CENTER FOR GLOBAL DEVELOPMENT

HANDBOOK FOR SPACE CAPABILITY DEVELOPMENT

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Contents

Figures

Boxes

Tables

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BY THE PRESIDENT OF THE CENTER FOR GLOBAL DEVELOPMENT

Foreword

Given the numerous problems countries are facing both individually and across borders in the slow recovery from COVID-19, many policymakers might wonder why space should be a priority for them. However, as this Handbook shows, many countries are already using space technology like satellites, but these countries often lack a well-defined space strategy. The Handbook makes the case that satellites and space-related technology should be thought of as another type of modern infrastructure, like roads or power. For a country with even a modest space program, access to and the use of satellites can enable key objectives and global goods—such as meeting the Sustainable Development Goals, peaceful use of space and space sustainability, security, and other common interests at the national, regional, and global level.

Space is not out of reach for low- and middle-income countries. As this Handbook lays out, a country's space policy strategy does not need to be grand and can be stepped up as levels of preparedness and capacity grow. The Handbook also explains why space is relevant, what is meant by "space capable," and how to build a sustainable space program.

This work is worth reading and thinking about because, first, countries need to realize the full potential of space technology to reduce poverty, increase well-being, and improve security, health, and education. Second, the steps outlined are practical and based on capacity and level of ambition. These steps bridge the gap between the idea of technology—specifically space technology—and tangible, on-Earth development.

Masood Ahmed
President
Center for Global Development

BY THE PRESIDENT OF THE SECURE WORLD FOUNDATION

Foreword

The Space Age began on October 4, 1957 with the launch of Sputnik, the first satellite to orbit the Earth. In the years that followed, space activities were dominated by the two Cold War rival superpowers, the United States and the former Soviet Union. Space activities were seen as the exclusive preserve of a few technologically advanced nations. However, in the decades that followed, more and more countries began to acquire space capabilities, and gradually those capabilities started to deliver tangible benefits to the citizens of those countries. These trends have continued, to the point where today more than 90 countries have launched or operated at least one satellite in space. Most of these countries have entered the space arena within the last 20 years as the financial and technological barriers to accessing space have been lowered by the advent of the commercially available off-the-shelf space technologies. This has led to an exponential growth in the number of active satellites in space in recent years. As of the start of 2023, there were more than 7,000 active satellites in orbit delivering services and benefits to citizens in every country on the globe.

Becoming a space-capable nation is a complex, multi-year endeavor that requires building coalitions across a wide spectrum of actors from government, industry, and civil society. Often a country's first steps into the space arena begin with building and launching a small satellite, and indeed a small satellite program can serve as a motor for developing a national space arena, but this must be purposefully managed from the start if the national space ecosystem is to be sustainable. If a satellite project is implemented in a policy and regulatory vacuum, and if there are no tangible societal benefits, then the space activity will not be sustained beyond the lifetime of the given mission. This is why it is so important to focus on building and sustaining a broad spectrum of national space capabilities that allow a country to access and use space-derived information and services for national development, instead of focusing narrowly on a series of satellite missions carried out in a policy and strategy vacuum, which inevitably leads to a vicious cycle of the acquisition, degradation, loss and subsequent costly rebuilding of capabilities and human capital previously acquired.

This book provides valuable guidance to those taking their first steps to develop the space arena in their countries. The book is essentially a guide on how to build a sustainable space sector through an incremental approach. It begins with a review of the societal benefits of space activities. It then defines the spectrum of space capabilities that a country may wish to develop and provides practical advice on how to develop those space capabilities. The discussion of concepts is supported with helpful illustrative use-case presentations and a guide to further reading. If you are in the position of starting to develop the space arena in your country, this book is for you!

Peter Martinez
President
Secure World Foundation

Executive Summary

The *Handbook for Space Capability Development* is an inclusive, pragmatic, and open-access resource focused on "foundational space capability" development. Its intended audience is the planner or planning team charged with drafting a national space strategy and building a national space program. Among its goals are to make a case for *why* all governments should establish a foundational space capability, to discuss *what* such a program might look like in real terms, and to suggest an approach for *how* to conduct early program design. The resulting foundational program, office, and strategy will be sustainable in scale, scope, and growth and will enable a country to

- Protect existing dependencies on space.
- More fully leverage existing space capabilities and applications.
- Encourage the growth of a local data and space ecosystem.
- Attract international and public-private collaboration and investment.
- Contribute to the development of norms and laws governing space.

WHY SPACE?

In short, satellites underpin telecommunications, utilities, financial institutions, and other elements of global daily life. If leveraged fully, satellites (Figure ES.1) can also accelerate economic growth, build resilience against natural and human-made disasters, and enable every one of the United Nations'

FIGURE ES.1 Types of satellites

Navigation satellites

GPS, one of five systems of satellites (or "constellations"), provides crucial position, navigation, and timing data for banks, utilities, transportation, and telecommunications networks.

Communications satellites

Communications satellites have evolved into a key segment of the global telecommunications infrastructure, one that is especially useful for connecting remote, difficult, landlocked, or sparsely-populated regions.

Remote sensing satellites

Remote sensing satellites—gathering information using in-orbit cameras, listening posts, and radar—have been greatly democratized. The resulting data is accessible as a public good, a private sector service, or through international cooperation.

Sustainable Development Goals, among other uses. However, despite the clear connection of space applications to development, there persists a common misconception that building domestic space capabilities is a luxury reserved only for rich and powerful nations and that all space-related development is a herculean, cost-prohibitive task. On the contrary, while the degree of space investment and activity varies, even a modest national space program can provide an outsized return.

WHAT IS SPACE CAPABILITY?

"Space capability" is the ability to access, use, and contribute to space-related infrastructure, as well as to access and use space-based natural common resources. These resources include the electromagnetic spectrum and room for satellites in particularly useful orbits (or "slots"). Space-related infrastructure includes satellites and associated ground-based systems. In the future, new natural resources will likely include various raw materials extracted from asteroids or the Moon, like metals and water, that would support Earth-based industry or further "in-space" activity, as in-space manufacturing, tourism, bases on the Moon and Mars, and so on. The focus of this Handbook is to describe those space capabilities best prioritized for an early space program—that is, foundational space capabilities.

A new space program intent on building foundational space capabilities does not necessarily prioritize putting a satellite into orbit or building a launch facility. Rather, it manages a continuous process through which a government can decide what effort would provide the best return on investment, considering a state's priorities, concerns, economy, geographic advantages, and so on. A space program office should be a government focal point for space-related affairs and should have the following capabilities:

- **Consultation, Advocacy, and Localization**. Provide internal technical advice and fully leverage space resources and technology.
- **Program Management**. Deliberately plan and develop space capabilities.
- **Coordination**. Proactively engage internally with government organizations and with external academic, private, and social sectors.
- **Representation and Regulation**. Participate in the global space sector and in the development of rules and norms. Provide the regulatory structure needed to fully leverage space resources and technology.

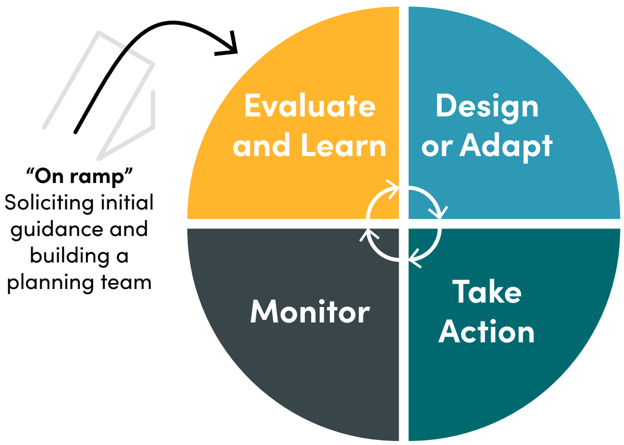
In addition to providing space-related services to other government offices, a space program office can seed, and then accelerate, the development of a national space ecosystem. Such an ecosystem has various independent parts, or "systems," that can be coordinated, integrated, and aligned, to achieve an overall greater national capability than the sum of its parts. A space program can also directly harness space capabilities—such as remote sensing; positioning, navigation, and timing (PNT); and satellite communications—to address specific national priorities.

HOW CAN STATES DEVELOP SPACE CAPABILITY?

There is no single way to establish foundational space capabilities. The actual method by which any country establishes or expands its capabilities is shaped by its history, culture, ideology, and political and environmental realities. Regardless, program design and implementation should be an iterative process, documented as a strategy, roadmap, or workplan that follows a deliberate, methodical, outcomes-focused process. That said, no plan is perfect, nor perfectly implemented, as both understanding of the challenges, needs, and political, budgetary, and other circumstances will naturally change over time.

Therefore, it is useful to envision program design and management as a repeating cycle with sequential phases for evaluation, planning, action, monitoring, more evaluation and learning, and adaptation, as illustrated in Figure ES.2. The "on ramp" to the program cycle is the action of soliciting initial national leadership guidance and appointing a dedicated planning team.

FIGURE ES.2 Program cycle



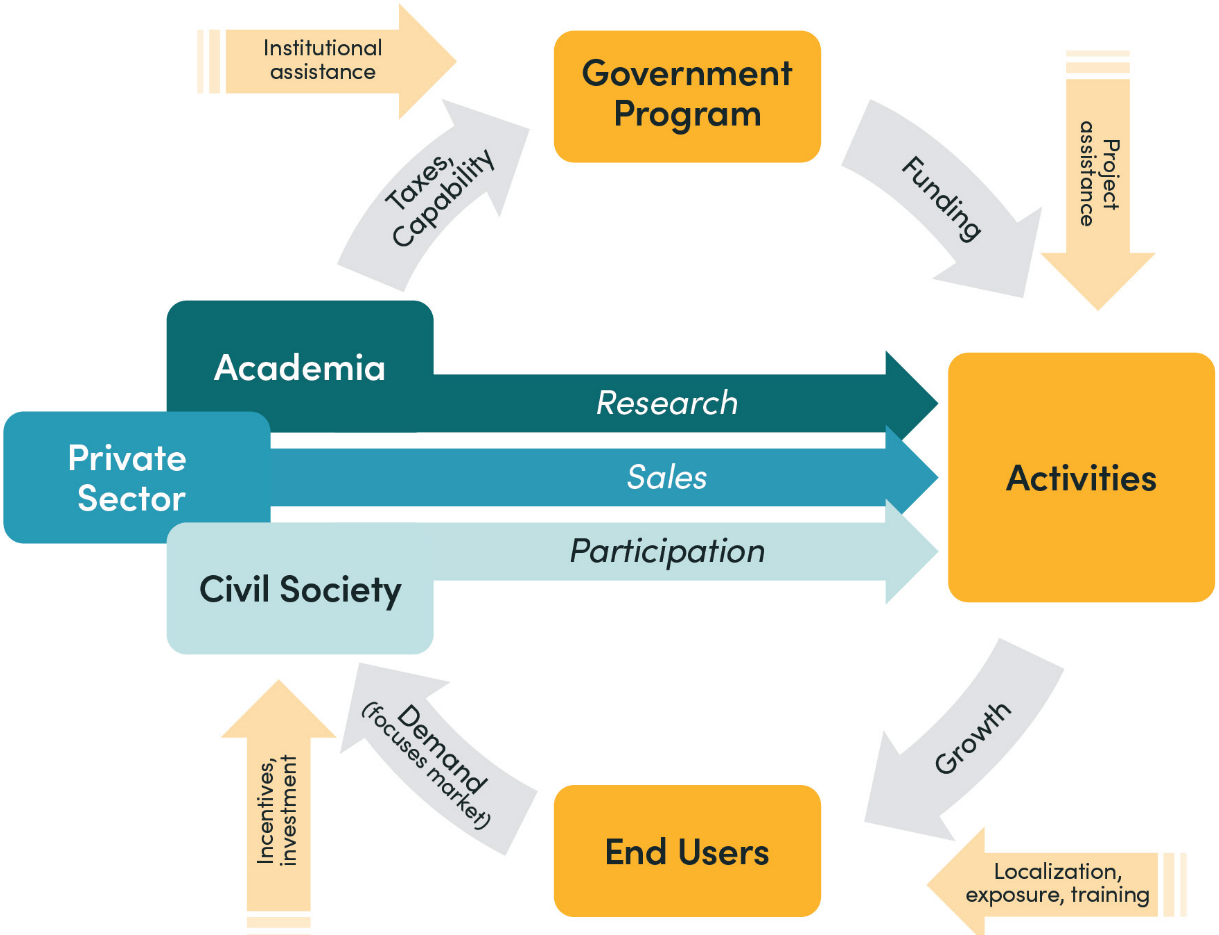
Leadership will need to allocate sufficient resources to the planning team to accomplish the task: people with dedicated time, a physical workspace, computers and internet connectivity, leadership support, and authority to communicate across departments and sectors and with stakeholders as necessary. The planning team's output should be periodic reports to executive leadership or senior management, culminating in a proposal for the space program intent, goals, organization, and estimated costs. In other words, a strategy. This strategy should articulate a logical link from intent to action to expected outcome, and to a plan to evaluate progress. Using tools like a systems map; strengths, weaknesses, opportunities, and threats (SWOT) analysis; and logic models, a planning team will be able to answer the following key questions:

- What space capabilities do we need?
- What space capabilities and capacity do we have now?
- How should we focus and sequence our efforts to build space capability? (This includes components like human skills, policy, and regulatory framework.)
- How do we know the space program is successful?

A state has both domestic and international options to support the development of its space capabilities and greater space ecosystem. An ecosystem is a "system of systems" way of looking at space capability, recognizing that the government, academia, the private sector, and civil society are interdependent. Domestic incentives, such as scholarships, tax incentives, and contracts, can be used to spur space-related activity, which in turn may grow its use and further demand. A state may also elicit or facilitate support from philanthropic organizations, the academic and research community, and the development community. It may use bilateral and multilateral cooperation and assistance, or most likely, a combination of the above. See Figure ES.3.

In conclusion, all countries use space applications daily. Those with a space program, however, are more prepared to absorb and magnify the benefits of space for the good of their economy and society. This Handbook's cases for *why* one should build capabilities, *what* capabilities to build, and *how* to go about it must themselves be localized to be truly useful and sustainable for a particular state. One could say this process of localization is another name for "iterative program design." The process of understanding satellites' function and applications, the inward examination of domestic use and expertise, the exploration of possible building actions nested within national priorities, the relentless asking of why we should do this and how could we do this better are crucial elements to building foundational space capabilities and beyond.

FIGURE ES.3 Using financing and advising support to spur the space ecosystem



Introduction

People use human-made satellites to navigate, understand our environment on Earth and beyond, and communicate across land and ocean, even to other planets. Satellites have come to underpin the global economy and activity through a set of very practical capabilities. Position, navigation, and timing data are used for banking, utilities, and transportation; remote sensing data are used for weather prediction and forecasting, research, and intelligence; and the "space segment" (i.e., satellites) of telecommunications infrastructure extends telephony and the internet beyond the reach of terrestrial networks (wire, microwave relay, optical fiber).

In 2021, United Nations (UN)–issued resolution "Space 2030 Agenda: Space as a Driver of Sustainable Development" formally recognized that "space science and technology and their applications are contributing immeasurably to economic growth and improvements in the quality of life worldwide." Despite such a clear connection of space applications to development, there persists a common misconception that building domestic space capabilities is a luxury reserved only for rich and powerful nations and that all space-related development is a herculean, cost-prohibitive task. On the contrary, while the degree of space investment and activity varies, even a modest national space program can provide an outsized return that enables every UN Sustainable Development Goal (SDG).

THE GOALS OF THIS BOOK

The intent of the *Handbook for Space Capability Development* is to establish an inclusive, pragmatic, and open-access resource focused on space capability development. Its intended audience is the planner or planning team charged with drafting a national space strategy and building a national space program. Among its goals are to make a case for *why* all governments should establish a foundational space capability, to discuss *what* such a program might look like in real terms, and to suggest an approach for *how* to conduct early program design. It aspires to ensure that the resulting program, office, and strategy are sustainable in scale, scope, and growth; contribute tangibly to national priorities; and enable full national participation in the regional and global space ecosystem.

The first step in this endeavor is to understand existing national dependencies on space and consider how space applications could be used to support economic growth, security, and other national priorities. A national space program can then structure methodical development of foundational space capabilities that, in turn, enable a country to

- Protect existing dependencies on space.
- More fully leverage existing space capabilities and applications.
- Encourage the growth of a local data and space ecosystem.
- Attract international and public-private collaboration and investment.
- Contribute to the development of norms and laws governing space.

HOW TO USE THIS BOOK AND OTHER KEY REFERENCES

The *Handbook for Space Capability Development* will focus on the why, what, and how of developing an early space program. It is best used in concert with other open-source references that focus more deeply on space and data-related terms, concepts, physics, law, norms, and management. This virtual, free "bookshelf" includes

- *Handbook for New Actors in Space*, Secure World Foundation (SWF) (www.swfound.org). Provides an authoritative overview of legal, regulatory, political, technical, and administrative issues in space (Johnson 2017).
- "New Space Law for New Space Actors" (in development), United Nations Office for Outer Space Affairs (www.unoosa.org). Describes the treaties, principles, and guidelines that, collectively, constitute the normative framework governing activities in outer space (UNOOSA, forthcoming).
- *Digital Regulation Handbook 2020*, International Telecommunications Union (ITU)/World Bank (WB) (www.itu.int). Guide to assist regulatory authorities and policymakers in deciding on appropriate digital regulations, to include radio-spectrum management, and evaluating the effectiveness of those regulations.
- "Broadband Strategies Toolkit" (ITU/WB) (https://lnkd.in/g8dz2FEX). This online toolkit is in a modular format, making it easy to move directly to topics of interest. It demonstrates how broadband enables economic and social development and provides policymakers and regulators with tools to create strategies, design policies, and implement programs that expand the reach and that increase the use of broadband information and communications technology (ICT).
- "Guidelines for the Long-term Sustainability of Outer Space Activities" by the Committee on the Peaceful Uses of Outer Space, United Nations Office of Outer Space Affairs (UNOOSA) (www.unoosa.org). The document (UNOOSA 2018) describes norms for safe space operations. It explicitly encourages international cooperation, capacity building, and scientific and technical research and development.
- "Newcomers Earth Observation Guide," European Space Agency (ESA) (www.business.esa.int). Provides an overview of different types of remote sensing imagery and example applications (ESA 2020).
- *European Global Navigation Satellite System and Copernicus: Supporting the Sustainable Development Goals* (UNOOSA, ESA) (www.unoosa.org). Joint UN/ESA exploration of space remote sensing and position, navigation, and timing data applicability to the SDGs. An excellent way to explore possibilities via a theme, like water management or health (UNOOSA and ESA 2018).
- International GNSS Service (IGS) (www.igs.org). Voluntary federation of two hundred agencies, universities, and research institutions in more than one hundred countries, providing, on an openly available basis, global navigation satellite systems (GNSS) data, products, and services in support of the terrestrial reference frame, Earth observation and research; positioning, navigation, and timing; and other applications that benefit science and society.
- Global Positioning System (GPS), www.gps.gov. Overview of global navigation satellite systems, specifically the US GPS system. Includes information about, and links to, Chinese, European, Russian, Indian, and Japanese GNSS.
- US Cybersecurity and Infrastructure Security Agency, "Position Navigation Timing" (www.cisa.gov/pnt). United States' guidelines to prevent, respond to, and recover from GNSS interference, whatever the cause.

Additional references and resources are listed at the end of this Handbook, organized by topic section.

SECTION 1.

Why Space?

Space capabilities can be best understood as a type of infrastructure, akin to roads or power, and has been championed by the UN as an enabler of all 17 SDGs as articulated in the Space 2030 Agenda for Sustainable Development.[1] However, even for countries with no national space policy or managed domestic space capability, it is important to understand satellites already underpin multiple ubiquitous national infrastructures such as public utilities and telecommunications. It is useful, therefore, to start by inventorying and protecting existing dependencies on satellites. Moving beyond "default" use, a relatively modest domestic space capability makes it possible to leverage billions of dollars of existing space infrastructure through international cooperation, nonprofits, or commercial services to grow the local economy, protect natural resources, support planning, and build resilience. Additionally, developing space capabilities offers a way to participate in the digital and space sectors, thus widening options and tools for further economic growth and technology independence. Concentrating existing space expertise into a government organization (an office, an agency, or similar) makes such expertise more accessible to other government ministries and to the civil, academic, and private sectors. It also provides a vector through which a government can participate in global space-related coordination, establish norms, and support international law development.

SPACE CAPABILITY AND COMPETING NATIONAL PRIORITIES

Every country must make tough choices when faced with finite resources. For low-income countries especially, efforts to address very immediate needs, such as hunger, shelter, education, health, and security, can be perceived as competing directly with efforts to develop a space capability. As Colonel Francis Ngabo from the Rwanda Space Agency put it during a 2022 panel, the question to some minds can come down to "space or hunger?"

