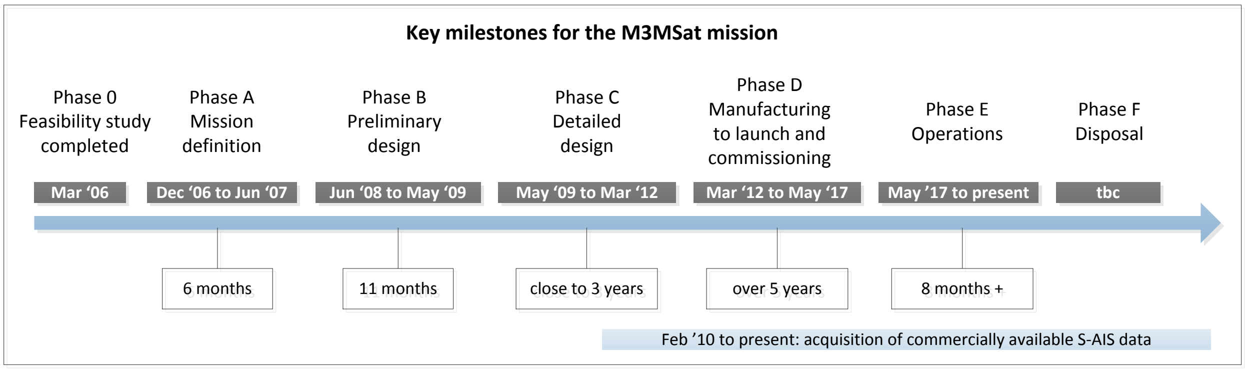

Figure 3

The revisions and delays in launching M3MSat have had a financial impact. The total allocated budget for the mission had to be increased by $7 million to mainly cover expenditures related to new launching arrangements and to the requirements for the storage and maintenance of the spacecraft while awaiting the launch.

4.2.1.3 Use of AIS data

Findings: As the M3MSat mission was unfolding, space-based AIS data services became commercially available, including services offered by the Canadian space industry that had developed relevant expertise through its early involvement in the mission concept and feasibility study of M3MSat. A number of federal departments and agencies have used these services to support the ongoing management of their services and operations. **(Evaluation questions: Performance #2, #3, #4)**

As the M3MSat mission was progressing, the commercial market for services based on AIS data emerged. In Canada, building on the acquired expertise it gained through the mission concept work and the feasibility study of M3MSat, COM DEV launched a nano-satellite with AIS detection capability in 2008, and a year later in 2009, established a subsidiary, exactEarth, to commercialize maritime vessel tracking information based on AIS data (exactEarth, 2015, p. 33). That same year, exactEarth started to assist DND and the DFO in using space-based AIS data to monitor "illegal, unregulated and unreported fishing activity in the Pacific Oceans" (exactEarth, 2015, p. 33). Between 2010 and 2012, exactEarth launched three new satellites hosting AIS payloads to enhance its service capacity. Among the various applications of this new technology is the contract that the CSA signed with exactEarth to provide AIS data in support of the security efforts deployed during the 2010 Olympics in Vancouver. This AIS data was combined to SAR images provided by RADARSAT-2 to monitor the maritime region surrounding the games (CISION, 2010).

Since 2011, through competitive procurement processes, the federal government has been acquiring AIS marine data services to support the work of the various MSOC (as described in sub-section 4.1.1.2). From 2011 to 2017, exactEarth supplied this service and, starting in 2017, the federal government switched to Maerospace. In order to provide this service, Maerospace uses AIS data provided by ORBCOMM, a U.S. based provider of such data (ORBCOMM, 2017).

As this was unfolding, and as described in sub-section 4.1.2.1, the CSA undertook some coordination activities, through a needs assessment on the use of AIS data, and through feasibility studies to explore the range of potential applications of space-based AIS data within the federal government.

4.2.1.4 Enhancing knowledge and expertise

Finding: A number of lessons learned emerged from the experience of the M3MSat mission, related both to the use of MMMB, and to the commercialization of new space-based solutions, which can inform future activities in the field of space-based communications technologies. **(Evaluation questions: Performance #2, #3, #4)**

While implemented to respond predominantly to the needs of DND (as the owner of the satellite), the M3MSat mission provided an opportunity for the CSA to advance its knowledge and expertise in key areas:

- The MMMB successfully hosted all three payloads, but in the absence of repeated microsatellite missions, its ability as a concept to minimize non-recurring expenses is limited. For M3MSat, the MMMB requirements expanded the scope of work, and since no new mission using the same generic bus is planned for the foreseeable future, the benefits of such investment are restricted.
- The mission provided an opportunity for the Canadian space sector to test and demonstrate emerging technologies. As with any innovation process, the extent to which these new technologies end up being successfully commercialized is determined by a number of factors. In the case of M3MSat, the AIS technology has been successfully commercialized, whereas the LDRS and the DDCM technologies have yet to achieve this outcome. While AIS was a specific requirement to meet the needs of DND (and was thus the primary payload on M3MSat), the LDRS and DDCM technologies were selected directly by COM DEV with the goal of commercializing these technologies. As such, the initial rationale for including the LDRS and DDCM payloads, and their potential commercialization, rest within the prerogative of COM DEV.
- Through the MSOCs, the AIS technology has been supporting a number of federal departments and agencies in delivering their programs and services. In that sense, the mission successfully reached beyond the primary client, DND, and benefited from a greater exposure of other departments and agencies to the advantages of space-based solutions.

From the perspective of DRDC and DND, M3MSat partially met the initial goals and objectives set for this mission:

- The concept of having a DND owned and operated satellite to gather AIS data for R&D activities related to security and surveillance purposes has, de facto, been replaced by a strategy of procuring this service from commercial providers, such as exactEarth and Maerospace. The extended period of time required to design and launch M3MSat forced DND to consider alternative options, and since commercially available AIS maritime data services became available as early as 2009 (when M3MSat was still in the design phase), the focus has promptly turned to commercial providers.
- Through commercially available AIS services, DND successfully combined SAR imaging and AIS data, as demonstrated during the 2010 Olympics in Vancouver, and used afterwards in monitoring and surveillance activities, including those conducted by the three MSOC.
- DND has gained greater experience using microsatellites as a model upon which to design space-based solutions that could respond to its specific requirements.

