The Australian Space Agency's inaugural Space Situational Awareness technology roadmap: Context, methodology and learnings

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ABSTRACT

The space sector has undergone a significant evolution over the last several years, with space becoming more affordable and accessible. Well established actors have been joined by private entities, creating new opportunities as well as major challenges. The coming decade will show an even more substantial change, as large satellite constellations will add thousands of new satellites to those already in orbit. This evolution, in players and numbers of satellites in space, puts sustainable use of space and its regulation at the forefront of international discussions.

Although Australia has a deep legacy of space activity, the Australian Space Agency (the Agency) is a young agency emerging in a new space era. The purpose of the Agency is to coordinate civil space matters across government and to grow a globally respected Australian space industry that lifts the broader economy, inspires and improves the lives of Australians. As part of its strategy, the Agency is developing the Space Situational Awareness (SSA) and Debris Monitoring roadmap.

This paper outlines the SSA roadmap approach, providing the details of each phase, from implementing the Technical Advisory Group, identifying market gaps and opportunities, to setting targets and a pathway to achieve the SSA roadmap vision and ambition.

1. INTRODUCTION

The space industry has gone through an incredible growth in recent years. With the increased presence of private entities and historical institutions, space as a platform is constantly evolving to become a more affordable and accessible endeavour. This transformation creates new opportunities, however also generates major challenges. A dramatic shift towards heightened activity in space is expected during the next decade. In 2020 alone, more than 1,200 small satellites were launched into space, and, in the coming years, thousands of satellites are expected follow in the form of large constellations [1]. The number of satellites that exist in orbit and the players that contribute to this will rise heavily, bringing forth the conversation of the sustainable use of space and its regulation to the international stage.

Focus and a sustained nationally coordinated effort are pivotal to facilitate the potential growth of Australia's space sector. The Australian Space Agency (the Agency) was established to provide this national focus, and to create and sustain the conditions necessary to grow this sector.

This paper outlines the Space Situational Awareness (SSA) and Debris Monitoring Space Priority Area (SPA) within the Australian Civil Space Strategy 2019-2028 and the associated roadmap development (hereafter referred to as the SSA roadmap) [2]. The paper will include an overview of the context, methodology and opportunities the roadmap aims to address with the next steps outlined.

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2. CONTEXT: AGENCY STRATEGY AND ROADMAP METHODOLOGY

2.1 The Australian Civil Space Strategy

The Australian Civil Space Strategy "*Advancing Space*" provides a 10-year strategy for the Australian space sector's growth and development [2]. The Strategy is built on four Strategic Space Pillars:

- Open the door internationally
- Develop national capability in areas of competitive advantage
- Ensure safety and national interest are addressed
- Inspire and improve the lives of all Australians

Seven Australian Civil Space Priority Areas (SPAs) are identified in the Agency's Space Strategy:

1. Communications Technologies and Services
2. Earth Observation
3. Robotics and Automation on Earth and in Space
4. Leapfrog Research and Development
5. Space Situational Awareness and debris monitoring
6. Position, Navigation and Timing
7. Access to space

The SPAs are all interconnected, rely on cross-cutting technology areas, facilitated by non-technical activities, and may be applied to multiple cross-cutting services. For each of the SPAs, the Agency is developing a roadmap to outline capability targets and potential pathways in these priority areas over the next decade. The first SPA roadmap, *Communications Technologies and Services*, was released by the Agency in December 2020, with the remaining SPA roadmaps anticipated to be released from 2021 [3].

2.2 The Agency roadmaps development methodology

This section outlines the roadmap approach, providing the details of each phase, from implementing the Technical Advisory Group, identifying market gaps and opportunities, to setting targets and a pathway to achieve the SSA roadmap vision and ambition. The roadmap methodology adopted by the Agency is built on a robust consultation process with industry, academia, government agencies and international counterparts. In order to outline the unique capabilities that Australia contains, there are four roadmap development phases [4].

2.2.1 Phase 1: Assess opportunity

Australia's key strengths within the international market are identified through state-of-the-art assessment, which are then evaluated. The ecosystem and value chain are then examined to find potential and growth for Australia through spin-in technologies from adjacent fields, market gaps, application needs and strategic value. Factors such as competitive advantages, capabilities and gaps are identified and assessed, alongside opportunities, risks and barriers.