As alluded to in the opening of this section, a useful starting point for answering questions such as this is to reframe space as infrastructure, akin to roads or power. Road systems and electricity grids, for example, don't directly feed people, but they do contribute greatly to the ability to grow, move, store, and sell agricultural goods and to quickly deliver emergency aid when needed. As many low- and middle-income countries can attest, roads must be built and electricity grids must be installed in balance with and in support of various national needs.

A state able to use space infrastructure has more tools to communicate and to access many types of useful information about its land, water, and people. That capability, in turn, supports hunger prevention and mitigation, and relief efforts. Three examples show how satellites help prevent or mitigate food shortages:

1 "Space4SDGs: How Space Can Be Used in Support of the 2030 Agenda for Sustainable Development," UNOOSA, https://www.unoosa.org/oosa/en/ourwork/space4sdgs/index.html.

- **Satellites protect resources**. Satellite sensors capture remote data that are commonly used, for example, to alert authorities to illegal fishing. The resulting information on suspicious activity is fed to maritime operations centers that (ideally) direct authorities to interdict ships at sea or inspect ships at port. Satellites trigger a series of actions that help protect an important food source (fish) for the local population and protect economic activity. Similar capabilities can be used to protect forests, wetlands, waterways, and other ecosystems (Canadian Space Agency 2018).
- **Satellites support planning**. Satellite data support crop forecasts, which can be relayed via the internet, radio, text messages, or print media to local populations. (Satellite communications can extend the reach of this communication.) These evidence-backed predictions can spur people to prepare for and mitigate food shortages and can be used to trigger government or international intervention (FEWS NET, n.d.).
- **Satellites build resilience**. A government uses satellite data to monitor the well-being of grazing lands for cattle and uses satellite-enabled digital financing to provide subsidized insurance to rural areas. A new area of economic activity creates jobs, and more pastoral households are insulated against loss of livestock, an important food source (Lung 2021).

As a preview to a central theme of Section 3— "How?"—note that the design and implementation of a space program also matters. No country starts the expansion of its transportation infrastructure with an eight-lane mega highway and a fleet of trucks. Similarly, the first objective of any early space program should not be to put satellites into space per se. Rather, the early goal should be to maximize the state's ability to apply existing space infrastructure to address national priorities, which can include hunger, climate change, disaster management, insecurity, and other issues. Building capacity to extend broadband internet access and to apply (free) geospatial data to local issues doesn't require state-owned satellites or a budget like that of the US National Aeronautics and Space Administration (NASA). Used thoughtfully and methodically, a relatively modest investment in localized space applications can unlock access to billions of dollars' worth of existing space infrastructure.

When ready to build homegrown satellites and associated ground components, states can avoid wasteful spending by ensuring such upstream systems also provide a unique and focused benefit to the population. The South African space program, for example, has been building its space capability since the 1980s. Its first fully domestic-designed and -developed satellites, the MDASats, were launched as part of the "Oceans Phaskisa" initiative. These satellites were charged with finding ships conducting illegal fishing, piracy, or other nefarious activity in South Africa's Exclusive Economic Zone, an area larger than the landmass of South Africa itself, thus enabling the protection of South African fish stocks, commercial and subsistence fishers, and the African Blue Economy in general. While food insecurity will be an enduring issue that periodically needs direct action, country policy must also incorporate such long-term solutions that address the drivers behind such crises.

So, it's true, space capabilities don't directly feed hungry people. But they are a powerful enabler of addressing the cause of and response to hunger, as well as other UN SDGs and national interests, such as security and long-term economic growth. An early space program should pursue and clearly communicate this purpose both internally and to the public, thus shifting the question from "build satellites or address hunger?" to "how do we balance investment in enabling infrastructure, like space, with direct action, like distributing food, to address hunger?" To take this question one step further, one could ask, "What is the cost of not leveraging these tools?" To make smart policy and development decisions, it's important to recognize that investing in space and addressing basic needs can go hand in hand.

SATELLITE SERVICES UNDERPIN OTHER INFRASTRUCTURE

In short, space capabilities and applications—to include navigation, position, and timing data; communications; and remote sensing—are already intermingled with most countries' utilities, transportation systems, finance systems, telecommunications, and so on. It is useful to recognize and roughly inventory use of these satellite services (Box 1.1) in order to make the best use of them as well as to manage the overall system should there be an interruption of service.

BOX 1.1. TYPES OF APPROXIMATELY 4,800 OPERATIONAL SATELLITES IN ORBIT AS OF 2022

- Communications: 63%
- Earth observation: 22.1%
- Technology development: 7.8%
- Navigation/global positioning: 3.6%
- Technology demonstration: 0.77%
- Earth science: 0.44%
- Space observation: 0.22%
- Space science: 2.3%

Source: Dewesoft 2022.

Global navigation satellite systems and position, navigation, and timing data

Positioning, navigation, and timing (PNT) services are a ubiquitous and critical aspect of space infrastructure. PNT services are provided by global navigation satellite system (GNSS) constellations (a group of artificial satellites working together as a system), such as the GPS, GLONASS, Galileo, and BeiDou, and feed common end-user applications like Google Maps and OpenStreetMap. They also provide critical data for safe aviation and other transport systems, financial services, energy grids, telecommunications, and all "spatially referenced" activities. GNSS location databases (datums) are increasingly replacing old (even colonial-era) surveying methods as an international standard for land development and good land policy. Telecommunication networks rely on GNSS clocks to synchronize calls and utility companies use GNSS timing data to fine-tune current flow and manage networks. Banks use GNSS data to timestamp credit card and market transactions. GNSS data are used to synchronize computer networks, digital television and radio, radar, seismic monitoring, and other uses worldwide.

GNSS signals, however, can be accidentally or purposefully jammed by more powerful emitters (GPS World 2020). The power of GNSS broadcasts is equivalent to the light from a 60-watt lamp but aboard a satellite, some 23,000 kilometers away. Accidental and natural interference, like solar flares, has disrupted signals in the past, resulting in situations in which ships were forced to navigate in heavy fog using onboard radar systems, or aircraft had to land using only onboard instruments (GPS World 2003). In 2016, a temporary software glitch on GPS disrupted police, fire, and emergency medical service radio equipment in the US and Canada (Glass 2016). Russia's 2022 use of GPS jammers on Ukraine targets also interfered with neighboring countries' airline navigation systems (RNT Foundation 2022). These risks can be mitigated by installing ground-based backup systems for vital infrastructure, and by using equipment that is interoperable with multiple GNSS satellite constellations' signals (Glass 2016).

Remote sensing satellites

It is important for governments to also understand the current use of and to protect access to "routine" but vital remote sensing data. States need to consider what remote sensing data are available as free to the public, shared through international agreements, or for purchase from commercial venders, and thus maximize their ability to put these data to use locally. Last, states need to be aware that satellite data concerning their own territory are also widely available to other state and nonstate actors via these same sources.

Remote sensing data, also called Earth observation data, are already woven into daily life for most people, though it may not always be obvious. Combined with cloud computing, machine learning, and data sharing, remote sensing satellites offer the opportunity to observe, monitor, and predict environmental and social phenomena with ever greater efficiency and precision. The resulting products may or may not take the form of an actual map. Consider, for example, weather forecasts. The longest-standing shared use of remote sensing data concerns weather and is managed by the World Meteorological Organization (WMO).[2] Most countries rely heavily on weather data provided by this global network of 545 Earth observation satellites (as of 2022), especially in regions where there is a shortfall of ground-based weather stations, as in the case in many developing counties (NOAA/NASA 2021). The loss of this shared resource would severely curtail the accuracy of weather forecasts worldwide. Remote sensed weather data are an example of data that are both widely available and widely depended upon by most countries irrespective of the country's having a national space program.[3]

Other remote sensing data sets underpin many government infrastructures. For example, PNT and remote sensing are often used to build governance tools, support disaster prevention and response, improve land use, strengthen transport systems, and protect forest, maritime, and extractive resources, among other uses. An immense amount of data and support without cost is available for countries that have enough capability to understand it is there and how to access it (Figure 1.1).

Case in point, it is possible to leverage existing satellites to quickly support emergency domestic disaster response and recovery efforts. International space agencies and some commercial companies share data free of charge through forums such as the International Charter on Space and Major Disasters, or regional networks such as Sentinel Asia. In June 2022, an especially heavy monsoon season in Bangladesh caused widespread flooding, which led the Bangladesh government to activate the Charter. The United Nations Institute for Training and Research (UNITAR), using Canadian satellite RADARSAT data, subsequently produced a map showing the extent and impact of flooding, which in turn helped Bangladesh direct the deployment of armed forces to speed up rescue and relief efforts (International Charter on Space and Major Disasters 2022). (See Use Case 1.) Since the Charter was formed in 2000, it's been activated more than 750 times in 131 countries. Even established space actors benefit from this arrangement. Notably, it was a NigSat-1, Nigeria's remote sensing satellite, that captured the first pictures of the hurricane Katrina's swath of destruction along the United States' southern coast in 2005.[4] The Charter is open to registration to any national disaster management authority able to submit and pursue activation requests in English and able to download and use the maps. In other words, for a relatively small investment—that is, having enough internal capacity in English and digital infrastructure to meet this threshold—a country is able to access billions of dollars of existing space infrastructure to support its response to various impending or ongoing types of disasters.

Last, states need to be aware that satellite data concerning their territory is also widely available via these same sources, an idea called *radical transparency or democratized intelligence*. There is no requirement in international law or norms that a country be informed when a remote sensing satellite is passing overhead. The remote sensing data collected can be used by foreign governments, investors, citizens, aid organizations, journalists, and other actors for various legitimate purposes, such as business prospecting, development projects, and research. The wide availability of data has also changed the security dynamic, as foreign forces, armed groups, and criminals are also increasingly able to leverage remote sensing data and other space applications to observe, understand, expose, or respond to state activity (Neubauer 2021).

Communications satellites: The "space segment" of telecommunications infrastructure

All countries rely on the "space segment" (communication satellites) as a part of global telecommunications infrastructure

2 See the World Meteorological Organization website, https://public.wmo.int/en.
3 NOAA (National Oceanic and Atmospheric Administration), "NOAA's Satellite and Information Service (NESDIS) International and Interagency Affairs Division, Global Partnerships," last modified July 18, 2017, https://www.nesdisia.noaa.gov/globaleocoordination.html.
4 See the International Charter on Space and Major Disasters website at disasterscharter.org

FIGURE 1.1 The World Meteorological Organization's space-based Global Observing System

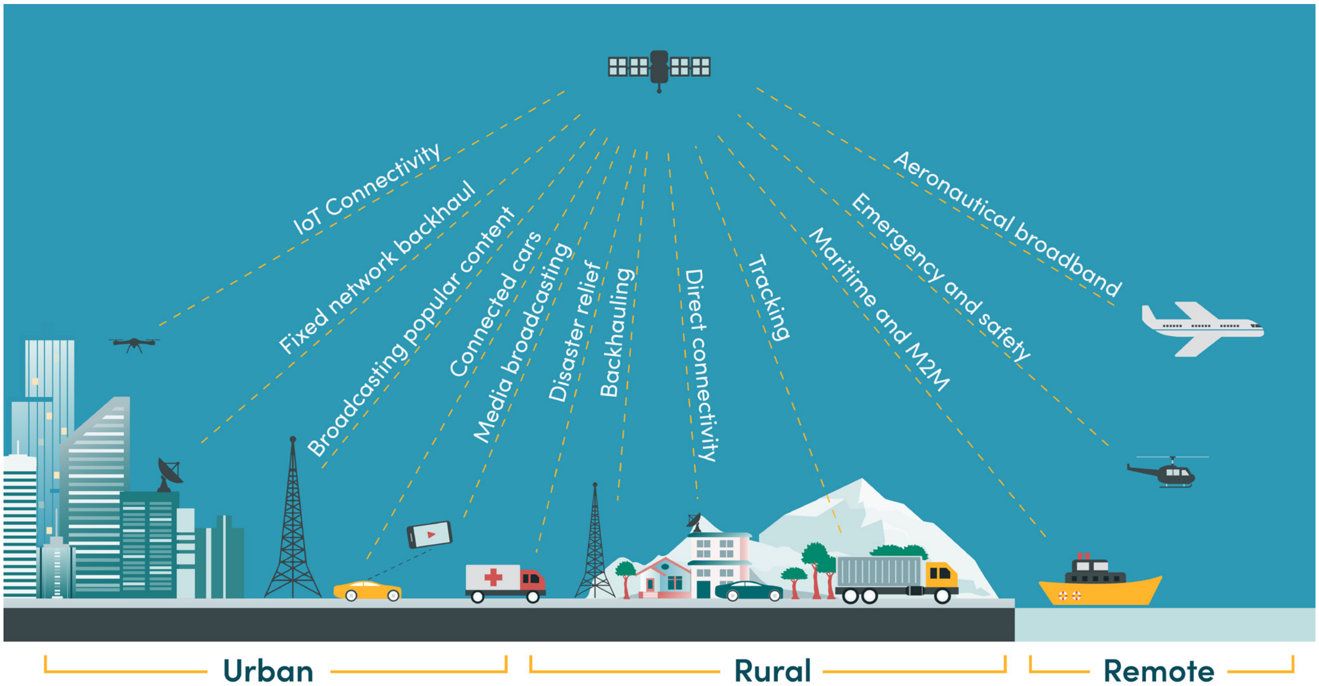
Many nations contribute to, and coordinate through, the WMO to provide remote sensing data to support weather forecasts and understand climate change.

Source: "Global Earth Observation Coordination," Satellite and Information Service, International and Interagency Affairs Division, National Oceanic and Atmospheric Administration, last modified July 18, 2017, https://www.nesdisia.noaa.gov/globaleocoordination.html.

(Figure 1.2), but not all take full advantage of its potential to reach underserved or unconnected populations. Telephone wires, cables, radio and cell phone towers, and microwave relay dominate on land and more densely populated areas. Massive undersea cables stretch along the ocean floor to connect continents and major islands. Communication satellites, collectively referred to as non-terrestrial networks (NTNs), handle only about 5 percent of the world's internet traffic at a time but extend the reach of telecommunications and provide a layer of resiliency should terrestrial connections fail during conflicts or natural disasters. For even well-connected population centers, satellites provide a critical failsafe should terrestrial connections fail as a result of power outages, conflict, accidents, or disasters (Mureithi 2022). Poorly regulated vessel traffic and lack of patrolling and enforcement of no-go lanes along cable routes mean damage to undersea cables tends to happen more often on the shores of developing countries (Kulkarni 2019). NTNs also include unmanned aerial systems and pseudo-satellites (or high-altitude platforms).

Satellites are especially useful at connecting entities, such as in transiting aircraft and ships, at sea and along remote shores, small islands, and other maritime outposts. Satellites also relay data vast distances over land, offering an economic lifeline for landlocked countries, such as found in Central Africa and Asia, that are unable to directly access undersea cables. This is no small consideration because landlocked countries' data must transit over the land of other countries, encountering natural and human-made risks, as well as

FIGURE 1.2 The many roles of satellites in communications infrastructure



Source: Satellite Communications in the New Space Era: A Survey and Future Challenges, IEEE Communications Society, 2021

Note: The illustration shows how satellite communications are used in urban, rural, and remote areas. "Internet of things" (IoT) refers to machines with sensors, processing ability and other technology that connect and exchange data with other devices and systems networks. "Fixed Network Backhaul" and "Backhauling" refer to the portion of a telecommunications network between an "edge" of a network and an internet exchange point (to the internet), usually paid for at wholesale commercial access rates. "Direct connectivity" is satellite communication, be it texts or high-speed internet broadband, that directly connects an end user. "Machine to machine" (M2M) communication occurs when machines automatically exchange data between themselves without relying on humans to do so.

Source: Kodheli et al. 2021, 73.

through coastal nations' telecommunications infrastructure, to access undersea cable landing points. A landing point is where an undersea cable connects to land-based telecommunications infrastructure.

SPACE IS A BUILDING BLOCK FOR THE ECONOMY

Acknowledging the many potential benefits of space applications, most countries give economic factors as their primary reason for investing in space, followed by geopolitical interests (Box 1.2). In practical terms, space capabilities can be seen as another type of infrastructure—one that supports better connectivity and data, growth of human capital, research and development, and access to new markets that contribute to economic growth.

Multiple studies show that increased broadband availability and affordability, as well as higher broadband speeds, support economic growth. To genuinely support growth, however, the connectivity must be meaningful—that is, usable, affordable, and empowering to the local population. Satellites are an increasingly viable option in this endeavor. Satellite communications are on track to make "last mile" broadband significantly cheaper, if not yet affordable to individuals in remote, sparsely populated, dangerous, or otherwise difficult-to-reach locations.[5] Space-based infrastructure currently complements terrestrial networks by "backhauling" (moving

5 The "first mile" and "last mile" are the same thing. The link between an internet service provider and end users is often called the "last mile" by service providers; from a user's perspective, it is the "first mile."

data between access networks, to include users' devices, and the core, or backbone, network where substantive computing happens) for terrestrial network service providers. Satellite communications capacity will likely increase steadily as multiple large constellations are launched and as data relay efficiency and satellite-based data processing improve (Croshier 2022). As the world transitions further into a digitized age, the use of information technology, and the integration of space infrastructure, will only increase.

The digital ecosystem comprises the stakeholders, systems, and enabling environments that together empower people and communities to use digital technology to gain access to services, engage with each other, or pursue economic opportunities (USAID 2022). The ecosystem supports participation in international production, trade, and investments (the global value chain). It contributes to inclusion by lowering transaction costs, addressing information asymmetries, and exploiting economies of scale. Further, it increases marginalized groups' access to markets and services and provides visibility to those markets seeking customers. Examples of markets and services include remote education, health services, and education and information access (e.g., digital libraries, YouTube instructional videos, health information, news, and entertainment), digital finance (mobile and online banking), e-governance (administration, services, and participation), the sharing economy (e.g., AirBnb and Uber), crowdfunding (e.g., Kickstarter, Indiegogo, and Ulule), and job matching/networking platforms (e.g., LinkedIn, Careerjet, 51Job) (Dahlman, Mealy, and Wermelinger 2016). The space segment—that is, satellites and associated ground components like earth stations and "gateway' connections to the terrestrial internet infrastructure as well as remote sensing and PNT data—is an integral part of this data or digital ecosystem. For example, the Association of Southeast Asian Nations (ASEAN) Digital Masterplan urges the adoption of satellite-based communications to foster a digital economy in Southeast Asia and incorporate rural populations (Verspieren et al. 2022). See Use Case 1.

BOX 1.2. REASONS 16 COUNTRIES ESTABLISHED A SPACE AGENCY, 2014–2019

- Economic growth
- Consolidating capability
- Focal point for international cooperation
- Promote commercial space industry
- National prestige
- Research
- Technologic development and application
- International cooperation
- Proposal and guidance of space policies
- Security/defense
- Disaster management
- Promote commercial space industry
- Grow inter-agency civil space activities

Source: Kommel et al. 2020.