With hindsight, the evaluation indicates it may have been more efficient to limit the federal government's involvement to a targeted support for technology development and space demonstration of specific payloads, rather than proceeding with the launch of a government-owned and operated satellite hosting these payloads. However, back in 2006 when it was first discussed, the rationale for proceeding with M3MSat was based on reasonable assumptions and included broader considerations related to the development of a generic microsatellite bus.

4.2.2 The Cascade payload

Finding: The CSA has supported the demonstration of the Cascade payload, which has not been commercialized, but has nonetheless provided benefits for the space industry, which have since been applied to other related communications technologies. **(Evaluation questions: Performance #3, #4)**

As noted in sub-section 2.3, the CASSIOPE mission (launched in 2013) successfully demonstrated the secure digital store-and-forward file delivery service technology contained in the Cascade payload. Over time, however, MDA (through Cascade Data Services Inc.) has been unsuccessful in securing commercial clients for this new communication technology. At the time of this evaluation, neither MDA nor Cascade Data Services Inc. was offering this space-based file delivery service. As such, the business case for Cascade did not materialized and the evaluation found no indications that it will do in the foreseeable future.

While the direct benefits associated with the Cascade payload were not attained, the evaluation indicates that indirect benefits were, in fact, realized. First, the CASSIOPE mission was undertaken in a period of systematic changes in the space industry as the commercially-driven New Space paradigm was emerging (CSA, 2014b, p. 16). Having both ISED (Industry Canada at the time) and the CSA involved in financially supporting the demonstration of the Cascade technology reflected an industrial goal of maintaining and enhancing space capacity in Canada (Ciuriak & Curtis, 2013, p. 18; CSA, 2014b, p. 3). In addition, the technical expertise gained through the Cascade project, particularly in the area of high speed Ka-frequency band, has since been applied by MDA to other projects, such as the recent contract that the company signed with the Franco-Italian aerospace manufacturer Thales Alenia Space for the provision of communication subsystems for its O3b constellation of medium earth orbit satellites (MDA, 2016a).

4.2.3 The Polar Communications and Weather (PCW) mission

Finding: As initially conceived, The PCW mission was not pursued. Through the ESCP-P initiative, DND, the CSA and other federal departments and agencies are now collaborating to explore how to address both military and non-military needs in the Arctic. **(Evaluation questions: Performance #3, #4)**

Improving communications capabilities in Canada's North is a longstanding goal of the federal government. Back in 2007, the CSA established the PCW Users and Science Team that was tasked with identifying the range of institutional needs among federal departments and agencies for communications services and meteorology in the Arctic region (Euroconsult, 2012, p. i). On that basis, the CSA, in collaboration with Environment Canada[9] and DND completed a Phase 0 feasibility study, followed by a Phase A detailed mission analysis and concept definition study. In 2014, PSPC issued a Request for Information to inform the Canadian industry about this proposed whole of government project, to seek the industry comments on the proposed business requirements, and to explore potential delivery models (PWGSC, 2013, p. 1).

Having both the weather and communications requirements included in the same mission and operating on the same satellite raised a number of technological challenges, and proved to be too expensive to be implemented. As already noted in sub-section 4.1.1.1, DND continues to explore options for space-based communications solutions that could support the command and control of military operations in the Arctic, through the proposed ESCP-P initiative. As this project evolves, the need of other stakeholders, namely other federal departments and agencies operating in the North, may be addressed as part of the proposed solution. The CSA continues to provide technical support as part of the ESCP-P initiative.

4.3 Program efficiency

This last sub-section of the report summarizes evaluation findings related to the efficiency of the program delivery. Since resource allocations for the Cascade payload occurred prior to the evaluation period, and are covered by the evaluation of the CASSIOPE mission (CSA, 2014b), and since the PCW mission did not proceed during this same period, this sub-section centres on the M3MSat mission.

Finding: The majority of resources allocated to the SCBL have been directed to contracts signed with the space industry to develop M3MSat and to provide commercially available AIS marine data services. The CSA has established a number of processes to support the ongoing management of its activities. Moving forward, the GBA framework of the CSA could support the planning and implementation of activities

[9] The title of Environment Canada is now Environment and Climate Change Canada (ECCC).

related to space-based communications technologies, particularly as it relates to isolated communities. **(Evaluation question: Performance #5)**

4.3.1 Resource allocations

Table 1 (on page 7) includes the distribution of the overall financial resources allocated to the SCBL over the five year period covered by the evaluation. A little more than two-thirds of the $36.3 million allocated to the SCBL were directed to contract expenditures. In the case of mission development, these expenditures were almost exclusively directed to COM DEV International (now Honeywell Aerospace) for developing and manufacturing the satellite bus and its components for the M3MSat mission. The involvement of COM DEV began in 2008, so other resources were directed to COM DEV prior to the period covered by the evaluation. In the case of service and data utilization, the vast majority of resources were directed to exactEarth, principally for the purchase of its AIS marine data services.

As for the allocation of Full Time Equivalents (FTE) to the SCBL, the trends presented in Figure 4 reflect the decreasing involvement of the CSA in satellite communications over the period covered by the evaluation and the fact that the launch of M3MSat was delayed, limiting activities during these waiting periods.