2.2.2 Phase 2: Set targets

A strategic direction is created in order to look to and beyond 2030, outlining the vision and the ambitions for Australia's future capabilities and roles. The vision serves as an aspirational statement whereas the ambition is a positional

Focus segments aim to achieve the vision and ambition, and are highlighted according to the SPA-related opportunities they bring for the next ten years of the Australian space industry. These opportunities also shape the identification of objectives (sub-visions), outcomes (sub-ambitions) and capability targets.

2.2.3 Phase 3: Devise pathways

A plan of action to fulfil these targets and objectives is realised and highlighted through the roadmap pathways diagram. This diagram outlines an action plan for the Australian space sector to achieve the roadmap's objectives. The Agency, where appropriate, may facilitate the progression of the pathways.

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Factors such as capabilities and external drivers are mapped alongside core paths towards the targets, in order to understand the scope of the coming years. According to their impact on the ability to reach these targets, these factors should be captured or mitigated.

2.2.4 Phase 4: Enable implementation and monitor progress

Though the roadmaps will be updated regularly to reflect the developing nature of the industry, they aim to guide economic growth through investment into the Australian space sector and inform Australian Space Agency activities. As more targets and capabilities are realised, the more contribution that is made towards the goals shared by the Australian Government to grow the industry. Progress will be tracked through State of Space reports and other publications.

3. CONSIDERATIONS FOR THE SSA ROADMAP

3.1 Defining space situational awareness

For the context of the roadmap, the Agency defines Space Situational Awareness (SSA) as the understanding of the space environment, the objects in it and the influences that act upon it, such as solar wind. It is crucial that users of the space environment have an awareness of their own activities and of other activities to ensure sustainable, safe and secure operations for all.

Space Traffic Management (STM) is considered a subset of SSA within the roadmap and includes the coordination observations and actions to reduce hazards in space for satellites, humans and spacecraft. STM is a multi-disciplinary field that includes technologies used for decision making as well as regulatory frameworks and global collaboration aimed at the responsible use of space.

Space is a dual-use environment with both military and civilian assets and activities. As Defence considers space as an operational domain, Space Domain Awareness (SDA) is a terminology used by Defence, who requires additional elements of consideration for the safety of Australia and its interests. The SSA roadmap is developed in consultation with Defence to ensure a coordinated approach to common civil factors.

The SSA roadmap is intended for all Australian SSA stakeholders, including industry, government agencies, researchers, the future workforce, investors and international partners; it provides a strategic direction for the sector, and informs and guides opportunities to support the growth of the industry.

3.2 Growing concerns

As the use of space increases, a range of new issues are to be managed and considered, this includes increasing our understanding of objects and debris in orbit, monitoring the effects of space weather, and avoiding collisions in space.

With approximately 29,000 debris objects currently being tracked through global Space Surveillance Networks, there are millions of pieces of varying sizes that are not accounted for [5]. The catalogued pieces of debris only account for 0.02% of the estimated number of debris [5]. Factors such as space weather and Near-Earth Objects (NEOs) also add to the ecosystem that exists around Earth, the Moon and Mars, and impact space activities.

3.2.1 Human-made factors

The increased human activity in space contributes heavily to SSA, with satellite collisions, discarded rocket bodies, inoperable satellites and lost items contributing to the generation of space debris. The impact of a collision with an active satellite can result in functional damages ranging from capability reduction to complete loss of the asset. Additionally, these collisions could lead to a cascading effect (known as the Kessler syndrome) rendering space activities in a given orbital range difficult to untenable for years to decades.

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Low Earth Orbit (LEO) is an orbit with a maximum altitude of 2,000 km and is the most congested orbit containing approximately 15,000 pieces of space debris [6]. LEO hosts satellites ranging in size and mass from CubeSats to the International Space Station (ISS). The risk of collision in LEO is increasing and the severity of impact can cause low to significant damage to the asset which could render the asset incapacitated, including endangering human life in the case of the ISS.