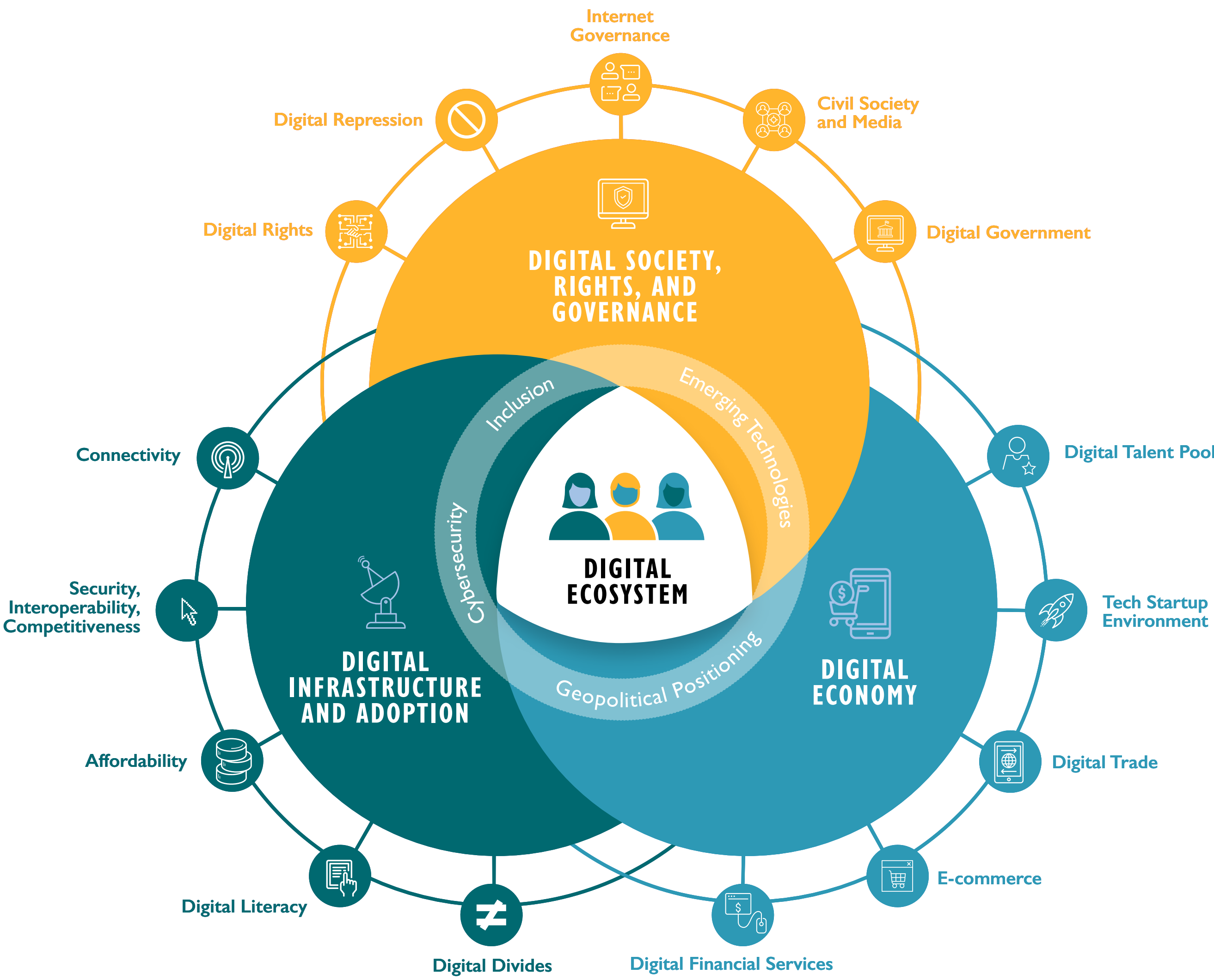
A government can take steps to maximize the usefulness of existing space infrastructure, to take advantage of "space as a service." The first GNSS system, GPS, alone is a "global good" that is estimated to have added US$1.4 trillion to the US economy alone, and has contributed substantially to the global economy at large, since it first became freely available (Nazario-Negron 2019). There are now four GNSS constellations of satellites broadcasting free PNT data, to include the US's GPS, China's BieDou, the EU's GALILEO, Russia's GLONASS, and two regional systems, Japan's QZSS and India's IRNSS, as well as various satellite-based augmentation systems that support regional accuracy.[6] Free remote sensing data are routinely posted online by the US, Europe, China, Japan, and other space actors. In India, for example, the market value of these data, in addition to paid and shared agriculture-specific earth observation data, was estimated at US$64 million in 2021 (GlobalData Plc 2022). Such remote sensing data, including optical, infrared, and radar data, are more useful when

6 See "Global Navigation Satellite Systems (GNSS)," UN Office for Outer Space Affairs, accessed July 27, 2022, https://www.unoosa.org/oosa/en/ourwork/psa/gnss/gnss.html.

combined with PNT data and other, Earth-based sources, a small sample of which includes weather stations, census data, and soil samples, which are adapted to local needs. A weather forecast application that accounts for local conditions (harmattan in Western Africa, monsoon season in southeast Asia) relayed on a 3G-capabile cell phone, or a crop price forecast relayed via text messages or as a traffic report on a radio, are real-world examples of applied space capabilities within a "digital ecosystem" (USAID 2022).

Additionally, a state can take discrete actions to make remote sensing and PNT data more useful, more accessible to the domestic economy. For instance, creating a regional-specific spatial reference system serves as a foundation for all national geospatial products (datums) that can be used for mapping and charting a wide variety of science and engineering applications, such as those used by transportation, utilities, aviation, and construction industries, as well as for making weather forecasts more accurate. In other words, the state can invest in another type of space subinfrastructure—that is, regional geospatial datums—that enables better use of data, thus serving as a foundation for better land policies, research, and small business growth (Poku-Gyamfi 2009). Figure 1.3, drawn from USAID's "Digital Ecosystem Framework," approaches space applications from the point of view of building a strong *digital ecosystem*, showing how acess to and use of satellites are an important component of that digital ecosystem (USAID 2022).

FIGURE 1.3 USAID Digital Ecosystem Framework for International Development



Source: USAID 2022. The framework includes satellite applications as an important component.

SPACE EXPANDS THE REACH AND DEPTH OF E-GOVERNANCE

Many countries are turning to electronic governance, or "e-governance," to enhance their ability to address the needs of the general public. Satellites are a tool through which, again, governments can gather, move, and broadcast data, all of which can contribute to e-governance capabilities. Communication satellites extend the reach of administration and services and provide previously unconnected or underconnected populations with the opportunity to participate in government. Satellites can contribute data that give policymakers information (even "intelligence") that can drive important decisions. Examples include understanding the value and health of crops or fishing nurseries, the level of pollution in a given area, or the change in value of properties for tax purposes, or understanding the impact of development programs. E-governance itself can increase transparency, simplify and streamline regulations, and facilitate reporting, registration, licensing, and filing. India, for example, is using satellites and commercial solar-powered earth stations to connect its *Gram Panchayats*, or village-level government offices, in very remote areas that lack terrestrial connectivity. India has greatly increased government services, such as telemedicine and land records, to rural areas using this BharatNet program.[7] See Use Case 2.

THE SPACE SECTOR ITSELF OFFERS OPPORTUNITY FOR ECONOMIC GROWTH

Space industry experts estimate the space economy is worth US$447 billion as of 2020 and could more than double to US$1 trillion by 2030 (Space Foundation, n.d.). A 2021 study from the Organisation for Economic Co-operation and Development (OECD), "Space Economy for People, Planet and Prosperity," makes the case to the G20 that space-related government research and development (R&D)—especially in the domains of launch services, Earth observation, and space exploration—have been particularly helpful in terms of knowledge and technology transfers.[8] NASA, for example, recorded more than 2,000 successfully developed commercial products between 1976 and 2019, with a majority of transfers to manufacturing and consumer products, computer technology, and the environment and resource management.

Although there is greater private sector participation in the space sector than ever before, governments still play a key role in the space economy as investors, developers, owners, operators, regulators, and customers (OECD 2021). Government programs are often the catalyst that triggers the growth of new industries, be it through legislation, tax breaks, offering of contracts, research funding, or other tools (to be discussed further the "how" section, Section 3). Local research institutions are more likely than foreign institutions to engage in local situational and culturally relevant questions. But studies show that geospatial-related research outputs from developing countries are low, in part because the countries lack sufficient bandwidth for downloading satellite data and they lack the hardware or skills for processing, analyzing, and storing the data. Research institutions also often provide the support needed for aspiring entrepreneurs to develop and refine their ideas and products before launching a small business. Governments need to be proactive in encouraging such growth of nongovernment space activity that includes civil society, the private sector, and academia in order to fully reap a return for their investments in the space sector.

A 2020 study (Kommel et al.) surveyed 16 countries between 2014 and 2019 and asked why they were establishing a space agency. The most common reasons given were economic, for many of the advantages previously discussed. The majority also stated they were establishing their agency to manage space activities rather than to execute space activities directly (Kommel et al. 2020). This is a significant change from how early space programs operated. The United States' NASA and

7 See the BBNL, India Ministry of Communications and Information Technology, website, https://bbnl.nic.in/.

8 The G20 countries are Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, the United Kingdom, the United States, and the European Union. Spain is also invited as a permanent guest.

Russia's Roscosmos implemented most of their early research, design, and execution of space activities directly, because only large and relatively wealthy governments had the massive resources necessary to do so.

More recently, the emergence of a robust commercial space sector, popularly referred to as "New Space," has resulted in the rapid proliferation of lower-cost access to space and spaceflight technologies. So long as a county establishes foundational capabilities, to be discussed in Section 2, the rise of commercial space-focused services enables a new space program to specialize according to national priorities using an almost *modular* approach, while encouraging its greater space ecosystem to grow in a more organic, loosely directed fashion. In other words, developing space capabilities no longer requires a NASA-like budget. It can be done gradually, sustainably, and in balance with other national priorities and needs. Additionally, space-related economic activity is expanding in all directions, from knowledge creation, specialized materials, and ancillary industries to hardware and operations, satellite applications-as-services, and numerous value-added services. Value-added services include expanding and densifying telecommunications networks; data aggregating, reselling, analytics and integration, and various combined uses in "non-space" localized domains like agriculture, development, and utilities. (See "Evaluating capability and exploring possibilities" in Section 3 for further discussion.)

SPACE SUPPORTS TECHNOLOGY INDEPENDENCE AND IMPROVES SECURITY

Many security forces use satellites for reconnaissance, surveillance, weather tracking, communications, and navigation to support planning activities and operations. Accordingly, national security imperatives have long been a driver behind the development of space capabilities. Satellite applications are often used to monitor large areas at once, such as maritime territory, coastlines, and borders; connect remote police, maritime, or ground forces and equipment; guide or control crewed units or drones; and undertake other security applications (SSPI, n.d.). Examples include using satellites to monitor for illegal activity (such as destruction of rainforest in Brazil, illegal fishing in Indonesia, drug smuggling in the Gulf of Mexico, illegal dumping off the Coast of Somalia, or poaching of animals from National Parks in Benin) and contested borders (India and Pakistan, Cambodia and Thailand, Russia and Ukraine, etc.) and other security or defense-related issues.

There is also great interest in "technical independence"—that is, independent access to communications, PNT, and remote sensing data. States often want to avoid overreliance on a second party, want to have full control of resulting data, or want higher resolution and/or more frequent or recent imagery than what is available in the public domain, shared, or through international cooperation. For example, even though the US GPS constellation of satellites broadcasts PNT data globally, Europe, China, Russia, India, and Japan all have established their own GNSS satellite constellation in order to both reduce reliance on a single (US) system and increase regional accuracy. Security is often one of many motivations. For example, although commercial communication satellite bandwidth was available to Egypt and Nigeria, both countries invested in launching state-sponsored satellites to establish secure communications for military and government agencies, to extend and strengthen internet service for their citizens, and to spur their private information and communications technology (ICT) sector (Space in Africa 2019). In addition, Nigeria added the Satellite-Based Augmentation System (SBAS) to its communication satellites to augment existing GNSS navigation signals specifically for aviation safety and air traffic management in Africa (Iderawumi 2021). Many countries include an intelligence component to their space program to address these interests. The Philippine Space Agency, established in 2019, works with the Philippine Department of National Defense to use space capabilities "to protect the country's sovereignty" through maritime domain awareness, area surveillance and monitoring, coastal surveillance, and satellite-enabled communications (Siacor 2022). See Use Case 3.

As stated by the former chief executive officer (CEO) of the South African National Space Agency when discussing the cost/benefit analysis of South Africa's investment in maritime-oriented satellites (MDASats), "The benefits accrued through such satellites more than outweigh the cost of the satellites. From a policy point of view, we are aware that foreign countries are more aware of what is in our back yard than we do because of satellite capabilities, a narrative that many developing countries, including South Africa, are trying to change."[9] The same sentiment was expressed by stakeholders in Australia, when developing their space strategy in 2020–2021. Tim Neale, from Data Farming, told the Australian planning team that other nations tend to know more about Australian crops than it does, and this has commercial implications: "Other countries like China and US know more about our wheat than we do and that we should be doing the same to the other countries too. And why not? We need the intelligence, and they're gathering a lot of intelligence on our production system."[10]

A SPACE PROGRAM CAN MAKE EXISTING SPACE CAPABILITIES MORE ACCESSIBLE WITHIN THE GOVERNMENT

A space program can break down departmental silos and enable the government to access functional expertise where and when needed, while also providing a structure through which it can deliberately build an overall greater national space (and data) capability and capacity.

Governments generally do have at least a few personnel with space-related skills and expertise, even if it's not obvious or the main purpose of their position. A space program can coordinate and leverage this hidden talent to achieve a greater effect, be it development of data-based domestic policy or more coherent and focused international space-related engagement. For example, most countries have a government office charged with regulating and coordinating internet service providers (ISPs) and mobile service providers (MSPs) and approving "landing rights" for satellite companies to establish satellite receivers or transmitters within national territory. Other personnel may allocate radio-spectrum frequencies to various government, private, and civil organizations, thus minimizing signal interference and ensuring that the radio spectrum is used efficiently and, ideally, benefits the public. It makes sense that these space-related actions be harmonized. There is also often an overlap within the governance of communications and finance institutions, since anything that requires moving money, digital or not, within and across national borders typically needs government approval. (Satellites extend the reach of digital finance options such as M-Pesa and India Stack, mobile microfinance and money transfer services popular in Africa and India, respectively.) Additionally, most militaries have a mapping or engineering office that uses satellite imagery, GPS, and, potentially, satellite phones to support operations. Universities, within the purview of a Minister of Education perhaps, often have geospatial and other data analysis embedded into science and technology coursework. These represent opportunities for active cross-pollination of skills and methods.

Establishing a space program can also save money by concentrating expertise for space-related tasks. When Australia was preparing to establish a space agency, for example, officials realized that multiple federal and state offices were paying for the same remote sensing data, using contracts with tight limits on who was licensed to access the data. Planners realized that it would be significantly cheaper to establish one contract that allowed a greater number of users. It took a blend of "regular" government contracting know-how, an idea of government internal customers' needs, and basic knowledge about remote sensing applications to enable negotiations with providers to achieve an appropriate fit-to-purpose contract.

9 Valanathan Munsami, personal communication, August 2, 2022.
10 *The Now Frontier*.

A SPACE PROGRAM CONTRIBUTES TO THE DEVELOPMENT OF NORMS AND LAWS GOVERNING SPACE

Global space activity has passed an inflection point and is rapidly transitioning from a primarily government-dominated arena to a vibrant mix of multinational government, academic, civil, and commercial activity. Space actors, to include countries and companies, are using space technology to test the boundaries of existing space norms and international law. The emerging "in-space" economy will include tens of thousands more satellites, a proliferation of commercial space stations, increased human spaceflight, satellite servicing, orbit transfer vehicles, in-space manufacturing, and commercial landers (for Mars and the Moon), among other yet unrealized activities. The Outer Space Treaty, set into force in 1966, and subsequent agreements are being tested in the process of "operationalizing" space activities, as the world moves from theory to practice, from laissez-faire experimentation to regulated, coordinated activity. One can draw parallels between the current pace of space development to that of the aerospace industry. In 1909, the Wright Brothers' College Park Airport in the US hosted a then-impressive 100 airplanes and a single flightline. Just over a century later, the global aviation industry consists of more than 26,000 aircraft and 41,700 airports, capable of moving over 2.2 billion people per year. The first satellite was launched in 1957. Sixty-five years later, about 4,800 active satellites are in orbit and are thoroughly integrated into the global economy. Over the next 30 years, analysts estimate the number and diversity of satellites will grow exponentially, the space sector and other sectors will continue to converge, and the "in-space" economy will mature (Black, Slapakova, and Martin 2022).

Space actors now are making decisions about how to operate safely and share common resources, such as how densely to pack particularly useful orbits balanced against the risk of debris or other satellites colliding into them, or how to deconflict frequencies used for astronomical observations, 5G internet, and a future interplanetary communications regime. Non-spacefaring, emerging, and developed space actors alike have an interest in making sure humanity is able to continue to use outer space for peaceful purposes and socioeconomic benefit over the long term. It is therefore important that all stakeholders are able to contribute to the formation of rules and norms for space.

A space program provides a focal point through which a nation can represent and advance national and collective interests at regional and international forums, including the UN ITU World Radiocommunication Conferences (WRC), UN Committee on the Peaceful Uses of Outer Space (UNCOPOUS) sessions, and other forums. As the New Space sector accelerates and diversifies space activity, more countries are participating in UNCOPOUS and other space-oriented organizations, like the International Astronautical Federation (IAF). Advancements in international law and norms, space sustainability, and management of space resources are top interests of these organizations.

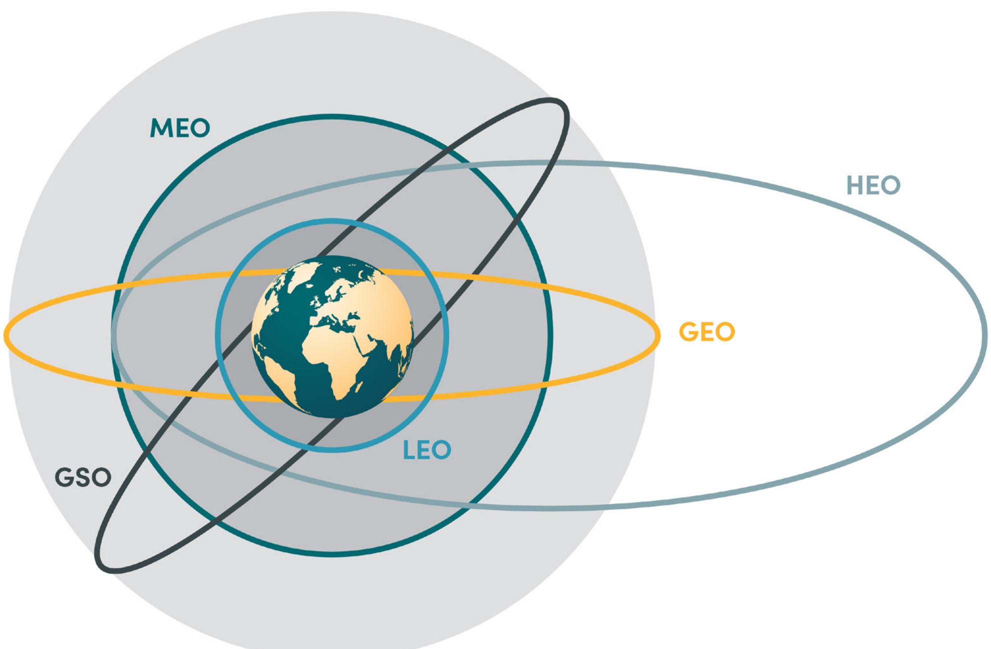
UNCOPOUS, the UN First Committee (dealing with disarmament and international security), and the International Telecommunications Union (ITU) are the primary assemblies in which the international community develops and codifies the rules for outer space activities. Increasingly, orbits and spectrum are being regarded as limited natural resources that must be used rationally and equitably. With the increasing congestion in Earth orbit and cis-lunar space (the region of space from the Earth out to and including the region around the surface of the moon), there is a greater emphasis on developing norms for responsible behavior in space and identifying "lawful but awful" behaviors that, while not unlawful under international law, would be considered unfriendly and irresponsible or set bad precedents.

Spectrum management, moving through the national, regional, and international stages, is needed to protect frequencies used by commercial and government services by preventing harmful interference, for all countries, spacefaring or not. Radio-frequency interference (RFI) is when one emitter, a radio or satellite for example, interferes with the function of another. Good frequency management (or "harmonization") allows more emitters to operate in proximity, enables new technologies to develop and deploy, and generally reduces the cost of telecommunications equipment for all through standardization. At the national level, governments deconflict satellite operators and terrestrial telecommunications operators for domestic use of spectrum, ideally finding a balance that accommodates both satellite operators and terrestrial operators, while also maximizing the public good.

Radio spectrum use is constantly being renegotiated by the international community as new uses and standards are proposed and inefficient or outdated uses are phased out. It is important for developing countries to participate in these forums to contribute broad concerns, interests, and perspectives, as well as pursue specific interests, such as setting standards that include technical requirements that best support their domestic telecommunications sector or maximize consumer access to broadband (Manner 2021).

An international organization, the ITU, actively coordinates all satellites' use of spectrum. A satellite operator must first contact the responsible government institution (often the national frequency regulator) and submit a filing–or application–for the satellite system. Once the state has approved and licensed the operation of the proposed satellite, it submits a frequency request to the ITU. If another member state is concerned the proposed project could cause interference in their existing or planned systems, the ITU will encourage a technical bilateral discussion, with the goal of ensuring both systems can co-exist without interfering with each other.[11] The ITU also actively manages geosynchronous orbits (GSO), inclusive of GEO, and provides regulatory procedures for non-geosynchronous orbits (NGSO).[12] The ITU's Radiocommunication Sector is responsible for assignment of orbital slots to member states on a first come, first served basis. To achieve this, the ITU identifies a satellite's specific planned orbital parameters (west or east

FIGURE 1.4 Overview of satellite orbit types



Note: Satellites in geosynchronous orbit (GSO) or its subset, geostationary orbit (GEO), both match the speed and direction of the Earth's rotation. Viewed from Earth, satellites in GEO appear "stationary" over a point on the equator, while satellites in GSO "move" north and south of the equator, depending on the orbit's tilt (or "inclination"). Other orbits include low Earth orbit (LEO), mid Earth orbit (MEO), and high Earth orbit (HEO). HEO can also stand for highly elliptical orbit. The majority of satellites in orbit in 2023 are in LEO.