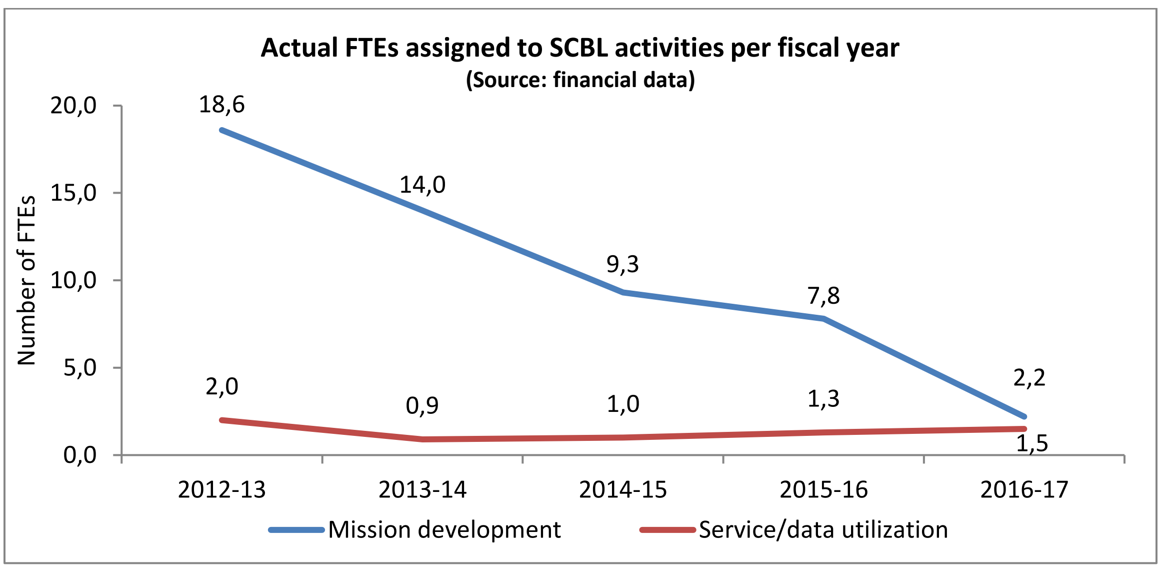

Figure 4

4.3.2 Processes to enhance efficiencies

The CSA used a number of processes to structure, monitor and execute the M3MSat mission:

- As noted in 4.2.1.1, a Joint Project Office was established to support the co-management of the mission and a supporting arrangement was signed in 2006 to further define the roles and obligations of both DRDC and the CSA throughout the implementation of the mission.

- A Joint Implementation Plan was established in 2007 to confirm the scope of the mission, the distribution of roles and responsibilities, the activities to be undertaken for each mission phase, and the overall project management and accountability structure.
- All contracting activities were undertaken in accordance with federal government requirements, and involved PSPC to manage procurement processes and negotiate all contracts signed on behalf of the Crown.

Evaluation findings indicate that the co-management of the mission was successfully carried-out. In particular, both the CSA and DRDC representatives indicated that the roles were well defined and that the two organizations offered complementary expertise and knowledge.

As already noted, additional resources had to be allocated in order for the mission to be fully executed. These additional resources were secured and managed in accordance with applicable federal policies and procedures.

The CSA completed a Project Closure Report that provides detailed insights and lessons learned on the M3MSat mission, particularly from a technical and internal management perspective, which includes a series of recommendations based on the experience of M3MSat. This closure report plays a highly complementary role to the findings included in this evaluation report.

4.3.3 Gender-Based Analysis Plus

In July 2016, the federal government released its new *Policy on Results* (Government of Canada, 2016c) , along with its associated *Directive on Results* (Government of Canada, 2016b). This new framework clarifies expectations related to gender-based analysis plus (GBA+). First, it confirms that in establishing their performance measurement strategy, program managers must include, where relevant, a gender-based analysis. It also identifies, as a mandatory procedure, that all evaluations be planned to take into account, where relevant, gender-based analysis.

In March 2017, the CSA approved its own policy and procedures governing gender-based analysis, which is based on the concept of GBA+, as defined by the Status of Women Canada (Status of Women Canada, 2017). This framework explores how “diverse groups of women, men and gender-diverse people may experience policies, programs and initiatives”. Put simply, GBA+ is an analytical tool that is expected to be used to support all programming cycles, from initial design, to implementation and evaluation with a view of ensuring equitable access and benefits.

For the purpose of this report, it is particularly important to emphasize the “Plus” segment of GBA+. In addition to sex and gender, GBA+ considers a range of identity factors, such as age, culture, income, and geography. For instance, a GBA+ analysis may wish to explore how isolated communities, regardless of gender, may be affected (positively or negatively) by the implementation of a certain program, policy or initiative.

During the period covered by the evaluation, the policy and procedures of the CSA relating to GBA+ were not in place. Consequently, this evaluation is not assessing the extent to which proper gender-based analysis plus had been performed as part of the management of the SCBL. However, it is relevant to note the role that the CSA has played during the implementation of the SCBL, particularly as part of the PCW mission, in ensuring that the communications needs of isolated communities in Canada's North could be addressed. By promoting and supporting access to proper communications in these regions, which in some cases are still under-serviced (by the absence of services or by the prohibitive costs associated with such services), the CSA plays an important role in ensuring that all Canadians can access and benefit from technologies that reflect the requirements and expectations of our times.

This type of considerations reflects the nature of activities in which the CSA is involved as a space agency, and can inform the implementation of its GBA+ policy moving forward.

5 Conclusions and recommandations

This section of the report concludes by summarizing the key findings of the evaluation, and includes observations and recommendations where applicable. More detailed information, substantiating each of these statements, is included in the preceding sections of the report.

5.1 Relevance

The evaluation confirms that the expertise and involvement of the CSA is required to ensure that federal departments and agencies can effectively integrate satellite-based communications solutions to support the delivery of their programs and mandates. More specifically, DND will continue to engage – just like most other defence and military forces around the world – in space activities to strengthen its operations and missions. The perspective and opportunities that space affords is particularly well suited to military operations, and technologies will continue to expand these opportunities. Other federal departments and agencies involved in large-scale surveillance, monitoring, and tracking of activities are also served by current and emerging space-based communications solutions.

Federal capacity to engage in space-based communications solutions

At the time of this report, some capacity existed within the federal government to navigate space-spaced communications technologies. DND is engaged in a number of space missions and has established a policy framework to guide the department in this field. In particular, the future of the ESCP-P project will have a significant impact on the department, which may also extent to other departments and agencies. Along the same line, the upcoming launch of RCM will allow DND to further integrate communications and imaging technologies to support its mandate. Through the three operating MSOC, DND is also collaborating with the RCMP, CBSA, TC, and DFO in integrating AIS data to their respective operations.

Despite these achievements, the evaluation confirms that federal departments and agencies still lack institutional capacity to fully engage in satellite-based communication technologies. In fact, there is still limited government-wide efforts undertaken in a systematic manner to support such an engagement. The evaluation provided an opportunity to explore what other nations are undertaking and the current SSGP initiative in the U.K. appears particularly relevant.