The chance of collision decreases in Medium Earth Orbit (MEO) with significantly less traffic, approximately 500 objects, made up of both debris and functional satellites [6]. MEO ranges in altitude between 2,000 km and just below 36,000km, where the Global Navigation Satellite System (GNSS) constellations are located (e.g. GPS, GLONASS, Galileo, BeiDou).

GEO is approximately 36,000 km from the Earth's surface and is the mainstay orbit for communication and meteorological satellites. There are approximately 900 objects in this orbit including debris and active satellites which is nearly double that of MEO [6]. A large number of debris crossing the orbital slots are highly elliptical objects such as rocket boosters or residual objects from past fragmentations. The impact of space weather at this altitude includes solar radiation and radio blackouts causing satellite failure. There is potential for future capabilities in the area of rendezvous or in-orbit servicing which will add to the collision risk in the coming years.

3.2.2 The natural space environment

The natural space environment including space weather and Near Earth Objects (NEOs) impacts the sustainability of objects in space. With increasing satellite launches, human space flight and a solar maximum expected in the coming decade, understanding, modelling, predicting and monitoring the natural space environment will provide confidence, protection and decision support for Australian space assets.

Space Weather

The Sun is the principal driver of what is known as space weather. The study of space weather ranges from understanding the sun's mechanics that drive Coronal Mass Ejections (CMEs), particle radiation and solar flares, to the impact on the Earth's magnetosphere, ionosphere, satellites and ground infrastructure.

Space weather can affect the near-Earth space environment by:

- Varying the Earth's magnetic field
- Enhancing electrical fields and currents in the atmosphere and the ground
- Increasing the amount of radiation entering the upper atmosphere
- Varying the density and stability of the upper atmosphere.

These can damage satellites and the services they provide, cripple ground infrastructure and prove hazardous to humans in space flight. Variations in the Earth's ionosphere create variable drag on objects in LEO, changing orbits and making conjunction analyses more complicated and uncertain. For re-entry events, this causes uncertainty in the location of terrestrial impact.

The Sun undergoes a semi-regular cycle of magnetic activity. The period of the cycles is typically about 11 years. The past three years have been benign because of solar minimum conditions, but solar activity is currently increasing towards solar maximum predicted to occur in 2025. As the frequency of solar storms increases, the space radiation environment will become more dangerous for satellites and people. The radiation environment causes numerous satellite anomalies and sometimes the complete failure of satellites and payloads.

Major solar storms heat the Earth's upper atmosphere, causing it to expand to greater heights, increasing the drag on satellites in LEO, and deorbiting them prematurely. During severe solar storms, the locations of thousands of objects are lost due to the unforeseen changes in their orbits. The loss of tracking is a high-risk condition for collisions. When recovered, satellites must expend fuel to manoeuvre and maintain correct orbits.

Disturbances in the Earth's upper atmosphere driven by space weather can also affect the availability and integrity of satellite communication, internet, and positioning systems (e.g. GPS). Hence space weather impacts services provided to industry on Earth.

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Near Earth Objects
One million asteroids are currently known and close to 25,000 are considered NEOs. On average, an asteroid will pass between the Earth and Moon once per week. Approximately 2,100 NEOs are considered Potentially Hazardous Asteroids (PHAs), being larger than ~140 metres, and having orbits coming within 7.5 million km (about 20 lunar distances) of the Earth. The Tunguska event of 1908 and the Chelyabinsk Event of 2013 are reminders of the dangers posed by asteroids and comets.

Australia's dark skies in the outback offer the appropriate environment for the detection of faint NEOs and PHAs using modest telescopes.

3.3 Growing the Australian SSA Industry

There is an opportunity for Australia to develop technologies and provide trusted SSA information to enable a responsible use of space while growing its space sector. A multidisciplinary approach will combine technology maturation, both ground and space based, with regulatory and coordination levers.

Australia has potential to provide a nationally coordinated SSA community supporting its own responsible use of space and setting a benchmark for other emerging space nations. As a trusted international partner contributing to the global technical effort, Australia seeks to have a strong voice in the development of international coordination for long term sustainability in space.