Source: Kosiak 2019.

11 See the ITU website at https://www.itu.int/hub/2022/02/itu-space-interference-free-satellite-orbits-leo/

12 ITU, "Non-Geostationary Satellite Systems," last modified June 2021, https://www.itu.int:443/en/mediacentre/backgrounders/Pages/Non-geostationary-satellite-systems.aspx.

degrees longitude), type of frequencies used, and covered regions (or "footprint"). From there, member states reference national regulations to license their use of assigned GEO slots. As of 2022, there were about 540 GSO satellites in operation, with about 40+ new satellites launched each year. An ITU-assigned orbital slot for newer satellites is generally +/-.1 degree, or 150 kilometers (km; 90 miles), wide, though many countries "stack" or "cluster" satellites within a designated slot with just a few kilometers separation. Otherwise, the UNOOSA maintains the "Register of Objects Launched into Outer Space," on the basis of a Convention that came into force in 1976. Space-faring states maintain their own national registry of satellites and provide information on their space objects to the UN Register, but, beyond frequency coordination, there is currently no UN approval process for using low Earth orbit (LEO) and mid Earth orbit (MEO) (see Figure 1.4).[13]

Left alone, a satellite will shift from its intended orbit owing to Earth's uneven gravitational pull, gravitational attraction of the sun and the moon, and the radiation pressure of the sun and, for satellites in LEO, the drag of residual atmosphere. To compensate, satellite operators routinely "boost-up" satellites to keep them in their designated orbits. However, a growing field of dead satellites, rocket bodies, and debris, both large and small, is steadily increasing the risk of collision, or worse yet, a cascade of collisions, known as "Kessler Syndrome" (Wall 2021). The risk of colliding into debris is highest within 2,000 km of Earth's surface, in LEO, with the greatest concentration of debris found near the 800–850 km range. LEO is the simplest orbit to reach, and so has a higher percentage of non-maneuverable and experimental satellites than other orbits; overall, it hosts the majority of satellites in operation today. UNOOSA and the Inter-Agency Space Debris Coordination Committee provide guidelines that strive to prevent adding debris to space. Several space actors, like China, the US, and others, and the private sector are building experimental satellites capable of removing existing debris and are tentatively exploring the processes and legal requirements for clearing debris from orbit. These efforts are tempered by a significant security concern that any nations' debris removal capability could also be used to interfere with operational satellites during a time of conflict. Regardless of a nation's direct control of any satellite, all states use satellites (for PNT, remote sensing, communications) and therefore have a vested interest in keeping the space environment peaceful, orderly, and accessible to all. It is therefore important that all states contribute to the development of norms and laws governing this space.

SUMMARY OF SECTION 1

Space applications have transformed from "unreachable" to "routine." They underpin and extend many types of infrastructure such as telecommunications, utilities, and financial, security, and market intelligence. Satellites are a part of the broader data ecosystem, collecting, moving, and transmitting or broadcasting data, and supporting e-governance and e-commerce. Space is an available tool that can be used to grow the economy, enable UN SDGs, and connect to the global economy. It supports a nation's ability to protect its resources, plan and build resilience against all sorts of natural and human-made disasters. Developing foundational space capabilities supports greater technical independence and enables meaningful participation in the global regulation and management of space resources. Even modest domestic space capabilities make it possible for a state to leverage substantive existing space services. Section 2 will unpack the concept of foundational space capabilities and discuss recommended roles and compositions of a space policy, strategy, and office.

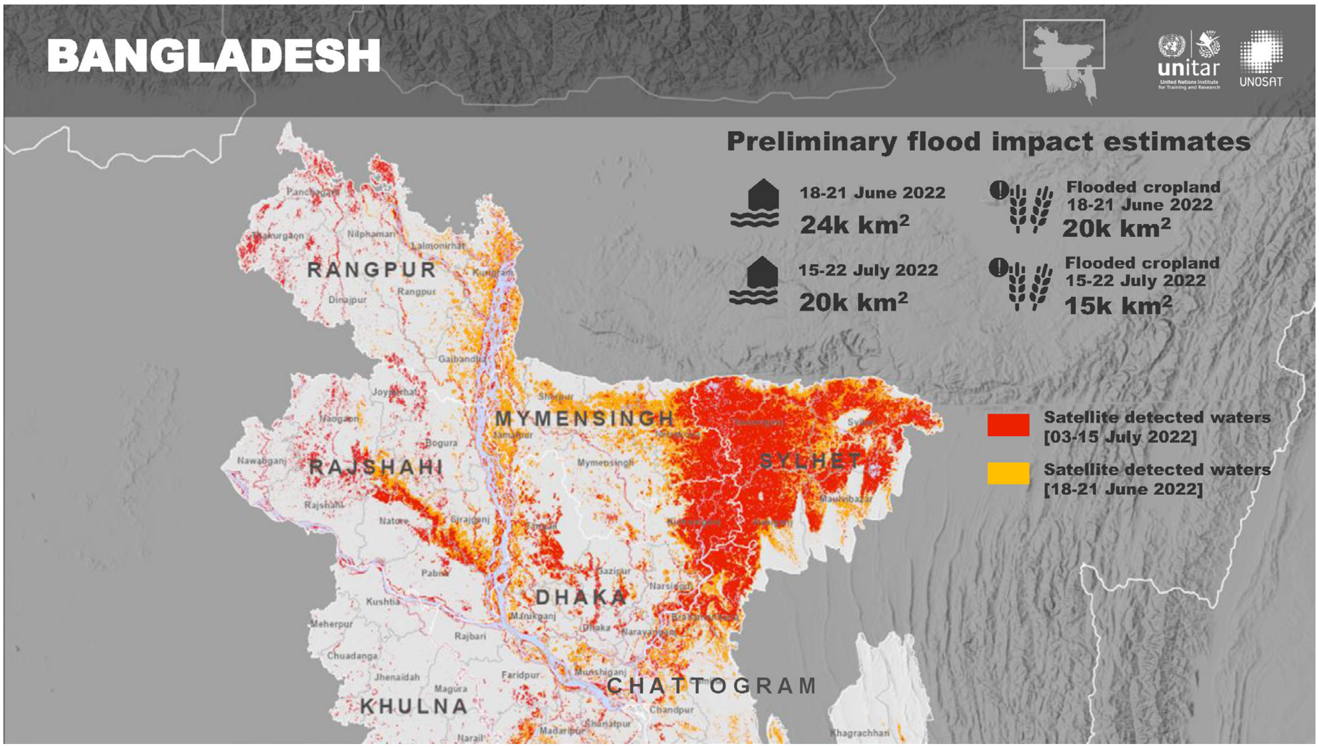
13 UNOOSA, "United Nations Register of Objects Launched into Outer Space," last modified December 13, 2022, https://www.unoosa.org/oosa/en/spaceobjectregister/index.html.

Annex 1A. Use Cases

Use Case 1. International Charter on Space and Major Disasters action in response to flooding

In response to major flooding in Bangladesh in June 2022, the United Nations' UNITAR/UNOSAT used Canadian RADARSAT imagery to produce a map to support disaster response efforts (Figure 1A.1), under the International Charter on Space and Major Disasters.[14]

FIGURE 1A.1 Screen shot of a UNITAR/UNOSAT remote sensing product



Source: UNITAR and UNOSAT, "Preliminary Satellite-Derived Flood Assessment as of 15–22 July 2022, Bangladesh," July 29, 2022, https://disasterscharter.org/.

Use Case 2. China's Broadband Village and India's BharatNet

China ran a program called "Broadband Village" in the rural areas of six western provinces from 2014 to 2019. In a study published in 2021, researchers found that the program improved the income of rural residents by approximately 1.5 times (Liu et al. 2021). India has a similar program underway, called "BharatNet," which connects all of the "Gram Panchayats" or village-level government offices, especially in remote areas of the northeastern states that lack terrestrial connectivity. Village offices are connected using Indian communication satellites GSAT-19 and GSAT-11 and commercial solar-powered earth stations. India has greatly increased government services, ranging from land records to telemedicine, to its rural areas through this program.

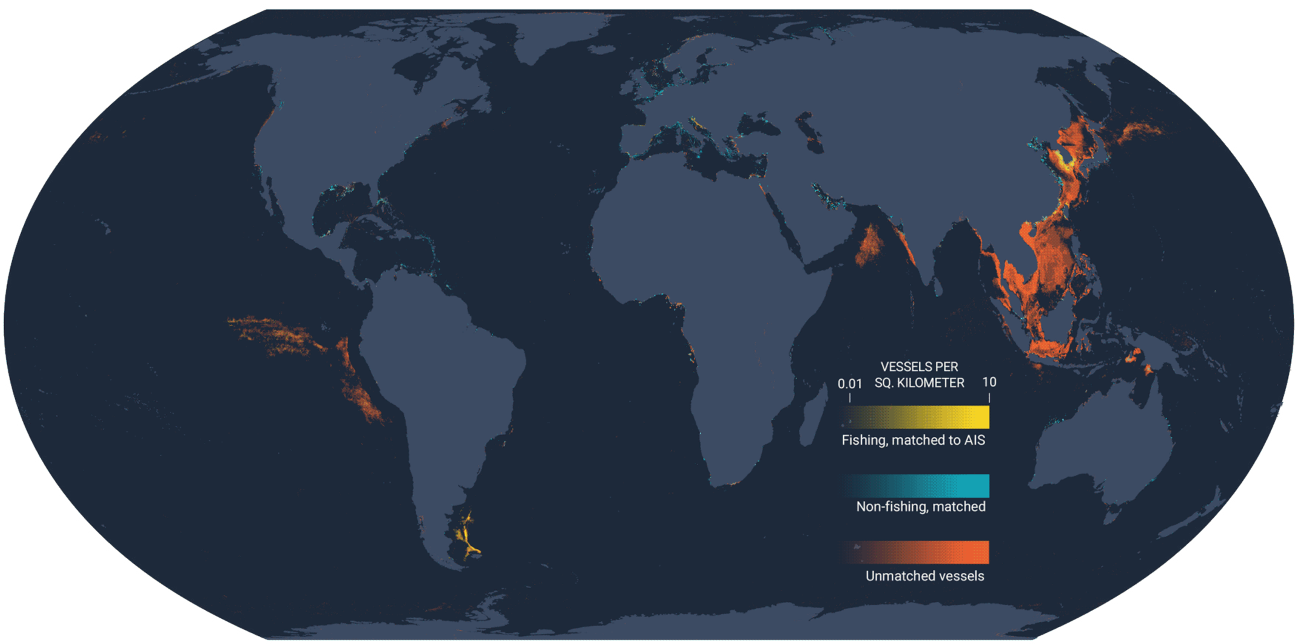
14 See the 2022 Activation List for the International Charter on Space and Major Disasters, https://disasterscharter.org/web/guest/charter-activations.

Use Case 3. Using space applications to detect and respond to illegal fishing

The International Maritime Organization and other management bodies require large ships, including many commercial fishing vessels, to broadcast their position using an automatic identification system (AIS) transmitter to avoid collisions. Each year, more than 400,000 AIS devices broadcast vessel location, identity, course, and speed information. Ground stations and satellites pick up this information, making vessels trackable, even in the most remote areas of the ocean, so long as their AIS beacon is turned on and operational. When conducting illegal fishing, many ships just turn off their AIS beacon to make it more difficult for maritime enforcement. Although AIS is a valuable source of information, only about 2 percent of the world's roughly 2.9 million fishing vessels carry AIS, according to Global Fishing Watch, a maritime-focused nongovernmental organization (NGO). Other types of free or commercial satellite data and processing can help fill in the blanks to support maritime fishing. Global Fishing Watch publishes remote sensing data from a satellite-based infrared sensor that looks for boats' lights (Kroodsma 2022; see Figure 1A.2). Companies like Hawkeye are selling data from satellites detecting faint signals emanating from their navigation radars and radio communications (The Economist 2021).

FIGURE 1A.2 Screen shot of Global Fishing Watch report

New Global Fishing Watch technology merges with nighttime satellite images with GPS datasets to observe vessels not broadcasting their positions



Note: Vessels detected with the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor between 2017 and 2021, matched to automatic identification system (AIS) signals, reveal large, previously unmonitored fleets. Data Source: Earth Observation Group, Global Fishing Watch
Source: Kroodsma 2022.

Use Case 4. Remote sensing and "radical transparency"

State and nonstate actors are increasingly using free, commercial, or shared data to monitor and act upon domestic and global activity. The Asia Maritime Transparency Initiative (AMTI), for example, uses data from DigitalGlobe to monitor ongoing territorial disputes in the South China Sea. Amnesty International has begun documenting atrocities, such as mass graves in Burundi, "clandestine" graves in Mexico, and the impact of Russia's 2021 invasion of Ukraine (Farfour 2019; Mondragón et al. 2022).

SECTION 2.

What is Space Capability?

"Space capability" is the ability to access, use, and contribute to space-related infrastructure, as well as access and use space-based natural common resources. These resources include the electromagnetic spectrum and room for satellites in particularly useful orbits (slots). Space-related infrastructure includes satellites and associated ground-based systems. In the future, new natural resources will likely include various raw materials extracted from asteroids or the Moon, like metals and water, that would support Earth-based industry or further in-space activities, such as in-space manufacturing, tourism, bases on the Moon and on Mars, and so on. The focus of this section is to describe those space capabilities best prioritized for an early space program—that is, foundational space capabilities.

This section describes the basic components of geospatial, PNT, and communications satellite systems and explores supporting skillsets, institutional support, and policy frameworks. The following pages also illustrate how a government space office and program could further the missions of non-space-focused ministries. Last, this section discusses possible program and office structures.

THE SPACE CAPABILITY LADDER

Historically, space capability development was thought of in terms of a state's ability to bespoke build and launch progressively complex satellites into orbit. (Wood 2012) This would start with procuring and building satellites designed for progressively more challenging orbits, then establishing a space agency and perhaps culminating in a domestic launch capability.

However, governments no longer need to marshal the resources to launch their own satellites to leverage space applications. The "New Space" private sector's space-as-a-service is a booming industry, a business model in which customers can buy access to satellite data or broadband without having to build satellites or launch vehicles themselves. Many developed space actors are providing space as a public good, like PNT and remote sensing data (especially for topics of broad concern like climate change). Multinational and public-private endeavors are increasingly pooling resources and risk to achieve space capabilities (Dewesoft 2022). Private, public, and shared capabilities still need a partner able to *use* said services.

If, however, a state builds a foundation with leadership, a pragmatic policy and strategy, and a proactive implementation plan, it can fully leverage available space services, advance its technical independence, and grow its domestic space ecosystem. Rather than retreading the path of the pioneering (and very well-funded) space agencies, such states can focus limited resources on holistically building on strengths that offer the most promise for their economy and national interests.

Accordingly, the "Space Capability Ladder" is divided into two major sections: "foundation" and "options" (Figure 2.1). The "foundation" layer enables a government to protect its current use of space, maximize the usefulness of existing space infrastructure, accelerate and stabilize the development of domestic space-related technologies, and participate fully in the formation of laws and norms for space. Building foundational space capabilities does not necessarily focus on putting a satellite into orbit or building a launch facility; rather, it is a process through which a government can decide what effort

FIGURE 2.1 The Space Capability Ladder

Options	Build and Operate Locally	8	Satellite Applications; Ground Equipment Manufacturing; Satellite Manufacturing; Launch Industry
	Build through Mutual Collaboration	7	
	Build with Support in Partner's Facility	6	
	Procure, with Training Services	5	
Foundation	Space Policy, Strategy, Office and Ecosystem	4	Cultivate a Space and Data Ecosystem
		3	Establish Foundational Space Capability (consult, localize, coordinate, manage, represent and regulate)
		2	Establish Government Space Office (assign staff, budget, objectives, plan)
	Preparation	1	Map Existing Space Applications Use (i.e., weather and climate, telecommunications), Stakeholders (i.e., government offices, universtiy programs, businesses, civil clubs and associations)

Note: This space capability ladder shows how establishing foundational space capabilities enable countries to "rent" some capabilities while selectively concentrating effort and resources on other areas to advance endemic, technical independence.

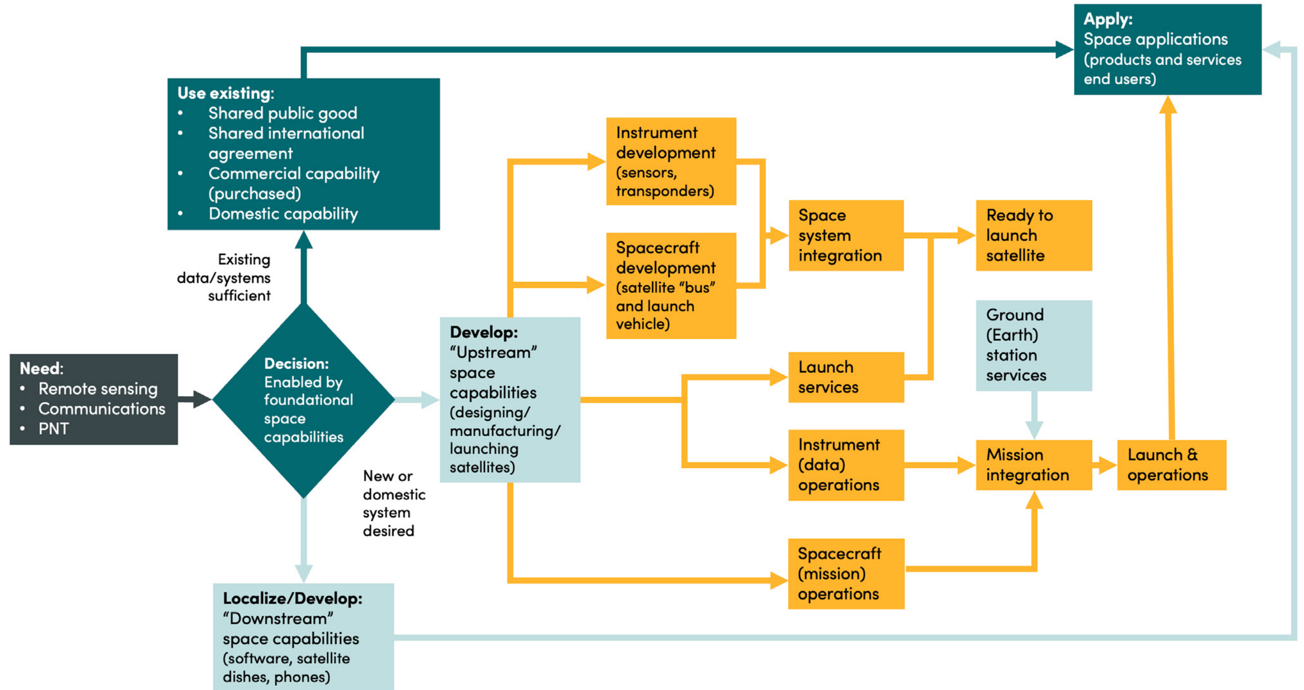
would provide the best return on investment, considering a state's priorities, concerns, economy, and so on.

This strong foundation (steps 1-4) provides maximum flexibility for future growth, development, and cooperation in any number of space specializations, such as:

- **Space applications**. Those activities using space technology (remote sensing, communications, PNT) that result in a product or service to the benefit of the economy, society, or national interests. These include products like business or military intelligence reports, information dashboards, phone apps, and telephony and internet access, support to city planning, among other uses. Space capabilities, either focused on Earth or looking out into space, can also be applied to advance scientific knowledge.
- **Support to ground equipment manufacturing**. The design and manufacture of equipment based on Earth used to communicate with or operate in-space platforms. This includes satellite control stations, satellite dishes, portable terminals, and other space-related equipment that is designed to stay on the ground.
- **Satellite manufacturing**. The design and/or manufacture of satellites and other hardware and software intended to operate in space, as well as subsystems and components.
- **Launch industry**. The design, manufacture, and/or operation of space launch vehicles needed to launch people or hardware into space. Rocket technology in the form of sounding rockets can be used to study the upper atmosphere (aeronomy), ultraviolet and x-ray astronomy, and microgravity, and to test remote sensors or use sensors for a brief but useful synoptic view of the Earth or space.
- **Future**. Disciplines will continue to emerge, including space tourism, asteroid mining, and in-space manufacturing. The global space value chain will continue to evolve and diversify. This will include software, exotic materials, specialized hardware, and other goods and services.