As the commercially-driven New Space environment allows for a greater number of industries to engage in satellite communications and expands the range of solutions being offered, there is a risk that this greater level of opportunities will, in fact, create a more confusing environment in which to operate if there is not sufficient expertise to guide decision-making processes. To this end, the CSA has an undeniable role to play to facilitate the adoption of space-based communications solutions among federal departments and agencies. **Consequently, the evaluation recommends that the Space Utilization branch explore options with regards to the role the CSA could play concerning the use of space-based communications solutions by federal departments and agencies in order to enhance their ability to deliver their programs and activities.**

Support to the space industry

World-wide, government authorities continue to support the space industry involved in communications technologies. There is long-standing recognition that innovation in satellite-based communications technologies involves a high level of risks, particularly in light of the financial investments it requires. For this reason, public investments are made in many regions of the world to support the research and development, the demonstration in space, and the commercialization of new technologies. This applies to the current environment, where broadband connectivity is a key priority, particularly as it relates to LEO constellations of communications satellites and other forms of HTS systems, which will open the door to countless commercial, government and civil applications.

During the early part of the period covered by the evaluation, the CSA had reduced its level of support for R&D and demonstration activities involving satellite communications. This approach was revisited during the evaluation period and, at the time of this report, the CSA had been using its STDP and demonstration funding, as well as its participation in ESA programs such as ARTES, to support communications projects in high risk but innovative space sectors. The QEYSSat mission and the support provided to MDA for the development of antenna subsystems for the planned OneWeb LEO Constellation, illustrate well this type of support.

The extent to which full missions involving government-owned and operated satellites will be required to meet the needs of departments and agencies, or to support the demonstration of new technologies, will be determined on a case-by-case basis. The current exploration of options around the ESCP-P project is one such case. With a targeted date of 2029 for the new satellite to be operational (assuming no delays), it raises once more the question of determining what other commercial solutions will have long been implemented before that date that could satisfy the needs of departments and agencies.

Finally, as government intensifies its engagement in space-based communications solutions, there is a need to ensure, to the extent possible, that its procurement practices are serving the strategic goal of supporting the Canadian space-industry. The evaluation indicates that a government-wide vision in that regard has yet to be established.

Is the Business Line model the most efficient approach?

The evaluation indicates that the Business Line model offers an appropriate structure for full missions involving government-owned and operated satellites such as M3MSat, but it is not particularly well suited to cover the entire range of activities that the CSA undertakes in support of space-based communications solutions. In particular, the STDP and space demonstration support provided by the CSA, or its participation in the ARTES program, fall outside of the scope of the Business Line. The new Departmental Results Framework that the CSA was in the process of implementing at the time of this evaluation focusses on the overall development of space capacity and space utilization, rather than pursuing separate business lines. This approach supports a more integrated perspective on satellite communications activities by covering all relevant activities of the CSA.

Space-based communications technologies will continue to offer a rich variety of opportunities for public, commercial and civic applications, which support the type of innovative economy that the federal government wishes to further grow. In this environment, the governing model that the CSA will apply to direct its involvement and contribution in this sector of space activities is bound to evolve beyond the current parameter of the SCBL.

5.2 Performance

The M3MSat mission

The M3MSat mission is the central communications project in which the CSA has been involved during the period covered by the evaluation. Jointly initiated in 2006 by DND and the CSA, the purpose of this technology demonstration project was to support Canada's involvement in an emerging opportunity to track AIS signals from space, which in turn, could support a range of marine monitoring, tracking and surveillance activities that were, up to that point, supported by ground-based technologies only. More precisely, the goal was to allow relevant departments and agencies to integrate this new technology, and to support the strategic positioning of the Canadian space industry in delivering AIS marine data services. The mission was also pursuing demonstration goals related to the use of MMMB, and to the LDRS and DDCM technologies.

The M3MSat mission achieved its demonstration objectives. The MMMB successfully hosted all three payloads, each of which was successfully tested. Since there was no demand for the ongoing operation of the LDRS and DDCM payloads, only the AIS technology has been operating since the full commissioning of the satellite was completed in May 2017.

The main challenge encountered with the M3MSat mission is the series of delays that significantly extended the initial mission timeframe. The CSA has proceeded with a full project closure analysis and report that identify a number of lessons learned. In some cases, such as the design of the MMMB and the AIS antenna, these delays were largely within the control of the CSA and DND. In the cases of launch arrangements, the challenges faced were outside of the control of CSA and DND. These delays have increased the level of investments required for the mission.

The M3MSat mission has supported the Canadian industry in further exploring AIS opportunities, as shown by the commercial offerings that exactEarth initiated in 2009, and has further expanded ever since, including with the integration of the M3MSat AIS data. The CIARS from Waterloo University also gained considerable expertise, which has further positioned this academic institution in space-based projects.

The decision to proceed with a demonstration satellite that was owned and operated by the federal government reflected the predominant approach to micro-satellite missions in the early 2000, particularly as the MMMB model was being tested. As such, this approach was based on reasonable assumptions. The same approach may not be required in the current New Space environment if such a mission was to be undertaken today. A more targeted support for R&D and demonstration activities would arguably be more effective.

Other activities

While successfully demonstrated, the Cascade payload (integrated in the CASSIOPE mission) has not been commercialized, and there were no indication, at the time of the evaluation, that any commercialization would be achieved in the foreseeable future. Despite this outcome, this project has served to support the Canadian space industry, and the expertise gained has since been applied to other space projects.

Finally, the PCW mission has continued to evolve during the evaluation period, but no decision has been made by the federal government on how best to meet the communications needs of DND, while also considering other civil applications of enhanced communications capability in Canada’s North. At the time of this report, an RFI related to the ESCP-P project was being managed with the support of the CSA.

Program efficiency

The resources assigned to the SCBL have been predominantly used for contract purposes in support of the implementation of the M3MSat mission, and the acquisition of commercially-available AIS data. The level of FTEs has decreased throughout the evaluation period, which reflected the reduced involvement of the CSA in communications technologies.

A number of processes have been implemented to support the work of the CSA, particularly as it relates to its direct collaboration with DND. Both the CSA and DND were successful in co-managing the M3MSat mission, with the support of other organization such as PSPC to support the procurement process.