The roadmap will be guiding the opportunities pursued for Australian space sector, with high potential to deliver to the market with competitive and comparative advantage over the next decade. With both human-made events and the natural space environment to consider, there is potential to explore various areas, including observation, sensing and gathering data. The scope of the roadmap will explore the importance of regulation and standards across all facets of SSA and highlight the notable technologies, painting a picture of the Australian SSA market in whole.

Noting the evolving nature of the field, the roadmap will be revisited approximately every 2 years to ensure that the current state of the industry is accurately reflected.

3.4 Highlighted opportunities

The Agency has identified several areas of opportunities for Australia's industry to contribute to the SSA ecosystem and grow the sector.

3.4.1 Debris mitigation through spacecraft design

Consideration of key design aspects can mitigate unintentional debris creation and provide a safe, responsible path forward for the lifecycle of the spacecraft. With the growing risk of collision in space, and expected additional regulation, developing, testing and operationalising innovative technologies to tackle the main debris creation processes (e.g. fragmentation due to failed passivation, general failure preventing effective deorbiting) will have the most impact.

3.4.2 Accurate and timely sensing of debris and spacecraft

The increasing number of objects and continuous manoeuvres in space has grown beyond the current global SSA system's capacity to detect and monitor continuously. More sensors are needed that can monitor LEO, GEO and the untapped markets such as equatorial and polar orbits to support the emerging commercial activities around the Earth and Moon. Australia's geographic location, electromagnetically quiet environment and stable weather conditions, together with world class capabilities, provide the foundation for a scalable network of sensors, becoming a trusted exportable asset.

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3.4.3 Understanding the natural space environment

With increasing satellite launches, human space flight and a solar maximum expected in the coming decade, understanding, monitoring, modelling, and predicting the natural space environment will provide confidence, protection and decision support for Australian space assets.

3.4.4 National collaboration and architecture

Generating accurate and timely information that adds value to the sensor data requires a system that integrates large datasets for curation and processing. A flexible system integration architecture enables data sharing, sensor tasking and development of services to coordinate the generation of data from multiple sensors and the secure dissemination of information between Australian and international space operators.

3.4.5 Data fusion and analytics

Data fusion and analytics enhance the value of the sensing segments and system integration architecture. Fusing SSA data across a suite of sensors, models and other information sources enables users to make decisions using tools such as those which provide alerts of likely collisions and options for satellite manoeuvres. Additionally, human-led analysis is likely to be insufficient to cope with the growing number of objects in space and the corresponding SSA data produced for continuous monitoring, creating a need for innovative solutions including Artificial Intelligence.

3.4.6 Regulation to support the industry

Regulation is a critical pillar of sustainable space activities. Developing a supportive and transparent regulatory approach, both nationally and internationally, will support a confident and responsible industry. Establishing norms, requirements and standards for sustainable and responsible behaviour in space will create clarity for space operators' project planning and activities. It will also generate clear market opportunities for SSA service providers, supporting investment planning. This approach includes a considered and appropriate implementation of the Guidelines for the Long-term Sustainability of Outer Space Activities (LTS Guidelines), from reviewing the licensing and permit process to adopting new operations procedures.

3.4.7 National coordination

With space traffic conditions becoming more congested, the modern operational environment requires not only monitoring but national and international coordination. Currently successful commercial entities remain dependent on Government direction and funding, using a range of mechanisms including purchasing of sensors, data, or services to address their SSA needs.
There is an opportunity for Australia to coordinate its SSA activities through strategic planning, to support national goals and help SSA industry to thrive nationally and internationally.

4. **NEXT STEPS**

The roadmap is expected to be completed by the end of 2021, with the implementation phase beginning in 2022. The national and international SSA community will be a part of shaping the future of SSA in Australia and implementing the roadmap to ensure a safe and sustainable space industry.

5. **CONCLUSION**

SSA and STM activities go beyond sensors, they require robust policy and legal frameworks, coordinating efforts both nationally and internationally, to achieve safety and sustainability in space.

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The Agency aims to empower and guide the Australian space sector, through a roadmap outlining the vision and ambition the Agency has identified for SSA, and, which will be delivered through the pathways specific to capability targets.

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