Figure 2.2 illustrates as a decision tree the flexibility provided by foundational space capabilities. Needed space capabilities are represented in the dark gray box. With foundational space capabilities, a state is best prepared to decide if existing data and systems are sufficient and then to apply them effectively (teal lines). If a certain capability doesn't exist, or if the state wants to establish a domestic system, then the state can focus resources to develop said capability (light blue lines). "Upstream" space capabilities such as satellite instrument development or launch services take greater resources and time to develop (yellow lines). "Downstream" includes downlink capabilities (ground terminals, relay systems, connection

FIGURE 2.2 Foundational space capabilities-enabled flow chart (for small satellites)



Source: Modified version of the "general process for supporting SmallSat development, launch, and product acquisition" diagram from National Academies of Sciences, Engineering, and Medicine 2022.

to telecommunications, data analysis and storage, and end user products, such as broadband connection, platforms, apps, maps, etc.).

FOUNDATIONAL SPACE CAPABILITIES IN DETAIL

Foundational space capabilities include the following roles and capabilities, illustrated by Figure 2.3.

- **Consultation, Advocacy, and Localization**. *Ability to provide internal technical advice and to fully leverage technology for local needs.*

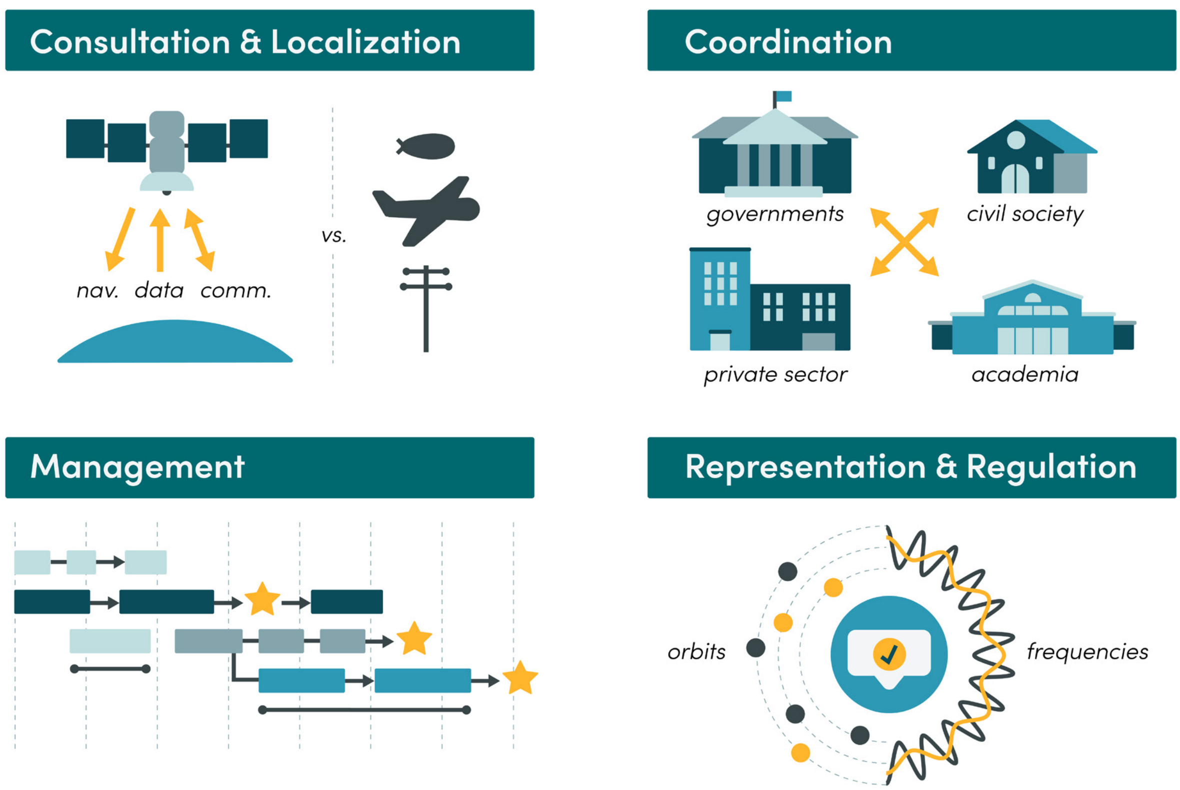
  A government should establish sufficient internal human capability to advise policymakers on space-related technology, to include position, navigation and timing data; Earth observation data; and the space segment of telecommunications. Sufficient human capability includes both understanding and protecting existing uses of space and the ability to advise policymakers on new applications. For example, there should be an internal ability to advise government leadership on the acquisition of shared or commercial geospatial data and on uses that can support better governance, land use, tracking, security, transportation, research, and other national areas of interest. Additionally, as communication satellites continue to diversify and specialize, satellite internet broadband is becoming more affordable and increasingly well suited to reach remote, difficult, and sparsely populated areas; thus government officials will need continued advice on developments in the space segment of telecommunications. As the world economy moves toward 5G and the Internet of Things (IoT), satellite broadband will play a greater role in data densification—the increasing density of data—flowing to populated areas as well. An internal ability to advise, manage, and regulate national spectrum frequencies and national satellite landing rights is crucial to balance market potential, public good, and emergency and security communications. Last, a government should have a degree of internal human capability to evaluate space-related versus alternative solutions (aircraft, balloons, ground-based infrastructure, traditional surveys, etc.) to address national priorities. Space applications are not always the most cost-effective or the technology best suited for a given situation. A country needs strong technical and procurement experts in the discussions to ensure, for example, that when the government is purchasing space-related services or products it is getting exactly what the country needs for a fair market price.

A government should strive to adapt or build space capabilities and applications to address the needs of its population, a process termed "localization." From researching the mix of earth observation data that is optimized for local crops and farming practices to developing cell phone applications focused on local needs and languages, localization is the action of maximizing the usefulness of space capabilities in a situational and culturally relevant way. A government should advocate for localization of satellite capabilities through its space strategy and policies.

- **Program Management**. *Deliberate planning and development of space capabilities.*

  A government should invest in deliberate management of existing space-related activities. This includes non-space-specific skillsets, such as leadership, program advocacy, planning, budgeting, executing, reporting, and regulating domestic space-related activity. Especially for nascent programs, space will likely be an enabler of the data ecosystem, a means to gather and move data. Program management can also include actions coordinated with various arms of government. For example, an agency would work with the Ministry of Finance to create favorable conditions for domestic and foreign investment, or to encourage new space and data-related businesses.

FIGURE 2.3 Foundational space capabilities



Source: Modified version of the "general process for supporting SmallSat development, launch, and product acquisition" diagram from National Academies of Sciences, Engineering, and Medicine 2022.

- **Coordination**. *Proactive engagement internally with government organizations and with external academic, private, and social sectors.*
  A government should proactively connect government, academic, private, and social sectors in order to encourage the development of an interlinked space and data ecosystem. A space and data ecosystem is one in which human capital and space applications can grow in a decentralized way and flow between different sectors, thus contributing to a positive feedback loop. A government should coordinate its activity between ministries, departments, and agencies and provide input to science, technology, and innovation-related efforts. It should spur growth of the space and data sector through tools such as scholarships, exchanges, grants, contracts, and strategic direction. For example, the government may solicit bids for a contract to develop a service. A local company may win this contract but then need to grow its staff to accommodate the workload, thereby creating a demand signal for local academic institutions to produce graduates with these skills.

- **Representation and Regulation**. *Participation in the global space sector and in the development of rules and norms. Provision of regulatory structure needed to fully leverage space resources and technology.*
  Space common resources include the radio-frequency spectrum and orbital slots used by various national and commercial satellites. There are a finite number of frequencies, and a finite number of satellites able to fit into a given orbit, so these resources need to be actively and collectively managed to preserve them as global resources. Norms for space operations and safety in context of a rapidly growing in-space economy are in development, and a government without representative apparatuses will find it difficult to advance national, regional, and collective interests and to contribute to the development of these norms. Important regional and world forums for the maintenance and establishment of norms and pursuit of interests include ITU and its World Radio Conference (WRC), UN Committee on the Peaceful Uses of Outer Space (UNCOPUOS), World Meteorological Organization, Group on Earth Observations for Cooperation in Earth Observation, and other regional and international bodies.

  National legislation needs to be adapted both to manage a budding space capability and to take full advantage of space applications, such as allowing satellite imagery as evidence in a court of law or to support the documentation of landownership.

PUTTING FOUNDATIONAL SPACE CAPABILITIES TOGETHER

It's one thing to list foundational space capabilities and another to translate these roles into specific actions. Table 2.1 uses an intention to expand internet access using communication satellites to illustrate the interplay between a government space office or advisor, other government offices, the private sector, academia, and civil society. The space office or advisor would have a role in each category: consultation and localization, coordination, management, and representation and regulation. Such work enables a government to protect its current use of space (such as national reliance on geostationary communication satellites), maximize the usefulness of existing space infrastructure (evaluate possible space-as-a-service offers and private sector access to in-country satellite earth stations), and build a strong foundation for the development of domestic space-related technologies (encouraging workforce growth, private sector activity, and institutional support.)

This interplay can be repeated with remote sensing and PNT data, or through the lens of a particular potential application. No matter how modest a space program, it can make a significant impact simply by providing expertise at the right time and place. Figure 2.4 on page 39 illustrates a space office's complementary and advisory roles in supporting security, communications, education, and so on.

TABLE 2.1 Example of interplay between a government space office or advisor and other government offices, private sector, civil sector, and academia

CONSULTATION & LOCALIZATION	COORDINATION
▶ Space advisor, Ministry of Communications (MoC), and policy representatives discuss emerging technology options. ▶ Space advisor supports government evaluation of national readiness to expand use of satellite broadband.	▶ Government leadership communicates desire to expand internet access via news articles and speeches. It solicits academia, the private sector, and civil society for recommendations to extend internet access. It further offers tenders, grants, scholarships, with Space Office advising. ▶ Private sector develops business plan, submits proposals, and communicates to universities and tech trade schools the need for new workforce skillsets. ▶ Academia refocuses research on localized and regional satellite broadband and updates curricula to meet new demand.
MANAGEMENT	**REPRESENTATION & REGULATION**
▶ Space office identifies the potential expanded use of satellites in telecommunications infrastructure. ▶ Space office meets with stakeholders (policymakers, MoC, telecommunications companies' representatives, perspective satellite broadband providers, representative users) to understand needs/capability. ▶ Space office develops annual workplan to include actions supporting integration of satellite capabilities, submits plan and request for funding in coordination with MoC.	▶ MoC posts a licensing regime to a government website. It includes clear guidance on how to obtain authority to use certain radio frequencies and to operate in-country. ▶ MoC frequency managers ensure satellite transmissions won't cause interference at regional or international by conferring with International Telecommunications Union. ▶ MoC allocates frequencies to satellite and telecommunication companies. Provides update on in-country space-related activity to Space Office.

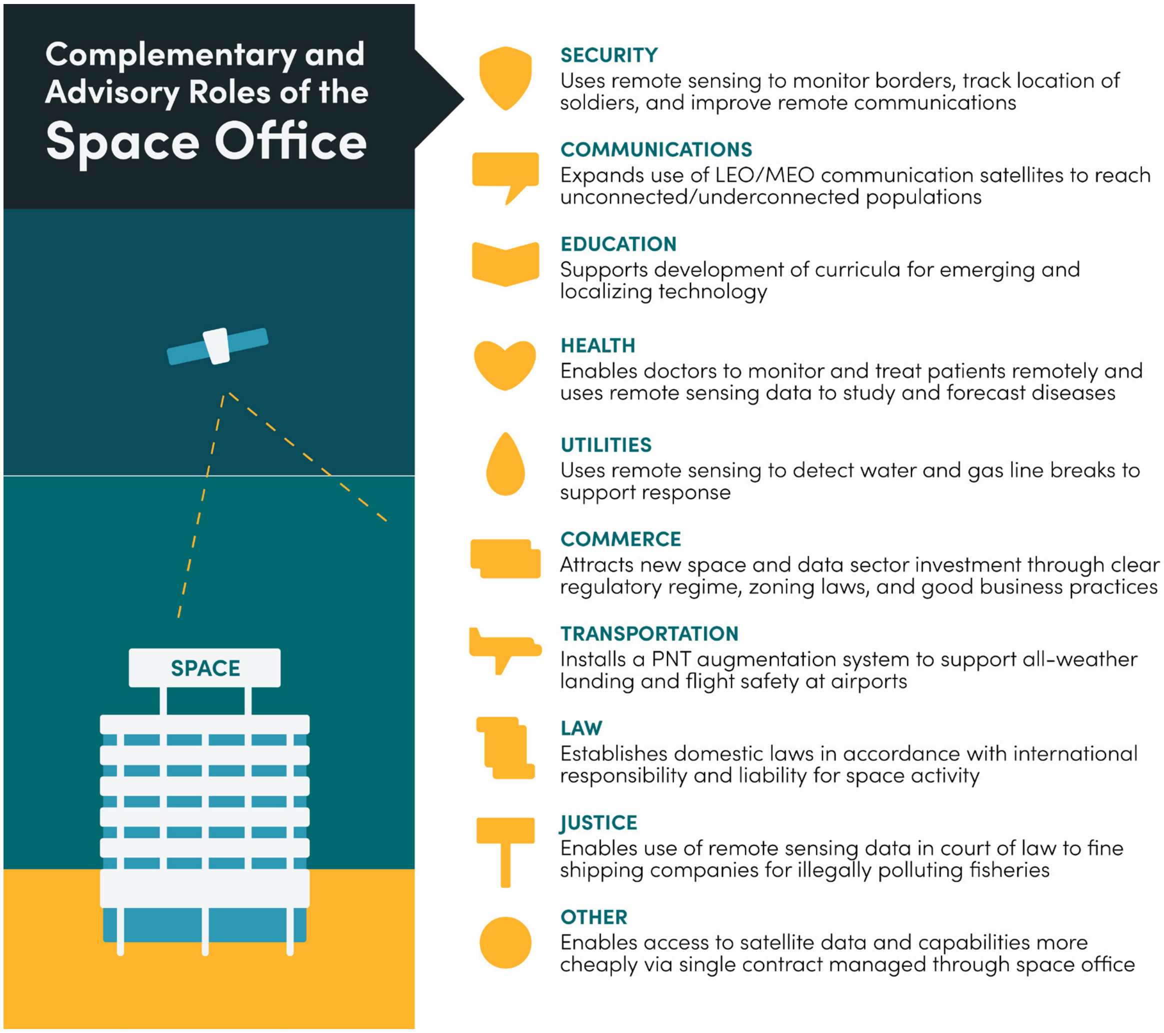
GEOSPATIAL ACTIVITY (REMOTE SENSING AND PNT) IN CLOSER DETAIL

Looking more closely at geospatial applications, this capability can be subdivided into different types, each important to the space and data ecosystem in its own way and crucial to extracting the most use out of free, commercial, shared, or domestic remote sensing capabilities. They range from the most technical activity, scientific research, to the most accessible activity, use of various geospatial products (Figure 2.5).

Researchers and scientists start the value chain by investigating new ways to collect and understand data, ideally focused on locally relevant research questions such as "What are the optical and near-infrared spectrum 'signatures' of a healthy crop through its lifecycle?" (Figure 2.6). A scholar based in a foreign country is less likely to be sensitive to locally relevant research questions. For example, the local crops in the American Midwest are corn, soybeans, and wheat grown in monoculture blocks with an average farm size of 175 acres. In West Africa and South America, local crops are often mixed and grown on smaller plots of land, averaging between 2.5 to 12.3 acres per farm.[15] The US-based researcher will more likely acquire and analyze data and design algorithms that are optimized for the US Midwest, and by nature the results would be less useful in areas with different vegetation, seasons, soil,

15 "Agricultural Expansion across West Africa: West Africa," Earth Resources Observation and Science (EROS) Center, US Geological Survey, (accessed August 13, 2022), https://eros.usgs.gov/westafrica/agriculture-expansion.

FIGURE 2.4 Complementary and advisory roles of a space office

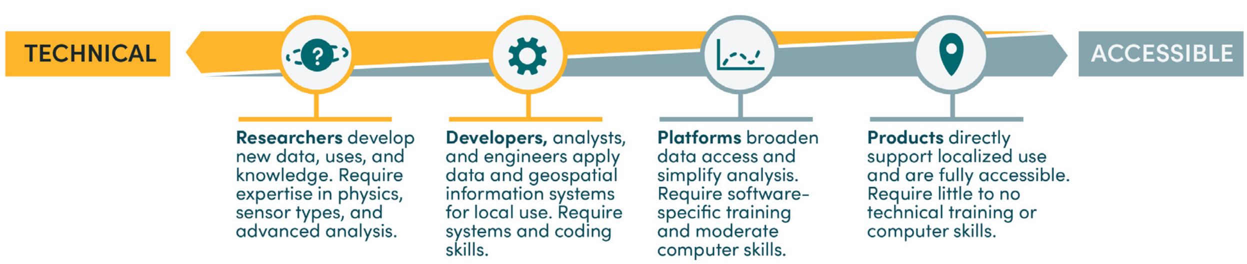


Note: LEO = low Earth orbit; MEO = mid Earth orbit; PNT = positioning, navigation, and timing.

pests, and other factors. If the majority of such research happens in only a handful of countries, a research gap will continue to exist, and even widen, over time (Zhao et al. 2022).

Another way to encourage domestic research is to make authoritative data (remote sensing and otherwise) easily accessible for low or no cost, such as by establishing open data portals. A data portal is an online application or website that holds data from different sources using current industry standard protocols and formats, organized under subsets or categories, to make it easy for users to find and use. Going a step further, open data ecosystems (ODE) is a concept for

FIGURE 2.5 Types of geospatial and position/navigation/timing activity

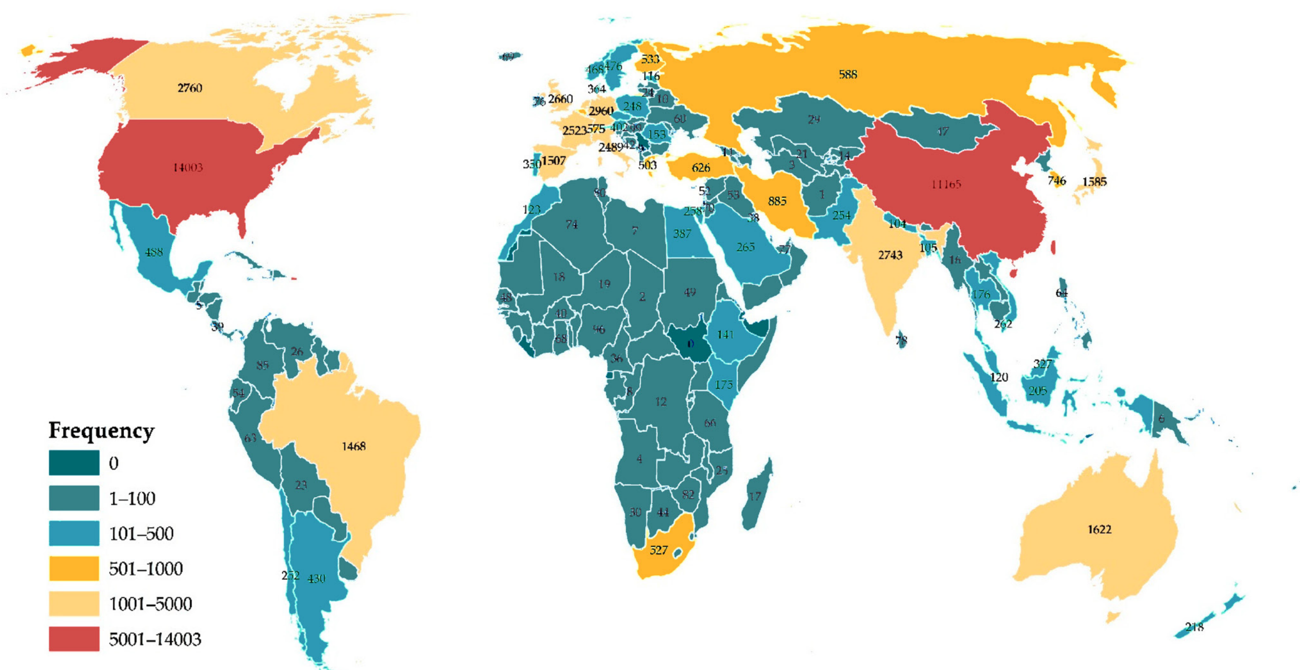


data sharing through public licenses in software ecosystems, leveraging both open-source software (OSS) and open government data (OGD). These open portals or ODE simplify access to and lower cost for data, ready to be used for new insights and applications by academia, government, civil society and private sector. In short, open portals and ODE can more readily incentivize and integrate data (to include geospatial data) with other open-ended services such as research, crop insurance, subsidies, cash transfers, and buyer-seller discovery.