In the specific case of M3MSat, an additional $7 million has been required to complete the mission and manage the delays encountered throughout the mission. As already noted, a portion of these additional resources were required to manage developments that were beyond the control of the CSA or DND.

Finally, satellite based communication solutions will continue to play a critical role in ensuring that isolated regions of Canada, particularly some of Canada's Northern communities, can access the range of technologies that are required to fully engage economically and socially, and to access government programs and activities. It is within the GBA+ framework that the program can further identify the differential impacts of various identify groups and explore its options with these needs in mind.

Management Response and Action Plan

	RESPONSIBILITY ORGANIZATION / FUNCTION	MANAGEMENT RESPONSE	DETAILS OF ACTION PLAN	SCHEDULE
RECOMMENDATION # 1				
The Space Utilization branch should explore options with regards to the role the CSA could play concerning the use of space-based communications solutions by federal departments and agencies in order to enhance their ability to deliver their programs and activities.	DG, Space Utilization With support from DG Policy and DG SS&T	The Space Utilization branch agrees that it is challenging for government departments to select satellite communication options and solutions. However, there are a number of government organizations that have a role to play in satellite communications.	Describe the Government Satellite Communications ecosystem and present analysis of gaps in responsibilities with recommendations on the role of CSA.	Fall 2019

Appendices

Appendix A: Logic model narrative of the SatCom Business Line

This appendix provides a description of the various components of the Sub-Program's logic model, illustrated in Figure 2. This narrative is based on the SCBL's performance measurement strategy.

Activities and Outputs

Canadian SatCom Satellites and Instruments

This group of activities and outputs includes mission concepts, feasibility studies (phase 0), and development of Canadian SatCom missions and Canadian instruments on foreign satellite missions (phases A through D).

Prior to the decision that an idea for a space mission becomes a project, feasibility studies are conducted to establish and validate the concept. The feasibility study to develop the concept of a SatCom project is the main focus of Phase 0. Once completed, Phase A feasibility studies are aimed at better establishing a concept that would address the needs of GoC organizations for space-based SatCom data. Following the completion of the Phases 0/A studies, decisions are taken whether the project is pursued to the next phases of development (B through D).

As of FY 2015/2016, feasibility studies are being performed for the SatCom concept referred to as "Microsatellites". Microsatellites are generally described as satellites with a mass of 10 to 100 kg.

Following satisfactory completion of Phases 0/A, selected SatCom missions progress to the design, development and implementation phases (Phases B/C/D). The current strategic model is represented in the logic model and shows that the CSA may decide to develop (1) a complete Canadian satellite system or (2) sub-systems, payloads, instruments or other components to provide to domestic and/or foreign satellites.

As of FY 2015/16, the only project in SSA 1.1.1.2 *SatCom Missions* is the M3MSat mission. It is expected that M3MSat will remain the main activity for the next couple of years. It is planned that M3MSat will be launched in 2016. Following the launch, the operational activities of M3MSat will fall under SA 1.1.2 *Ground Infrastructure* for handling the data, and under SSA 1.1.3.2 *SatCom Data and Imagery Utilization* for the utilization of the data. Thus, during the lifecycle of a space mission, from its feasibility studies up to its operational phase, the responsibilities and accountabilities are transferred from one group to another within the Space Utilization Branch.

Canadian Ground Infrastructure

This group of activities and outputs includes feasibility studies, development of Canadian ground infrastructure, and the Canadian ground infrastructure itself.

SatCom ground infrastructure activities contribute to a reliable national ground infrastructure, including operational capacity, in order to fulfill data needs of users from satellite missions. When main projects enter Phase D, expert advice and recommendations from the satellite operations and data handling perspectives are also provided to support the manufacturing, testing and operations development phase based on the experience gained through current Phase E satellite missions such as RADARSAT-1 and RADARSAT-2.

Satellite Operations will manage satellites in orbit by tasking the payloads and associated ground segments, commanding and controlling the spacecraft, maintaining its orbit, analyzing its telemetry, safeguarding its health and safety, and supplying the requested data to users. This includes managing order desks for user request handling and orbital debris avoidance, and operational upkeep of satellites and ground infrastructure. Activities consist of responding to operational requirements for the CSA operated missions. Operational requirements refer to maintaining the nominal orbit of the spacecraft and maintaining the spacecraft's health and safety, resolving satellite anomalies when they occur, as well as conducting collision avoidance manoeuvres as required.

Satellite Operations and Data Handling

This group of activities and outputs includes satellite operations, data handling, tasking of the infrastructure, and management of the data.

Data handling refers to activities that are conducted in order to manage payload data from acquisition to delivery for CSA operated missions and for supported foreign missions. This includes such functions as data reception, processing, archiving, data quality control and delivery in order to meet GoC and other clients' data needs. Data related to M3MSat are archived as per mission requirements. Also, data from archives are supplied to users, to meet their requests.

This SSA also addresses the optimization of Canadian SatCom data consumption. The pursued objective is to effectively maintain a balance between the supply and the demand of SatCom data since there are multiples sources, as stated before, of SatCom Data.

SatCom Data Utilization Activities and Outputs

The main activities and outputs of this SSA are developing the utilization of data so GoC organizations are able to offer more diversified or cost-effective programs and services.

The source of SatCom data comes from projects established within the CSA and other data from commercial or foreign satellites, accessible through international partnerships, to increase the potential usage for GoC organizations.

This activity includes but is not limited to the data provided through satellite telecommunications, satellite navigation systems and space-based search and rescue. These SatCom systems provide data to enhance the development of the utilization of SatCom data within the Canadian government. Examples of data are those provided by the Automatic Identification System (AIS), the Global Positioning System (GPS) and Galileo, and the Ka-band communications satellite for innovative and advanced public services in Northern Canada. It is expected that M3MSat, a government owned satellite, will be a source of AIS data when it becomes fully operational. There will also be an AIS payload on each of the three RCM satellites, providing AIS data to GoC organizations.

This SSA has concentrated its activities around the industry stakeholder in order to enhance its ability to use SatCom space-based solutions. By funding activities and data accessibility this activity supports innovation and provides for the development by the Canadian private sector of SatCom applications for use by GoC organizations and by the private sector more generally. Support for application development provided by this type of activity will also contribute indirectly to the development of an internationally competitive Canadian SatCom data utilization industry.