Geospatial developers and analysts focus more on applying existing data to locally relevant questions. They use geographical information systems (GIS) and geospatial coding to combine, process, organize, analyze, and apply data in new ways. Developers create geospatial platforms or products that make geospatial and PNT data more accessible to non-experts. In this subsector one could also include the creation of a national spatial reference system to broaden the use of geodetic, photogrammetric, and remote sensing technologies. This system consists of networked points, a well-defined and updated shoreline, a network of Continuously Operating Reference Stations (CORS), and a set of digital models that describe ongoing geophysical processes (like shifting of tectonic plates along fault lines) that produce spatial measurements. A spatial reference system is a type of infrastructure (within a digital ecosystem), in that it serves as a foundation for many types of private, civil, academic, and government activity. Such positional markers and reference data make it vastly easier to accurately overlay different types of remote sensing data and aids in all sorts of planning and activities, such as mining, forestry, agriculture, and airport operations.

Geospatial-related scientific research requires extensive post-secondary education, expertise in physics and data science, understanding of various sensors, and an ability to conduct advanced and novel analysis (Table 2.2). Developers typically have completed secondary school and often have post-graduate experience and extensive self-directed or on-the-job training in GIS (in Esri ArcGIS, QGIS, GeoMedia, etc.) and in coding (Python, SQL, JavaScript, etc.). Human capital with these skills is in demand in strong data ecosystems,

FIGURE 2.6 Worldwide distribution of 45,673 papers related using data from 15 well-known remote sensing data sources



Note: Countries colored in blue used the least amount of remote sensing data.
Source: Zhao et al. 2022.

TABLE 2.2 Examples of human capital, institutional support, policy, and regulatory framework that make up the ability to conduct this range of geospatial activity

ACTIVITY	HUMAN CAPITAL (EXAMPLES)	INSTITUTIONAL SUPPORT (EXAMPLES)	POLICY/REGULATORY FRAMEWORK (EXAMPLES)
RESEARCH	Data scientists, physicists, engineers, geologists	University system and facilities, research grants, electricity, computers, internet access, data storage capacity	Policies that support funding for research and research institutions, propose topics, and encourage collaboration. Government-assisted bargaining for commercial/shared data and spectrum use
DEVELOPMENT, ANALYSIS	Academics focused on applied sciences, software engineers, database and systems designers, geospatial entrepreneurs	Good business environment, small business/startup loans, incubators, accelerators	Policies that support business growth. Open-data portals, clear data-handling and storage regulations. Protection of intellectual property, including patents
PLATFORMS	GIS specialists and programmers to design and run a platform, in concert with subject experts (agriculture, weather, etc.). End-users trained to use the platform; can include policymakers, managers, evaluators, specialists	Funding, training, platform maintenance, oversight, electricity, data infrastructure	Proactive engagement from government with nonprofit/foreign developers to ensure stakeholders are included and core questions addressed. Open-data portals, clear handling and storage regulations
PRODUCTS	Empowered citizenry that is ready to find and use reputable data in multiple forms	Education, public engagement	Policies that support digital literacy and regulations that protect users. Policies that encourage use of geospatial and PNT data and satellite communications.

thus it is difficult to hold onto such workers if they are not being actively engaged domestically.

The "accessible" side of figure 2.5, however, is more focused on removing as many roadblocks as possible for the (non-space-specialized) end user. Platforms, like the Famine Early Warning Systems Network (FEWS NET) or GEOspatial Platform for Andean Culture, History and Archaeology (GEOPACHA), are organized to answer a specific enduring question for a particular audience. FEWS NET, for example, monitors a large area for indicators that point to current or future food insecurity (crops affected by drought, fires, conflict, etc.). GEOPACHA is designed to support surveys in South America by observing large areas and highlighting archaeological features of interest for further investigation. The data going into these platforms could be used for other purposes (flood monitoring, land-use surveys, etc.) but they are being used in this one particular way for the platform. Development aid funding does tend to support this type of geospatial activity more than others because the resulting platform most clearly addresses the issue driving the aid (FEWS NET, for example, clearly addresses food insecurity.) Moreover, platforms and dashboards require end users to have some computer skills and software-specific training. These end users tend to consist of a narrow strata of those interested (journalists, civil society, and others) and empowered to act (policymakers, administrators, and similar leaders). There is usually a concern about the ability of external actors to keep up maintenance and data and about the difficulty in tracking actual use.

The most widely accessible geospatial and PNT activity is the use of space capabilities baked into a variety of products, be it smartphone or computer applications, television and radio broadcasts, texts between friends, and so on. Such products include the weather forecast that goes to farmers and fisherman, the transfer of funds from one person to another, the detection of a new oil slick by maritime police, the implementation of a tax system based on physical property changes impartially observed over time, and thousands of other use cases. The proliferation and diversification of use by end users in governments, the private sector, civil society, and academia are an indicator of a healthy digital ecosystem, and themselves exponentially expand the usefulness of existing space infrastructure.

SPACE SEGMENT OF TELECOMMUNICATIONS IN CLOSER DETAIL

The space segment of telecommunications consists of the mix of satellites and ground stations (also referred to as Earth stations, Earth terminals, and receivers/transmitters). The space segment works in concert with other technologies, such as undersea cables, terrestrial fiber, and microwave relay, to move information to and from data centers filled with computers busy storing and processing data (that is, the internet). There are about 8,000 data centers in the world, with the majority located in the United States (about 33 percent) (Daigle 2021). The largest data center in the world, however, is located in Langfang, China (Allen 2018). As discussed in Section 1, the bulk of the world's data are moved between continents and internationally to national nodes using terrestrial fiber or undersea cables. Satellites are most often used for the "middle mile," but they also support the national or regional backbone or "core network." Satellites are being increasingly used to reach end users directly [direct to home (DTH), "direct connectivity," or "the last mile"], as the cost of satellite broadband steadily decreases (Croshier 2022). New technologies, such as satellite-to-cell phone technology, offer increasingly affordable uses in commercial and military transportation, agriculture, oil, gas and mining, and utilities, as well as remote residential broadband connectivity (UNCTAD 2021) (Figure 2.7).

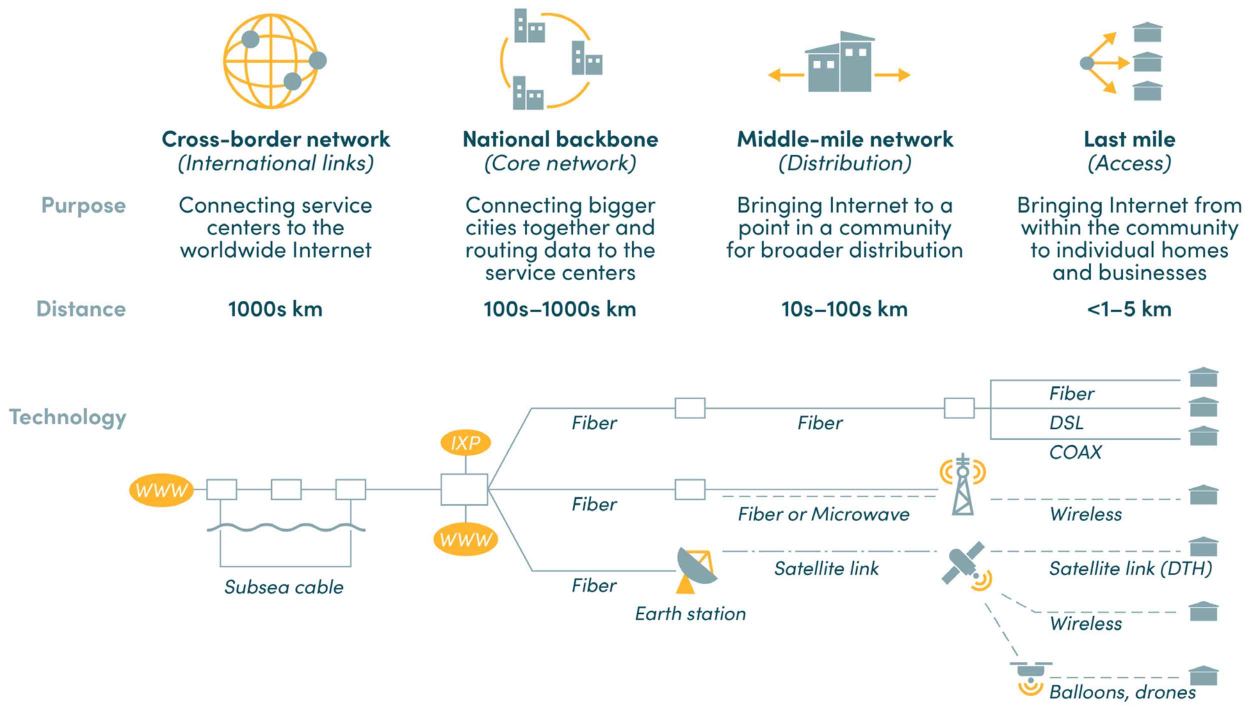
Maximizing the good of non-terrestrial networks isn't limited to just selecting the hardware that is physically moving data around. One can also look at the space segment through the same lens as was used for geospatial and PNT data, sifting activity into roughly four categories: researcher, developer, platform creation, and product design. (See Figure 2.8.) Domestic researchers and scientists contribute to the global effort to cram more data into a finite spectrum. Developers, analysts, and engineers Figure out how to retool domestic telecommunications infrastructure to accept new technology. Telecommunications and mobile service operators scale up and incorporate these capabilities into the services offered to end users. End users simply have cheaper or more accessible data, manifesting in various ways, be it their cell phones, IoT, or in mediums yet to be imagined.

The space communications community, however, generally sorts itself into three broad categories (Table 2.3; see page 44). This includes the space segment (satellites), ground segment (satellite control stations, large satellite dishes, industrial connections to the terrestrial telecommunications infrastructure), and user terminals (cell phones, small satellite dishes).

SHORT ORIENTATION ON SATELLITES' USE OF ELECTROMAGNETIC SPECTRUM

In the electromagnetic spectrum, satellites tend to use the subset radio spectrum (3 kilohertz [kHz] to 3,000 gigahertz [GHz]) for communications and the higher frequency optical spectrum to gather data—detect visible light, infrared wavelengths nearest to visible light (near infrared), and microwaves. There isn't a strict division between these broad categories. Optical communications, for example, use frequencies in the

FIGURE 2.7 Broadband infrastructure value chain, technologies, and reach



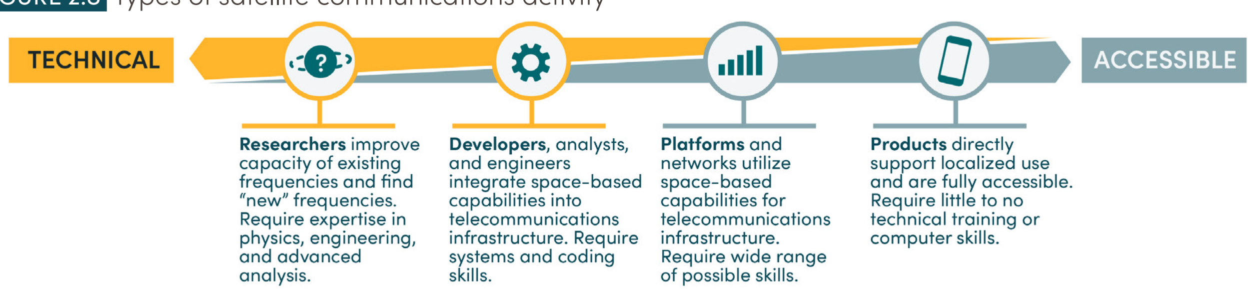
Note: Exploring technical options for telecommunications infrastructure, to include the "space segment" of telecommunications. A digital subscriber line (DSL) transmits digital data over telephone lines, usually made of one or more twisted pairs of copper wire and insulated by a plastic outer layer. Coaxial cable (COAX) is made of a core strand of copper or copper-coated steel, and is additionally insulated by a woven metallic braid. Both DSL and COAX transmit data as an electric current. Optical fiber, or just "fiber," is a flexible, transparent fiber made by drawing glass (silica) or plastic to a diameter slightly thicker than that of a human hair that can transmit data in the form of light. Optical fibers permit data transmission over longer distances and at higher bandwidths (data transfer rates) than DSL or COAX. Satellite direct to home (DTH) traditionally refers to the distribution of satellite data broadcast through space and the Earth's atmosphere directly to an end-user's receiver. Wireless is the two-way transmission of data between an end user and a satellite or a terrestrial access point (like a cell phone tower or a building-mounted antenna array).

Source: World Bank Group 2018 , fig. 1.2.

optical spectrum (e.g., lasers) to send data across space or to the Earth instead of using radio frequencies.

The two main characteristics of satellite communications are the ability to transmit these waves, called the "process of propagation," and the amount of information these waves can move, called "throughput." National spectrum managers and regulators issue licenses or permissions to use specific frequencies, called "allocations," to private sector companies or government entities. All satellites rely on such allocated or coordinated radio spectrum, to include communications (fixed services, mobile, television, radio), broadband internet (included 5G, in-flight, and maritime services), remote sensing (weather, intelligence), and global navigation and satellite systems (GPS, GLONASS, BeiDou, and other PNT satellite

FIGURE 2.8 Types of satellite communications activity



constellations). Governments also designate a range of frequencies that are license exempt (i.e., unlicensed). Unlicensed spectrum is usually limited to very low-power levels, meaning the signal can travel only a short distance, and includes Wi-Fi, baby monitors, key fobs, microwaves, and so on.

Satellite communication generally requires technical and business licensing to access ground stations and gateways (to the internet) in a specific country. It also requires regulatory approval for service provision to customers (end users) in every country of operation. Good national spectrum policy makes this process transparent, nondiscriminatory, and economically efficient and can accelerate citizens' access to new services and capabilities as new technologies and companies enter the market.

The ITU provides enabling provisions through regulations that ITU member states in turn reference to establish domestic policies and regulations. These include licensing and authorizations, spectrum user rights, revenues and fees, spectrum planning, and technical standards. The ITU manages the Master International Frequency Register (MIFR), a database that contains the spectrum characteristics ("frequency assignments") of emitters throughout the world. Table 2.4 provides a simplified overview of common radio frequency bands and applications (Weeden 2013). The ITU is discussed in greater detail under "Identifying Funding and Advising Support" in Section 3.

THE MANY FORMS OF A SPACE PROGRAM

Foundational space capability is built through a combination of management, policies, regulations, skilled workforce, physical space, hardware and software, and engagement with civil society, academia, the private sector, and the international community. A very modest program can still advance core functions, like advising the government on space-related technology and regulations and advocating for localization of space applications and operations. If empowered, program staff members can coordinate some government activity and

TABLE 2.3 Examples of human capital, institutional support, policy, and regulatory framework make up the ability to conduct this range of communications activity

ACTIVITY	HUMAN CAPITAL (EXAMPLES)	INSTITUTIONAL SUPPORT (EXAMPLES)	POLICY/REGULATORY FRAMEWORK (EXAMPLES)
SPACE SEGMENT	Develops, builds "upstream" capabilities. Satellite operators, software engineers, frequency managers	Research, development, testing facilities. Grants, scholarships	Technology-neutral policies (that ensure sufficient radio spectrum), balanced spectrum policy (maximizing efficient use and consumer welfare and state revenue), and accommodating zoning policies (for ground components like receivers/transmitters). Policies that support funding for research and encourage collaboration. Clear, transparent, and timely licensing regimes (includes radio frequency and authority to operate from the government)
GROUND SEGMENT	Academics focused on applied sciences, software engineers, database and systems designers, geospatial entrepreneurs	Good business environment, small business/startup loans, incubators, accelerators	
USER TERMINALS	Technicians familiar with DTH and wireless internet systems and options. Policymakers, developers, businesses, various professionals aware of space-related options	Funding, training, platform maintenance, oversight, electricity, data infrastructure	Policies that support business growth. Clear data-handling and storage regulations, accommodating zoning/data access policies that allow satellite receivers/transmitters. Clear and transparent Earth station licensing regimes.

directly represent or feed talking points to appointed representatives in order to advance national and collective interests at regional and world forums. A more robust program would be able to do more, more directly. These functions include regulating space activity, promoting space activity and implementing space activity. At some point, the program will need to split into more specialized functions, since it is problematic to promote and implement, and regulate, space activities.

Beyond size, the composition of a program matters. A space program can be military or civilian led, or a blend; it can be rooted in civil society; or it can operate through a public-private partnership. There is no one way to organize a space program, but its form does create certain strengths and weaknesses and influences how the program is approached for potential international cooperation. Some states, such as the United States, have separated their space program into

TABLE 2.4 Common radio frequency bands and applications

International organizations, like the North Atlantic Treaty Organization (NATO), the Institute of Electrical and Electronics Engineers (IEEE), and International Telecommunication Union (ITU), do not label bands in exactly the same way

BAND NAME			FREQUENCY (ITU)	COMMON USES	
ITU	NATO	IEEE		SPACE	GROUND
Very High Frequency (VHF)	A Band (0–250 MHz)	VHF	30–300 MHz	Satellite uplinks	Analog TV
Ultra High Frequency (UHF)	B Band (250–500 MHz) C Band (500–1,000 MHz)	UHF (300–1,000 MHz) L Band (1–2 GHz) S Band (2–3 GHz)	300–3,000 MHz	• Mobile satellite services • Satellite navigation signals (PNT)	• Analog TV • 2-way radios • Wi-Fi • Bluetooth • Mobile phones
Super High Frequency (SHF)	F Band (3–4 GHz) G Band (4–6 GHz) H Band (6–8 GHz) I Band (8–10 GHz) J Band (10–20 GHz) K Band (20–30 GHz)	S Band (3–4 GHz) C Band (4–8 GHz) X Band (8–12 GHz) Ku Band (12–18 GHz) K Band (18–27 GHz) Ka Band (26.5–40 GHz) V Band (40–75 GHz) W Band (75–110 GHz)	3–30 GHz	• Fixed satellite services • Broadband satellite services • Satellite uplinks and downlinks	• Weather radar • Amateur radio • Imaging radar • Air traffic control
Extremely High Frequency (EHF)	K Band (30–40 GHz) L Band (40–60 GHz) M Band (60–100 GHz)		30–300 GHz	• Inter-satellite links • Military communication satellite • Navigation satellites (GNSS)	• Microwave data links • Active denial system

Source: Table is adapted from Weeden 2013.

civilian (National Aeronautics and Space Administration [NASA] and National Oceanic and Atmospheric Administration [NOAA]) and military (US Space Force, US Space Command) organizations, while others blend these functions into one organization. The newly established Kenya Space Agency, for example, is a civilian agency whose leadership includes military officers.

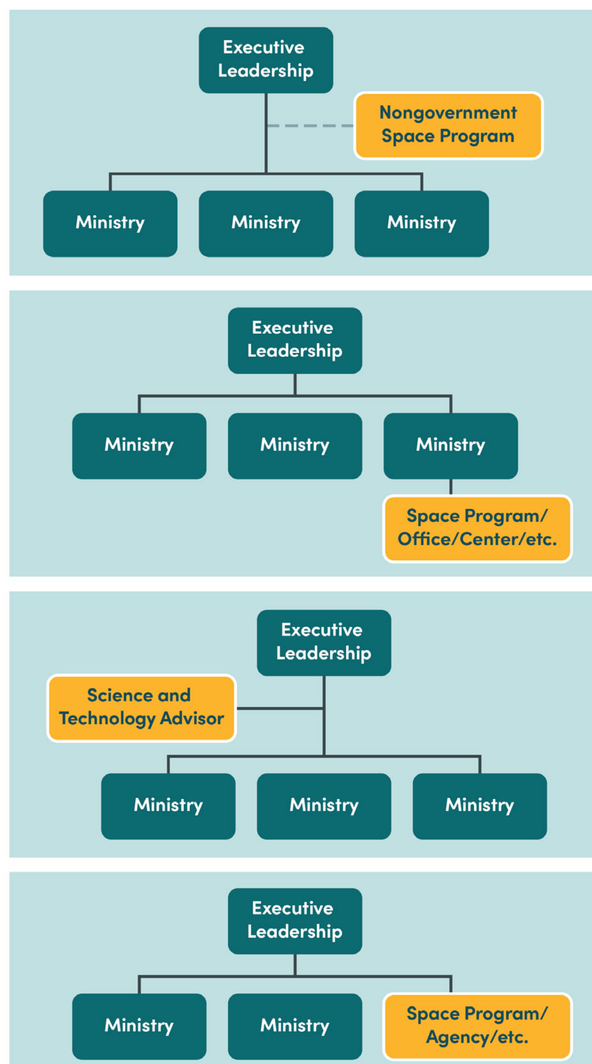
UNOOSA and long-standing international space organizations like the IAF tend to organize the international community around, and emphasize, nonmilitary applications, commercialization, research, and exploration, and encourage the peaceful exploration and use of space. Space has long been an arena where states in opposition could cooperate, as embodied by US and Russia (plus Canada, Japan, and ESA) cooperation in building and running the International Space Station. However, it's generally accepted that space capabilities and applications are dual use by nature, since using space to gather and relay information is useful for both military and civilian purposes. Military-related space cooperation tends to gravitate toward standing political-military alliances, such as demonstrated by the North Atlantic Treaty Organization (NATO). This thirty-member alliance routinely shares space capabilities for early warning (monitoring for missile launches, environmental monitoring, monitoring weather to support mission planning), secure satellite communications (supporting consultation and command and control), and remote sensing for military intelligence (building situational awareness, support planning, and decision-making).