Resources are allocated in this SSA to the development of the utilization of data and information from future Canadian missions. As for FY15-16, financial and human resources are allocated to AIS data related projects so that GoC organizations are prepared to use the full potential of the new capabilities of this data source.

Spectrum management is performed under this SSA for securing the proper frequency spectrum necessary to monitor and control CSA satellites (Tracking, Telemetry and Command TT&C), to make use of the instrument/payload on-board CSA satellites and to retrieve the valuable data from the satellites to the ground station. Also, spectrum management allows for the protection of current and future CSA space missions from potential harmful interferences from frequency transmissions of other terrestrial or space systems which use frequency spectrum similar to the ones used by CSA.

Finally, participating in GoC and international working groups, and creating and managing agreements and contracts are also activities and outputs in this group of SSA's.

Communications and Outreach

The aim of this activity is to ensure that GoC organizations are aware of the opportunities provided by SatCom space products and services and are guided, when appropriate, on how to best benefit from these opportunities. Communications or outreach can take many forms but the privileged means is the organization of information sessions to demonstrate space products and services with presentations. The number of outreach activities depends on CSA's human resources availability, GoC organizations need for information and support, and on the maturity of space products and services.

Immediate Outcomes

SatCom missions provide GoC organizations with space communication services (Result of SSA 1.1.1.2) [Responsible: Director Space Utilization Development];

This immediate outcome results from the definition, design, technology development and implementation of SatCom satellites dedicated to producing data or information for communications services, ranging from search and rescue operations, navigation systems and relevant and timely communications links contributing to the protection and safety of lives across a vast geographical area. This outcome includes continuous operations and is necessary to produce pertinent SatCom data that assist with the mandate delivery of GoC organizations that deal especially with key national priorities, such as safety and security, natural resources and energy, and environment and agriculture Services.

CSA's satellites are functioning as per operational requirements; foreign satellites missions are supported (SSA 1.1.2.1) [Responsible: Director, Satellite Operations, Infrastructure and Applications];

This outcome results from the development of an integrated and coordinated national system of ground infrastructure to receive data from domestic or foreign satellites is in place. In addition, the ground infrastructure houses and uses the equipment required for satellite operations. This outcome is the operation of satellites as well as making available space-based data received by the Canadian Space Agency to assist GoC organizations in delivering their mandate.

Satellite data is provided to GoC organizations and Academia (SSA 1.1.2.2) [Responsible: Director, Satellite Operations, Infrastructure and Applications]

This outcome includes a coordinated national approach to establish space data acquisition and handling facilities in their optimal location and capabilities. This outcome results from the planning and tasking of data acquisition, as well as the capture, calibration, validation, cataloguing, archiving and availability of space data received from domestic or foreign satellites to assist GoC organizations in delivering their mandate. This outcome includes evidence-based management of data utilization by accomplishing the systematic verification and monitoring of data consumption by type for the use by GoC organizations.

The ability of GoC organizations and the Canadian Industry to turn SatCom data into useable products is enhanced [Responsible: Director Space Utilization Development], [Responsible: Director, Satellite Operations, Infrastructure and Applications] (SSA 1.1.3.2).

This outcome is the utilization of SatCom data acquired from Canadian and foreign space assets and includes the broadening of the applicability of currently available SatCom space products and satellite services (optimization) or the creation of new ones (innovation) for the user community (GoC organizations and industry).

Increased awareness of SatCom potential

Through Communications and Outreach activities carried out at CSA, supported by subject matter experts in the Space Utilization branch, the aim of this immediate outcome ensures that GoC organizations are aware of the potential impact of SatCom activities on their programs and services. This is done through the demonstration of space products and services by making presentations in technical and non-technical forums.

Intermediate Outcomes

GoC organizations are using satellite generated space data and services to deliver on their mandate. (Result of SA 1.1.1). [Responsible: Director, Space Utilization Development and Director, Satellite Operations, Infrastructure and Applications]

This intermediate outcome results from the development of complete Canadian satellite systems or sub-systems, payloads, instruments or other components provided to domestic and foreign satellites and results in GoC organizations using the data and services generated to deliver on their mandate. The activities leading to this outcome also includes the development of advanced technologies that could enable or determine the nature of potential new SatCom satellite missions to provide improved data and services to GoC organizations. The outcome is that GoC organizations use satellite generated data and information to deliver their mandate. Canadian capacity is also demonstrated by this outcome.

Expressed Canadian and foreign data needs are fulfilled by reliable national ground infrastructure (PMF 1.1.2). [Responsible : Director, Satellite Operations, Infrastructure and Applications]

This intermediate outcome is the development of an integrated and coordinated national system of ground infrastructure to receive data from domestic or foreign satellites. In addition, the ground infrastructure houses and uses the equipment required for satellite operations. This outcome is the capability to operate satellites and to process and make available space-based data received by the Canadian Space Agency to assist GoC organizations in delivering their mandate.

GoC organizations are using space based solutions to deliver on their mandate (PMF 1.1.3) [Responsible: Director, Satellite Operations, Infrastructure and Applications].

This intermediate outcome is the development of the utilization of space-based data and information, and of communications services available on space assets for the benefit of the user community, primarily GoC organizations. The outcome is an increase in the ability of GoC organizations to use space-based solutions (applications, models, algorithms) for the delivery of their mandate and to foster the development of a Canadian value-added industry. This activity has traditionally been mostly focused on CSA missions.

Ultimate Outcomes

The GoC offers more diversified or cost-effective programs and services due to their utilization of space-based solutions (PMF 1.1) [Responsible: DG Space Utilization]

The ultimate outcome of the SatCom Business line is to provide space-based solutions (data, information and services) and foster the progression of their utilization. It also serves to install and run ground infrastructure that processes the data and operates satellites. This Program utilizes space-based solutions to assist Government of Canada (GoC) organizations in delivering growing, diversified or cost-effective programs and services within their mandate, which is related to key national priorities, such as sovereignty, defense, safety and security, and protection of Canadian interests in the North.