A space program can also be established outside of the government structure proper, through civil society or in partnership with the private sector. This can create some ambiguity regarding the ability of the organization to also represent its host state's interests and intensions. The Sideralis Foundation in Ecuador, for example, is a civil space organization that serves to concentrate space-related expertise and advocacy as well as providing a forum for coordination and learning, but it isn't endorsed to represent Ecuador in international forums. In contrast, ArmCosmos is an Armenian private agency that officially acts on behalf of the government of Armenia and is charged with advancing the development of Armenia's commercial space industry, coordinating domestic activities, and facilitating international cooperation.

OPTIONS FOR HOUSING A SPACE PROGRAM

There is no one way to house a space program (Figure 2.9). A lead advisor and small supporting team charged with advancing foundational space capabilities can be housed within a ministry, state university, or research program, or as an advisory body to the executive branch. Examples of this approach include the Sri Lanka Office of Research and

FIGURE 2.9 Examples of ways to house a space program



Innovation, housed within the Ministry of Education, or the Bahamas Environment, Science and Technology Commission, housed within the Office of the Prime Minister. Alternatively, a state could establish a larger office (or organization) with layered management, again nested within a larger government organization. Examples include Egypt's National Authority for Remote Sensing and Space Sciences, Scotland's Space Leadership Council, and Ghana's Space Science and Technology Institute. This approach allows greater output and specialization than a small advising office does, while minimizing the overhead cost and manpower needed for a fully independent organization. The challenge of this approach, however, is that the agency that hosts the space office will also significantly shape its focus. The US, for example, has opted to establish several space-related offices. NASA is an independent, civilian agency answering to the US executive branch and is the office most present on the international stage. The US Space Force and Space Command fall under the Department of Defense. There are additional space-focused offices in other departments: Commerce, State, and Transportation.

Establishing a space agency usually implies the greatest amount of independence and widest mandate, ideally to include the pursuit of all foundational space capabilities, and often a degree of government-run space activity. Examples of such activity include managing a space port, conducting research, and directly operating government-owned satellites. Examples of agencies include NASA, the Australian Space Agency, and the Japan Aerospace Exploration Agency (JAXA). As another example, over the course of forty years the Malaysian government progressed from a vision ("Vision 2020") to a series of several specialized offices (a center, two divisions, two agencies), and, as capability grew, to a multi-faceted, internationally engaged agency, the Malaysian Space Agency (MYSA). See Use Case 5.

States can also leverage membership to one or more cooperation mechanisms to pool resources and space capabilities and work toward collective space-related goals. Examples include the Asia-Pacific Regional Space Agency Forum (APRSAF), the Asia Pacific Space Cooperation Organization (APSCO), the African Space Agency (AfSA), the Latin American and Caribbean Space Agency (ALCE) and the European Space Agency (ESA). Some organizations are specialized in one aspect of space capabilities, such as the Inter-American Telecommunication Commission (CITEL), the Arab Satellite Communications Organization (ARABSAT), and the World Meteorological Organization (WMO).

SUMMARY OF SECTION 2

Foundational space capabilities maximize a state's access to and use of space. These capabilities encourage a positive feedback loop between the government, private sector, civil society, and academia, and they connect space applications to real world priorities and challenges, ranging from resiliency to economic growth. Foundational capabilities are not necessarily about putting satellites into space; rather, they involve taking full advantage of existing space infrastructure and deciding how to organize and where to invest time, money, and people to the best effect. A state should strive to find the right size and composition of a space office and program so that the program can maximize a return in services and support to the government and tangibly support the development of a national space and data ecosystem. Section 3 will recommend a progressive, step-by-step approach for designing an early space program.

Annex 2A. Use Cases

Use Case 5. Evolution of a space office from a Malaysian perspective

In the 1980s, the Malaysian government developed a "Vision 2020," which highlighted the importance of science, technology, and innovation and identified "space science" as a possible catalyst. In 1998, the government established the Malaysian Centre of Remote Sensing (MACRES) as a research and development center for remote sensing and related technologies. In 1991, it established its "Planetarium Division," which became the core of informal space and technology education for the general public in Malaysia. By 1994, Malaysia had built both a more formal National Planetarium and had established its Space Science Study Division (BAKSA), with the purpose of "capitalizing on space science and technology from economic and social perspectives for the needs of the people." By 1995, its space capability and activity having grown, the government of Malaysia transferred BAKSA to the Ministry of Science, Technology and Environment (STE). It also established Astronautic Technology Sdn Bhd (ATSB), a wholly owned subsidiary (government-owned company) of the Ministry of Finance, charged with developing space and satellite technology. Having started with 17 staff members in 1998, MACRES had expanded to 226 professionals by 2002 and was elevated to an agency, renamed the Malayasian Remote Sensing Agency (MRSA). Malaysia then transformed BAKSA into a National Space Agency (Angkasa). In 2002, it merged both agencies into a single organization, the Malaysian Space Agency (MYSA) (Verspieren, 2022).

SECTION 3.

How Does a State Develop Space Capability?

There is no single way to establish foundational space capabilities. The actual method by which any country establishes or expands its capabilities is shaped by the country's history, culture, ideology, and political and environmental realities. That said, a solid first step is to commit to the development of a space program, of any size or budget, to act as a national focal point for space-related affairs. Whether run by a single advisor or by a well-staffed agency, the core function of taking deliberate action to maximize the benefits of existing space infrastructure can be achieved. To that end and beyond, this section provides a framework that enables

- A deliberate, methodical, outcomes-focused planning process;
- Strategic decisions about a space program's intent, goals, organization, and resourcing;
- Inclusion of stakeholders from the government, civil society, private sector, and academia; and
- A demonstratable chain of logic, from intent to action, outcome, and evaluation.

ORIENTATION

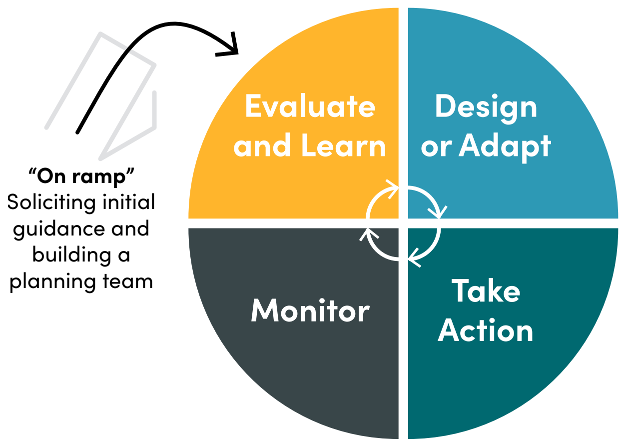
One can think of a national space program as a lever that serves multiple purposes. In addition to providing space-related services to other government offices, it can seed, and then accelerate, the development of a national space ecosystem. Such an ecosystem has various independent parts, or "systems," that can be coordinated, integrated, and aligned to achieve an overall greater national capability than the sum of its parts. A space program can also directly harness space capabilities—such as remote sensing, PNT, and satellite communications—to address specific national priorities.

Building the entirety of a space ecosystem at once would be a herculean task, like suddenly deciding to build a national transportation infrastructure system at once. It is better to start in one area where roads (or a space application) would provide the most good, then grow capability from there, methodically and sustainably in size and complexity. Each expansion in capability and capacity casts the boundaries of space activities outward, tapping new benefits, building domestic and international connections, and strengthening the overall space ecosystem.

Program design and implementation is an iterative process, documented as a strategy, roadmap, or workplan. No plan is perfect, nor perfectly implemented, as understanding of the challenges, needs, and political, budgetary, and other circumstances will naturally change over time. It is useful to envision program design and management as a repeating cycle with sequential phases for evaluation, planning, taking action, monitoring, and again evaluation, learning, and adaption, as illustrated in Figure 3.1. The "on ramp" to the program cycle is first soliciting initial guidance and building a dedicated planning team.

Space programs almost always have a particular built-in challenge thanks to their science fiction roots, and that is demonstrating to policymakers and the public that such programs

FIGURE 3.1 Program cycle



have value in a practical, tangible sense. Section 1 makes the case for "why" foundational space capabilities are important, and Section 2 discusses "what" such a capability may look like. In the program design phase, it is up to program designers and managers to answer "how" space could most concretely benefit national priorities, economic well-being, and the public good, and then methodically pursue those capabilities. The evaluation phase also addresses the first rung in the Space Capability Ladder: Preparation.

SOLICITING INITIAL GUIDANCE AND BUILDING A PLANNING TEAM

National leadership and senior management should start by appointing a space program design team. The selection of the design team's chairperson will be an important determinant of the success of the enterprise. The chairperson will have a principal leadership role, ensuring meetings are well organized, inspiring full participation, protecting teams from diverting or time-wasting activities, and representing the planning team as its Figurehead to the national or more senior leadership. Assuming the first task of a design team is to identify national goals and priorities for space-related activities, the planning team will need one or more sponsor from national executive leadership or senior management. Sponsors' presence initially and during periodic reviews can be an important focusing tool for the team. Such participation also helps to keep senior leadership engaged, but not micromanaging.

Senior leadership may start by providing the team with a vision, or a broad statement of intent. For example, India's vision is, "Harness space technology for national development, while pursuing space science research and planetary exploration." Ideally, however, the chairperson works with the sponsor and other leadership to establish full terms of reference (ToR.). A ToR is a one- or two-page document that establishes the planning team and presents its objectives and brief context. It generally provides initial guidance ("create a space program"), along with a suggested schedule and an appointment of the planning team leadership and supporting offices within the government.

The planning team composition itself should comprise people with experience in program design, management, or both, as well as in national priorities or concerns and in general space capabilities (PNT, remote sensing, and communications). The team's essential objective is to forge a credible consensus on a way forward, built with disparate but respected members. Both the personal qualities and the community or stakeholders they represent are important considerations in selecting members.

Considering all the skills and constituencies involved in developing a space program, a planning team will likely consist of 6 to 10 core members. In European and American cultures, larger groups (of about 10) tend to lead to serial monologues, and the group tends to be overly influenced by dominant speakers. The chairperson, therefore, should take special care to draw out quieter personalities and temper more dominant personalities (Fay, Garrod, and Carletta 2000). It may be valuable to engage a professional facilitator to improve organization, drive focus, and accelerate discussions, consensus, and decision-making (Delaney 2015).

The core team should also identify additional stakeholders from within the government, private sector, civil society, and academia and be prepared to implement a consultation process, using tools such as a document review, calls for input, in-person meetings, online questionnaires, email submissions, focus sessions, and other methods. Low-cost technologies and existing online platforms can help widen the reach of the planning team. If there are skill gaps, such as a lack of space expertise, a government may consider hiring a consultant or reaching out to international bodies, regionally or bilaterally, for support (see “Identifying Funding and Advising Support” later in this section). Regardless, it is rare that everyone supporting the process will have a space systems, design, and policy background, so it is recommended that the group establish a common foundation of knowledge by briefing across areas of expertise. That process of exchange will also highlight when and whom to approach for support to address remaining knowledge gaps.

The planning team will need its own workplan to define roles, activities, and desired outcomes—a miniature version of the space program design effort. Leadership will need to allocate sufficient resources to the planning team to accomplish the task: people with dedicated time, a physical workspace, computers and internet connectivity, leadership support, and authority to communicate across departments, sectors, and stakeholders as necessary. The team’s output should be periodic reports to executive leadership or senior management, culminating in a proposal for the space program intent, goals, organization, and estimated costs. In other words, a strategy. This strategy should articulate a clear theory of change, a logical link from intent to implementation to expected outcome, and a plan to evaluate progress. In general, as the team works it is better to provide periodic updates on progress, maybe monthly, rather than to hold recommendations until there is a final proposal. This approach enables leadership input and awareness while reserving necessary independence and flexibility for the planning team during the design process.

EVALUATING CAPABILITY AND EXPLORING POSSIBILITIES

Evaluate and Learn

Once a planning team is assembled and has established its own workplan, timeline, and knowledge foundation, the team should proceed with its first set of *evaluation* questions:

- What space capabilities do we need?
- What space capabilities and capacity do we have now?
- What do we want our space program to do?

There are two ways to determine a space program’s goals and to sketch a path toward those goals. The first is using a wide aperture, understanding space capabilities as a type of enabling infrastructure, like roads or power. Such an infrastructure supports critical day-to-day functions as well as development goals and national interests, like security and long-term economic growth. The second, tighter aperture, considers specific national priorities and concerns, and then weighs how space capabilities could be applied specifically to these issues. Combined, a program can incorporate actions that address near-term, high-interest needs for the state, while also investing in the development of a space ecosystem that would benefit a broad set of stakeholders.

Quickly circling back to Section 2, “What?,” recall that this Handbook discussed possibilities for the function and structure of a new space program. It also recommended the following “foundational” roles for a space program:

- Protect existing dependencies on space,
- More fully leverage existing space capabilities and applications,
- Encourage the growth of a local data and space ecosystem,

- Attract international and public-private collaboration and investment, and
- Contribute to the development of norms and laws governing space.

To determine if these roles are appropriate, and if there are also short-term, specifically space-related capabilities needed, the planning team should endeavor to understand its government's priorities and concerns. These priorities and concerns are often captured in national (and regional) strategies, policies, and initiatives, in addition to the guiding vision that prompted the program design process itself. Nongovernmental sources, such as the UN and international development banks, usually house functionally oriented documents that provide additional insights and recommendations. The World Bank, for example, codevelops strategies with many low- and middle-income countries that include detailed analysis of "economic constraints" that are slowing growth. Examples of identified bottlenecks may be poor internet connectivity or regulatory shortfalls. Many states have also created strategies to prioritize and implement the UN SDGs, and many philanthropic organizations, like the World Food Programme or Refugees International, work to address persistent challenges and often recommend strategies or specific actions to host countries. The UN Technology Bank recently completed a survey of forty-six least developed countries to support understanding the status of science, technology, and innovation capabilities by measuring the countries' tertiary education, number of research personnel, private sector expenditure on research and development, and other factors. The survey document also provides many recommendations for action that touch on the space and data sectors (United Nations Technology Bank for the Least Developed Countries 2022). Still other multinational groups, like the African Union, have collectively formed space-relevant policies and strategies that articulate collective challenges, intent, and actions to develop and use space capabilities. As a group, these sources document areas of national attention and can therefore inform the purpose, agenda, and role of a space program, as illustrated in Table 3.1. See also Use Case 6 in Annex 3.A.

TABLE 3.1 Examples of sources addressing national priorities and concerns, their recommendations, and possible space applications or space-related activities

EXAMPLE SOURCE	RECOMMENDED ACTION	POSSIBLE SUPPORTING SPACE APPLICATIONS/ACTIVITIES
Information and Communication Technology Agency (ICTA) of Sri Lanka, "National Digital Policy, 2020–2025"	Improve the quality of government service delivery through integrated and efficient processes, to reduce bureaucracy and improve accountability and transparency.	Combine remote sensing and positioning, navigation, and timing (PNT) data with survey data to objectively assess the impact of government program(s). Publish results via a public dashboard or periodic reports.
Inter-American Development Bank, "Bolivia Country Strategy 2021–2025"	To improve the business environment, increase the pace of transactions, and increase the quality and transparency of information, update regulations.	Synchronize and update banking and satellite use regulations to enable/quicken mobile international internet banking.
"Peruvian National Development Strategic Plan that implements the 2030 Agenda"	Increase the participation of provinces in developing emergency response plans. Increase virtual engagement due to the COVID-19 pandemic and restrictions on travel.	Use new lower-cost satellite dishes and subscriptions to connect key remote government offices to 5G internet (and online government mechanisms).

TABLE 3.1 Continued

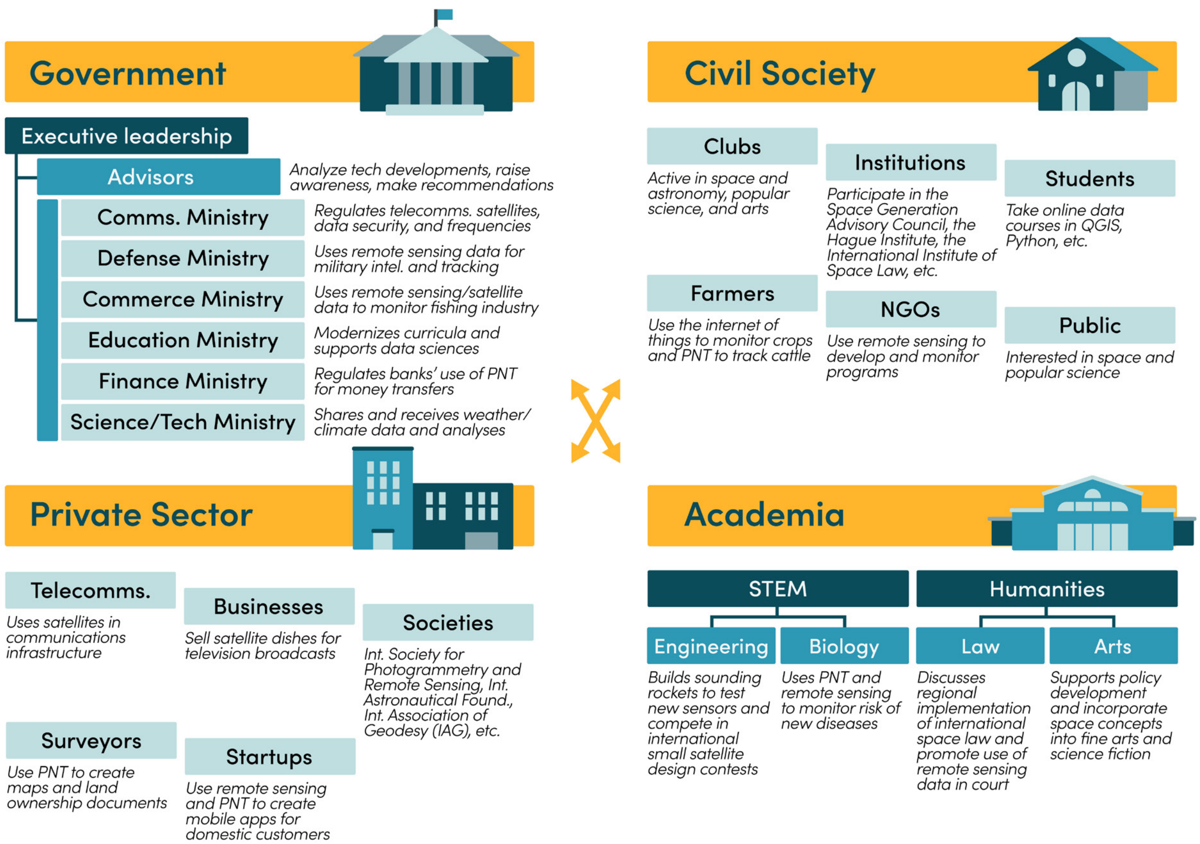
EXAMPLE SOURCE	RECOMMENDED ACTION	POSSIBLE SUPPORTING SPACE APPLICATIONS/ACTIVITIES
World Health Organization (WHO), "Country Cooperation Strategy 2017–2021: Mongolia"	Strengthen programs to improve the provision of safe water and adequate sanitation.	Use remote sensing to monitor current and predict future availability of groundwater to support planning.
NGO Report: "Paths of Assistance: Opportunities for Aid and Protection along the Thailand-Myanmar Border"	The government of Thailand should engage regional partners to press the military junta in Myanmar to end grave human rights abuses.	Use remote sensing data to monitor restricted areas for evidence of serious human rights abuses such as mass graves.
Multinational "Kigali Communique, 2022" on Energy Transition in Africa	Catalyze technology transfer mechanisms to ensure that the entire continent has access to the latest energy innovations, on fair terms. Make modern sustainable energy available to the entire continent.	Reduce the use of gas generators powering remote cell phone towers by integrating satellite-to-cell technology into telecommunications infrastructure. Use PNT data to synchronize traditional and renewable power sources like wind and hydropower, improving system efficiency and reliability.
African Union "Africa Space Strategy, 2019"	Create an enabling environment for small and medium enterprises by supporting their effective participation in the development of the space industry and market.	Include representatives from the business community as a stakeholder in space policy development. Offer contracts to local enterprises to provide geospatial services to government organizations.
"Asia-Pacific Regional Space Agency Forum (APRSAF) Principles, 2013"	"...carry out collaborative activities... identify and undertake measures to contribute to the sustainable socio-economic development in the Asia-Pacific region."	Participate in the "Sentinel Asia" program. Incorporate requests for free remote sensing data and analytical support in cases of natural disaster into national disaster response procedures.
Associations of Southeast Asian Nations (ASEAN) "Plan of Action on Science, Technology and Innovation (APASTI) 2016–2025"	"...establish innovative system and smart partnership with dialogue and other partners to nurture STI [space, technology, and innovation] enterprises to support...enterprises, nurture knowledge creation and space technology... applications to raise competitiveness."	Establish the ASEAN Research and Training Centre for Space Technology and Applications (ARTSA) in Thailand (completed).
"Industrial Policy and Strategic Plan for Mauritius (2020–2025)"	"Develop a digital roadmap for priority manufacturing sectors and ensure digital infrastructure is in place for evolving business models."	Facilitate storage of, access to, and use of remote sensing data to support manufacturing sectors and encourage startups in the localization of value-added services.