Appendix B: Bibliography

BCE Inc. (2005, March 24). Telesat pioneers next-generation EMS technology on Anik F2 satellite. Retrieved from http://www.bce.ca/news-and-media/releases/show/telesat-pioneers-next-generation-ems-technology-on-anik-f2-satellite

CCG. (2017, December 14). Marine Security Operations Centres (MSOC). Retrieved from http://www.ccg-gcc.gc.ca/eng/CCG/Maritime-Security/MSOC

CISION. (2010, June 9). exactEarth space-based AIS data makes contribution to security efforts for 2010 Olympics and Paralympics. Retrieved from https://www.newswire.ca/news-releases/exactearth-space-based-ais-data-makes-contribution-to-security-efforts-for2010-olympics-and-paralympics-544186182.html

Ciuriak, D., & Curtis, J. M. (2013). The Resurgence of Industrial Policy and What it Means for Canada. *IRRP Insight*, *2*. Retrieved from http://irpp.org/research-studies/insight-no2/

CSA. (2014a). *Canada's Space Policy Framework: Launching the Next Generation*. St-Hubert. Retrieved from http://www.asc-csa.gc.ca/pdf/eng/publications/space-policy/canadas-space-policy-framework.pdf

CSA. (2014b). *Evaluation of the CASSIOPE Contribution Program*. Retrieved from http://www.asc-csa.gc.ca/eng/publications/er-1314-0201.asp

CSA. (2014c, June 20). Polar Communication and Weather mission (PCW). Retrieved from http://www.asc-csa.gc.ca/eng/search/video/watch.asp?v=1_90abnser

CSA. (2015a). *Evaluation of the International Market Access Program (Comprising the European Space Agency Contribution Program) of the Canadian Space Agency*. St-Hubert. Retrieved from http://www.asc-csa.gc.ca/eng/publications/er-1415-0202.asp

CSA. (2015b). *Space-Based Automatic Identification System (S-AIS) in Canada: Final Report*. St-Hubert.

CSA. (2015c, March 25). CASSIOPE: Observing Space Weather with a Hybrid Satellite. Retrieved from http://www.asc-csa.gc.ca/eng/satellites/cassiope.asp

CSA. (2016a). *Departmental Performance Report 2015-16*. Retrieved from http://www.asc-csa.gc.ca/pdf/eng/publications/pr-2016.pdf

CSA. (2016b). Performance Measurement Strategy - Satellite Communications Missions Business Line.

CSA. (2016c, June 21). Building the Next-Generation Space Antenna. Retrieved from http://www.asc-csa.gc.ca/eng/blog/2016/06/21/building-the-next-generation-space-antenna.asp

CSA. (2017a). *Departmental Plan Sub and Sub-Sub Programs 2017-18*. Retrieved from http://www.asc-csa.gc.ca/pdf/eng/publications/dp-2017-2018-sub-programs.pdf

CSA. (2017b). *State of the Canadian Space Sector 2014*. Retrieved from http://www.asc-csa.gc.ca/eng/publications/2014-state-canadian-space-sector.asp

CSA. (2017c, May 18). Maritime Monitoring and Messaging Microsatellite (M3MSat). Retrieved from http://www.asc-csa.gc.ca/eng/satellites/m3msat/Default.asp

CSA, & DRDC. (2007). *Maritime Monitoring & Messaging Micro-Satellite (M3MSat) Project: Joint Implementation Plan (JIP)*.

DND. (2012, January 17). Canada's Participation in the Wideband Global Satellite Communications System. Retrieved from http://www.forces.gc.ca/en/news/article.page?doc=canada-rsquo-s-participation-in-the-wideband-global-satellite-communications-system/hgq87xyn

DND. (2013, November 7). Polar Eplison Project. Retrieved from http://www.forces.gc.ca/en/news/article.page?doc=polar-epsilon-project/hnps1uo5

DND. (2014, January 30). Space Situational Awareness and the Sapphire Satellite. Retrieved from http://www.forces.gc.ca/en/news/article.page?doc=space-situational-awareness-and-the-sapphire-satellite/hr0e3oag

DND. (2015, March 12). Mercury Global - Strategic Deployable Terminals. Retrieved from http://www.forces.gc.ca/en/business-defence-acquisition-guide-2015/joint-and-other-systems-178.page

DND. (2016a). *Strategic Context Document: Enhanced Satellite Communication Project – Polar (ESCP-P)*. Ottawa.

DND. (2016b, May 26). Enhanced Satellite Communication Project. Retrieved from http://www.forces.gc.ca/en/business-defence-acquisition-guide-2016/joint-and-other-systems-444.page

DND. (2017). Strong, Secure, Engaged: Canada's Defence Policy. Retrieved from http://dgpaapp.forces.gc.ca/en/canada-defence-policy/docs/canada-defence-policy-report.pdf

ESA. (2010, August 2). AIS on ISS. Retrieved from http://www.esa.int/Our_Activities/Space_Engineering_Technology/AIS_on_ISS

ESA. (2018). ARTES Advanced Technology. Retrieved from https://artes.esa.int/advanced-technology

Euroconsult. (2010). *Maritime Telecom Solutions by Satellite: Global Market Analysis & Forecasts*.

Euroconsult. (2012). *Study of the socio-economic benefits related to improved communications and weather services in the Arctic/North delivered by the Polar Communications and Weather (PCW) Mission*. Montréal.

Euroconsult. (2013a). *Government Space Markets: World Prospects to 2022* (pp. 1–220). Paris, France.

Euroconsult. (2013b). *Government Space Markets: World Prospects to 2022* (pp. 1–220). Paris, France.

exactEarth. (2015, June 23). Preliminary Prospectus. Retrieved from https://www.sedar.com/DisplayCompanyDocuments.do?lang=EN&issuerNo=00037341

Friesen, J. (2014, June 6). Surveillance aircraft played key role capturing Bourque. *The Globe and Mail*. Retrieved from https://www.theglobeandmail.com/news/national/surveillance-aircraft-played-key-role-in-bourque-search/article19059589/

Gainor, C. (2012, September 6). Alouette 1 – Celebrating 50 Years of Canada in Space. *SpaceQ*. Retrieved from https://spaceq.ca/alouette_1_celebrating_50_years_of_canada_in_space/

Government of Canada. (2014, May 22). Global Navigation Satellite Systems. Retrieved from https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf10805.html

Government of Canada. (2015, November 12). Minister of National Defence Mandate Letter. Retrieved from https://pm.gc.ca/eng/minister-national-defence-mandate-letter

Government of Canada. (2016a, June 17). Polar Epsilon 2 Project: Backgrounder. Retrieved from https://www.canada.ca/en/department-national-defence/news/2016/06/polar-epsilon-2-project.html

Government of Canada. (2016b, July 1). Directive on Results. Retrieved from https://www.tbs-sct.gc.ca/pol/doc-eng.aspx?id=31306

Government of Canada. (2016c, July 1). Policy on Results. Retrieved from https://www.tbs-sct.gc.ca/pol/doc-eng.aspx?id=31300

Government of Canada. (2017a). Canada's Innovation and Skills Plan. Retrieved from https://www.budget.gc.ca/2017/docs/themes/Innovation_en.pdf

Government of Canada. (2017b, May 2). Polar Epsilon 2. Retrieved from https://www.ic.gc.ca/eic/site/086.nsf/eng/00042.html

Government of Canada. (2018, February 27). Equility and Growth: A Strong Middle Class (Budget 2018). Retrieved from https://budget.gc.ca/2018/docs/plan/budget-2018-en.pdf

International Marine Organization. (2018). AIS transponders. Retrieved from http://www.imo.org/en/OurWork/safety/navigation/pages/ais.aspx

ISRO. (2016, June 22). PSLV-C34 Successfully Launches 20 Satellites in a Single Flight. Retrieved from https://www.isro.gov.in/update/22-jun-2016/pslv-c34-successfully-launches-20-satellites-single-flight

MDA. (2016a, January 7). MDA to provide communication subsystems for O3B Satellites. Retrieved from https://mdacorporation.com/news/pr/pr2016010701.html

MDA. (2016b, June 1). MDA to build antennas for the OneWeb Constellation. Retrieved from https://mdacorporation.com/news/pr/pr2016060101.html

NASA. (2017, February 2). Space Technology Announcement of Collaboration Opportunity. Retrieved from https://nspires.nasaprs.com/external/viewrepositorydocument/cmdocumentid=572607/solicitationId=%7BE4466534-6C43-2367-5E53-EE2165C396C2%7D/viewSolicitationDocument=1/NNH17ZOA001K%20Solicitation%20(Revised%20May%2030,%202017).pdf

National Research Council. (1989). *NASA Space Communications R&D: Issues, Derived Benefits, and Future Directions*. Washington, D.C.

Norwegian Space Centre. (2018). Norway's Satellites. Retrieved from https://www.romsenter.no/eng/Norway-in-Space/Norway-s-Satellites

OneWeb. (2018). Satellites Make It All Possible. Retrieved from http://www.oneweb.world/#solution

ORBCOMM. (2017, February 28). ORBCOMM's Partner Maerospace Awarded Multi-Year Contract for Canadian Government. Retrieved from https://www.orbcomm.com/en/company-investors/news/2017/orbcomm-partner-maerospace-awarded-multi-year-contract-canadian-government

Pace, S., Frost, G. P., Lachow, I., Frelinger, D. R., Fossum, D., Wassem, D., & Pinto, M. M. (2005). *The Global Positioning System: Assessing National Policies*. Rand Corporation. Retrieved from https://www.rand.org/pubs/monograph_reports/MR614.html#relatedProducts

Parliamentary Committee on Science and Technology. (2016). *Satellites and space*. U.K. Parliament. Retrieved from https://publications.parliament.uk/pa/cm201617/cmselect/cmsctech/160/16002.htm

PSPC. (2017, December 4). Request for Information (W6369-180123/A): Enhanced Satellite Communication Project - Polar. Retrieved from https://buyandsell.gc.ca/procurement-data/tender-notice/PW-ST-046-32020

Pugliese, D. (2017, March 19). U.S. military satellite, funded in part by Canada at a cost of $340 million, now launched. *Ottawa Citizen*. Retrieved from http://ottawacitizen.com/news/national/defence-watch/u-s-military-satellite-funded-in-part-by-canada-at-a-cost-of-340-million-now-launched

PWGSC. (2013, November 1). Polar Communications and Weather (PCW) Project / Projet de Télécommunications et de météorologie en orbite polaire - Request for Information.

Space Advisory Board. (2017). *Consultations on Canada's Future in Space: What We Heard*. Ottawa. Retrieved from https://www.ic.gc.ca/eic/site/ad-ad.nsf/eng/ad03996.html

SSGP. (2016). *Sara Huntingdon, SSGP Manager, UK Space Agency - Introduction at SSGP Showcase 2016* [Video]. Retrieved from https://www.youtube.com/watch?v=faJAXcQZS40

Status of Women Canada. (2017, May 25). Gender-Based Analysis Plus. Retrieved from http://www.swc-cfc.gc.ca/gba-acs/index-en.html

Telesat. (2018). Telesat LEO – Transforming Global Communications. Retrieved from https://www.telesat.com/services/leo

Transport Canada. (2012, May 5). Interdepartmental Marine Security Working Group. Retrieved from https://www.tc.gc.ca/eng/marinesecurity/partnerships-285.htm

Trendall, S. (2017, December 14). UK Space Agency to offer public sector workers crash course in satellite applications. *Public Technology.Net*. Retrieved from http://www.publictechnology.net/articles/news/uk-space-agency-offer-public-sector-workers-crash-course-satellite-applications

UK Space Agency. (2015). *UK Space Innovation and Growth Strategy: 2015 Update Report*. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/444918/_SPACE-IGS_report-web-JJF-V2.0.pdf

UK Space Agency. (2017). Space for Smater Government Programme. Retrieved from http://www.spaceforsmartergovernment.uk/about-us/

US Department of Defense. (2008). Global Positioning System: Standard Positioning Service Performance Standard. Retrieved from https://www.gps.gov/technical/ps/2008-SPS-performance-standard.pdf

Vachon, P. W., Kabatoff, C., & Quinn, R. (2014). *Operational Ship Detection in Canada Using RADARSAT*. Presented at the 2014 IEEE International Geoscience and Remote Sensing Symposium, Québec City. Retrieved from http://ieeexplore.ieee.org/document/6946595/