Regarding the second question, the difference between what a nation wants to do and what it can currently do is the capability or capacity gap, or both, that a space program should strive to address. A capability gap is the lack of being able to do a task. A capacity gap is the lack of being able to do enough of a task. For example, a small office consisting of three people may have the capability to produce geospatial maps that show likely flood zones in urban areas, but they lack the capacity to produce such maps more often than once a year, or for rural areas of the country.

To find reservoirs of existing space capability, the planning team will need to engage extensively with ministers of government, customary leaders of civil society, CEOs in the private sector, and university chancellors in academia. The leaders may not be fully aware of how their organization uses space capabilities. A good approach may be a combination of informative briefing about the planning team's intent to develop a space program and an overview of space applications in general, followed by surveys or interviews.

Another way to approach understanding the various systems that make up the space "system of systems" is to build a systems map. A "systems map," or "actors map," is a visual representation of the interplay between various actors, organizations, and policies and of the ways in which each connects, affects, and relates to the others. The example in Figure 3.2 illustrates this idea at a national level and shows activity within broad categories of government, civil society, the private sector, and academia. A systems map can also enable planning teams to identify and better understand relationships between specific offices or activities.

FIGURE 3.2 An example systems map showing space capabilities in the government, civil society, private sector, and academia, regardless of a space program



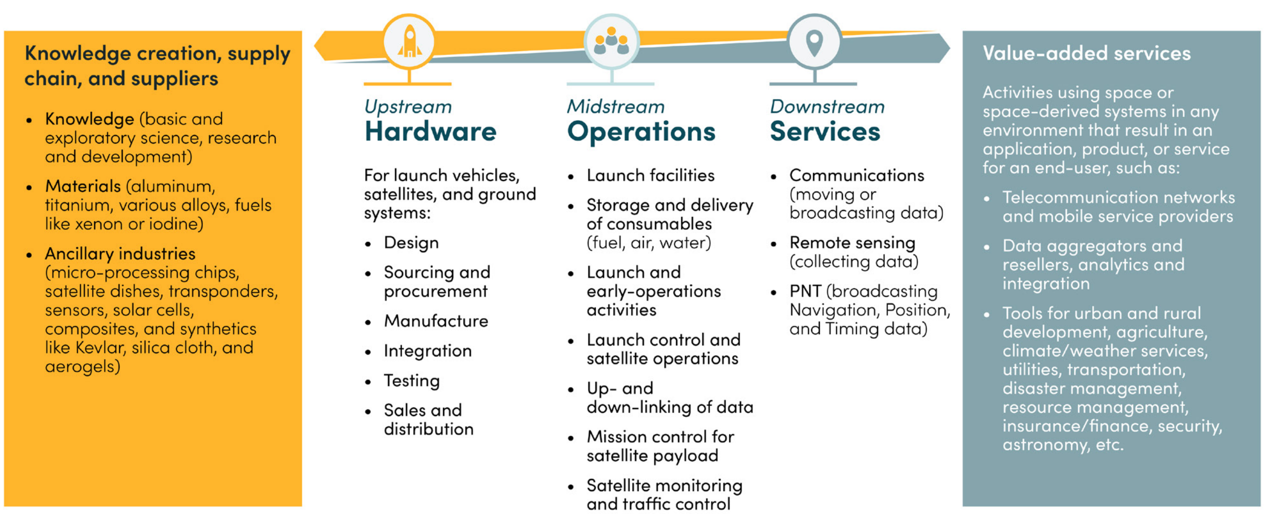
Using a systems map, a planning team should be able to answer the following questions:

- Who are the key stakeholders? Who is, has been, or should be involved in the space ecosystem?
- What are their roles (especially in the context of achieving foundational space capabilities)?
- Where are the greatest connections, activity, or both?
- How are they currently supporting national priorities or addressing national concerns?

It's also useful to consider areas of existing resources, strengths, or growth that can be parlayed into a catalyst for the space ecosystem. The space sector is often discussed in terms of upstream, midstream, or downstream activity. It can also be viewed as a value chain (Figure 3.3) that shows a progression of activities taken by the space industry to deliver a valuable product (i.e., goods, services, or both) to the end user (or customer). Every element, from knowledge development, materials, design, manufacture, services, and operations to a multitude of end user applications, is a link in this chain. These elements are also potential entry points into the global space sector, where a particular country or economy may have a particular comparative advantage.

Another national attribute should also be noted—geography—which can be uniquely leveraged for space-related activity. For example, due to the Earth's rotation on its axis, rocket launch facilities located closest to the equator can take advantage of the momentum of the Earth's easterly spin to launch satellites using less fuel (Figure 3.4). Launch facilities closer to the poles, on the other hand, are better positioned to launch in north-to-south, polar orbits. All launches' flight paths tend to be over water or very sparsely populated areas to avoid possible debris or unused propellent causing collateral damage. It is for this reason that the European Space Agency's primary launch facility (also known as a spaceport) is located on the coast of French Guiana.

FIGURE 3.3 Opportunities in the space sector value chain



Note: The term "value chain" is often used in the private space sector to evaluate all the elements and dependencies involved with creating, selling, and distributing a product. The dividing line between "upstream" and "downstream" activities is not sharply defined, so the term "midstream" generically addresses this area of overlap.

FIGURE 3.4 Examples of advantageous launch facility and Earth station sites

Geography and associated climates can also be advantageous for other space-related activities. Earth stations need to be able to send and receive a signal to a satellite within line-of-sight as it passes from horizon to horizon overhead. Satellite operators have to make careful decisions about where to place their Earth stations so that they are best suited to direct, maintain, and employ their satellite. Space optical communications (free space optical, or FSO) technology, for example, allows greater throughput than typical radio frequency technology, but it is vulnerable to cloud cover. Thus, areas with cloudless skies are advantageous for FSO receiving ground stations (del Portillo et al. 2017). A ground station located at the North Pole will be able to see a satellite in polar low Earth orbit up to fifteen times per day, but a ground station located on the Equator may only see the same satellite three or four times per day. Equatorial stations have other advantages though, like being well positioned to communicate with satellites in—or transiting through—GSO. Generally speaking, satellite operators are interested in having access to more than one Earth station so they are able to communicate with their satellite more frequently as it circles the Earth.

For example, Libreville, Gabon, is located on the Atlantic coast and on the Equator, an ideal location to monitor the launch path from ESA's launch facility in Kourou, French Guiana. From Gabon, ESA launch vehicles remain "visible" during the most critical phases of the mission as a launch vehicle climbs eastward from French Guiana, over the Atlantic Ocean, and into orbit. The ESA tracking and telemetry station network also includes stations in Natal (Brazil), Ascension Island (UK) in the South Atlantic Ocean, and Malindi (Kenya.) This network feeds information back to launch operators about the conditions on board the launcher, its performance, trajectory, and placement of the payload—one or more satellites- into orbit. "Space as a service" companies often build strategically positioned Earth stations and then sell access to them for multiple satellite operators. This is less expensive than building a station for each satellite (Prasad 2020). Geography is a very real "natural" resource worth considering when it comes to space operations.

The above exploration would result in a general inventory of government priorities, current capability and capacity, possible desirable applications, and an understanding of potential entry points within the space value chain and advantageous geography. The planning team may find it useful to document this inventory in an early report. Such hard-won understanding will serve as a starting block for the program that can be built upon, as well as an internal directory of expertise and interest.

Tools to build a policy and strategy

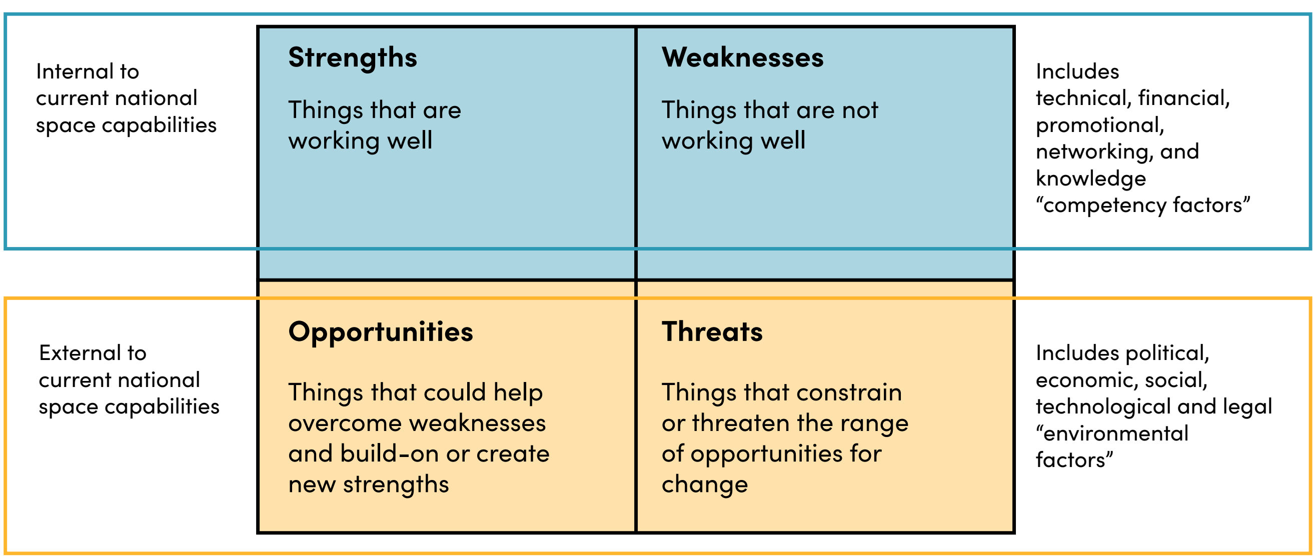
Prepared with an inventory of government priorities, current capability and capacity, possible applications, and familiarity with potential entry points within space value chain and advantageous geography, the planning team should be ready to explore and evaluate options for a space program. A useful tool to explore and organize said options is the popular "strengths, weaknesses, opportunities, and threats" (SWOT) analysis. This tool was originally developed in the 1960s to help an organization assess how it compares with its competitors, but over time it's been adopted by many organizations to facilitate the formation of strategies. The goal in this analysis is to narrow down an impossibly large range of space capabilities relevant to national priorities or concerns, into a set of capabilities that would best take advantage of existing strengths, that would be the most beneficial, or both.

A SWOT matrix consists of a two-by-two square grid, with the top section allotted to listing the strengths and weaknesses of (in this case) current national space capabilities (Figure 3.5). These include technical, financial, promotional, networking, and knowledge "competency factors." The bottom section is allotted to opportunities or threats, external to current national space capabilities. These include political, economic, social, technological, and legal "environmental factors."

When documenting this analysis, the planning team should make significant effort to explicitly use detailed phrases and sentences. Clipped submissions tend to be too vague and open to interpretation as the list develops and is reconsidered over time.

It is best to start the analysis by considering opportunities and threats external to current national space capabilities (the bottom two Boxes). These broad conditions often (but not always) exist not only for the host country, but also for the region, or the world, and can provide useful context for the following strengths and weaknesses sections.

FIGURE 3.5 SWOT matrix



1. The **Opportunities** section is where the team can identify conditions that are positive or helpful, *external* to what a space program can or will do by itself. Examples:

- Space companies and telecommunications companies are increasingly conducting joint ventures to provide affordable, remote internet broadband. This is an opportunity because a new space office could facilitate domestic space and telecommunications company (telco) partnerships.
- Free or low-cost remote sensing data are publicly available (but are not being taken advantage of by most government agencies). This is an opportunity because a space office could support other ministries' use of free or low-cost data.

2. The **Threats** section is where the team can identify conditions that constrain or threaten the range of opportunities for space capabilities. Examples:

- The recent pandemic and other natural disasters have absorbed most unallocated public funding for the next year. This is a threat because it may constrain funding for space-related activity.
- Most policymakers don't understand current reliance on, and the potential usefulness of, space capabilities. This is a threat because it is unlikely a space program will be successful if policymakers don't understand how it benefits the country and people.

3. Next, working the internal **Strengths** section, the team can highlight conditions that are working well, even without a dedicated space program (top left Box). It's more useful to list attributes in a comparative context. For example, a country may have a particularly responsive frequency management office compared to neighboring countries. Examples:

- Frequency managers are active in the ITU and update national regulation every two years or so to align with international standards. They are responsive to space-related frequency requests. This is a strength because clear regulations make it easy for companies to understand how to operate in a given country.
- At least twenty individuals in the maritime forces have been trained in geospatial information systems and can apply remote sensing data to track suspicious ships in our exclusive economic zone. This is a strength because it represents a reservoir of capability and capacity that can be tapped by the space office.

4. Last, addressing the internal **Weaknesses** section, the team can list conditions that are not working well (presumably in part due to the lack of a space program.)

- Acquisition of or contracting for remote sensing data is inefficient. At least three offices paid for the same data separately last year. This is a weakness because the government is wasting funds.
- Risks to current uses of satellites are not well understood, nor mitigated against. No formal guidance exists. No office is responsible for proposing recommendations to improve domestic resiliency in case current space services are interrupted. This is a weakness because the government is unprepared for any interruption of satellite services.

The African Union completed a SWOT analysis in 2019 that ambitiously encompassed the strengths, weaknesses, opportunities, and threats for all fifty-five member states. It provides an excellent reference for considering a wide range of internal and external factors. (See Use Cases 8 and 9.)

5. The last phase in SWOT analysis is to use the sorted data to **Generate Recommendations** for the program. An example template phrase is this:

> "Given the condition of [external factor], our ability to [internal factor] leads to our recommendation that we [recommendation to do something]." (Minsky and Aron 2021)

An example recommendation using SWOT analysis could be, "The availability of free and low-cost remote sensing data and the proven usefulness in applying these data to monitor illicit maritime activity lead to our recommendation that we expand use of remote sensing data to other ministries and national concerns." The goal is to narrow down an unmanageably large range of capability or capacity development possibilities (the "blue sky" wish list) into a set that is most useful, or opportunistic, given environmental realities and national strengths or weaknesses. A good rule of thumb is to use strengths to exploit opportunities and overcome threats, and take mitigation measures where weaknesses and threats combine. Some questions that may assist this discussion include these:

- Where is there growth, energy, and expansion, and where are there gaps, blockages, or constraints?
- Where are areas of broad interest, concern, or excitement?
- Where should relationships be strengthened or forged?

Some weaknesses of the SWOT brainstorming and sorting analytic method include that it tends to be a snapshot of a specific time and circumstance. It is also subject to the experience and perspective of its current participants (Minsky and Aron 2021). It may be useful, therefore, to run the exercise several times with different "themed" focus groups over time. If the main planning team, for example, sees early-on that increasing use of remote sensing in agriculture would be a likely focus area for the space program, the planning team could bring in stakeholders with a tailored mix of farming, remote sensing, telecommunications, and agriculture-focused development backgrounds to do a deeper analysis of this subset of strengths, weaknesses, opportunities, and threats.

At the end of each round of analysis, the planning team should group the resulting recommendations and action statements into like areas. Some outputs and outcomes will be "quick-wins," where positive results could be expected in a just a year or two. Others will have dependencies that need to be addressed before they can proceed, creating a sort of waterfall programming pattern, as illustrated by Figure 3.18. A small, even notional, space project can also serve by exercising or creating new processes and relationships for space-related activity. It can also help illuminate what policies, directives, contracts, and regulations need to be established or modified to facilitate space activity. Many space actors with large, expensive projects have been significantly delayed due to unforeseen national and international requirements.

The Pareto Principle states that roughly 80 percent of desired outcomes are driven by 20 percent of causes (the vital few actions) (Hugh 2021). Which 20 percent of the planning team's recommendations, or three or four major themes of effort, would potentially result in the best outcomes in addressing national priorities or concerns (outcomes)? Which would (also) advance the establishment of a healthy space ecosystem? It may be useful to again consider the planning teams' interpretation and adoption of the "foundational" roles recommended in Section 1.

At this point, it is important to document the analysis and conclusions the planning team has completed thus far, potentially as the second "in progress" report to leadership. This information provides an important reference point to measure progress and change over time, to make sure future planners have full context for why decisions were made. In general, it is recommended that the chairperson draft such a summary document, because that is the person best situated for synthesizing input from the team and government stakeholders, both informing the following program design phase and posterity. The evaluate phase of program design completes the "Preparation" rung of the Space Capability Ladder.

Now that the *evaluation* phase has provided a good understanding of a nations' current versus desired (and prioritized) capability and capacity, and defined the gaps between the two, the planning team is ready to develop a program.

DESIGNING A SPACE PROGRAM

Design or Adapt

The program *design* phase is the mechanism through which a government can organize itself to refine and act on the evaluation phase's recommendations, while also building overall institutional (or foundational) space capabilities. Quickly recapping, foundational space capabilities include the government's ability to advise, localize, manage, coordinate, and regulate space activity and advance national space interests at regional and world forums. Now that the evaluation phase has provided a good understanding of a nation's current versus desired (and prioritized) capability and capacity, the planning team is ready to develop a program. A program is a set of related projects and activities, managed in a coordinated manner, under a structure that allows for the delivery of outcomes and benefits.

Planning considerations

Essential documentation of this effort includes a space policy, which primarily describes a country's intent for space issued by senior leadership, and a national space strategy, which is a more specific roadmap of who, how, and when gaps will be addressed, to what end. In a perfect world, the planning team would draft a policy first, have it reviewed and adopted by national leadership, and then would develop a more specific, time-bound strategy. Since reality rarely matches the ideal, the planning team may very well need to work on these efforts in parallel or in very quick succession. It is vital, however, that senior leadership approve the planning team's interpretation of leadership's vision or policy, because every follow-on action should be able to coherently explain how it is contributing to that vision.

Another important step in building a space program is establishing a leading office of some sort (an advisor, office, center, institute, agency, or similar) that is focused on foundational space capabilities and is empowered to build, connect, order, and harness the system of systems that enhances a country's access to and use of space. A space office's basic components

TABLE 3.2 Examples of components that contribute to government "foundational space capabilities" and a national space program

POLICY AND REGULATORY FRAMEWORK	SKILLSETS	INSTITUTIONAL SUPPORT
International treaties and commitments	Space-related data utilizers and managers (PNT, geospatial)	Facilities and nondata Infrastructure
Space private sector and operations	Data infrastructure management (hardware, cloud-based)	Data infrastructure
Government activities (such as courts of law, weather, other data for decisions)	Radio frequency and telecommunications	Oversight
Radio-frequency spectrum, telecommunications	Policy advising and program management	Human capital development
	Training, academia, research coordination	Science and technology, research and development
	Interagency and international coordination	Financing/funding
	Civil society and private sector development	Culture, risk acceptance
	Space-related data utilizers and managers (PNT, geospatial)	

include a policy and regulatory framework, a skilled workforce, and institutional support (Table 3.2).

Space program component: Skills

Lack of a domestic skilled workforce is a common shortfall faced by most countries trying to establish a new, complex capability. It takes a skilled workforce to leverage and localize space applications. As discussed in Section 2, a wide range of skills, to include management, research, design, operations, and support to end users, is needed to take advantage of the full range of space-related activity.

Many programs fail because talent development is too focused on short-term needs, without casting a wide enough net for a diverse set of talent and without considering the necessary arch of a career in which a professional can expect to move between different projects and even sectors while increasing capability and responsibility over the course of a lifetime. If there aren't opportunities for professional development and progression, particularly if demand is insufficient to pay a competitive wage, talent often moves on to greener fields, "poached" by a foreign NGO, business, or other opportunities abroad. Gender and diversity should be also considered as part of building human capital for space applications. Such a strategy is important not only because pursuing gender equality in the workplace is a worthwhile goal in itself, but also because increasing diversity leads to better results through the inclusion of new perspectives. A recent study of 6.6 million academic papers in the medical sciences showed that gender-diverse teams produce more novel and higher-impact scientific ideas. In other words, if a space program is working to develop skills for a specific project and build its ecosystem more generally, then it must foster diverse training, an academic pipeline, to steadily develop and progress talent.

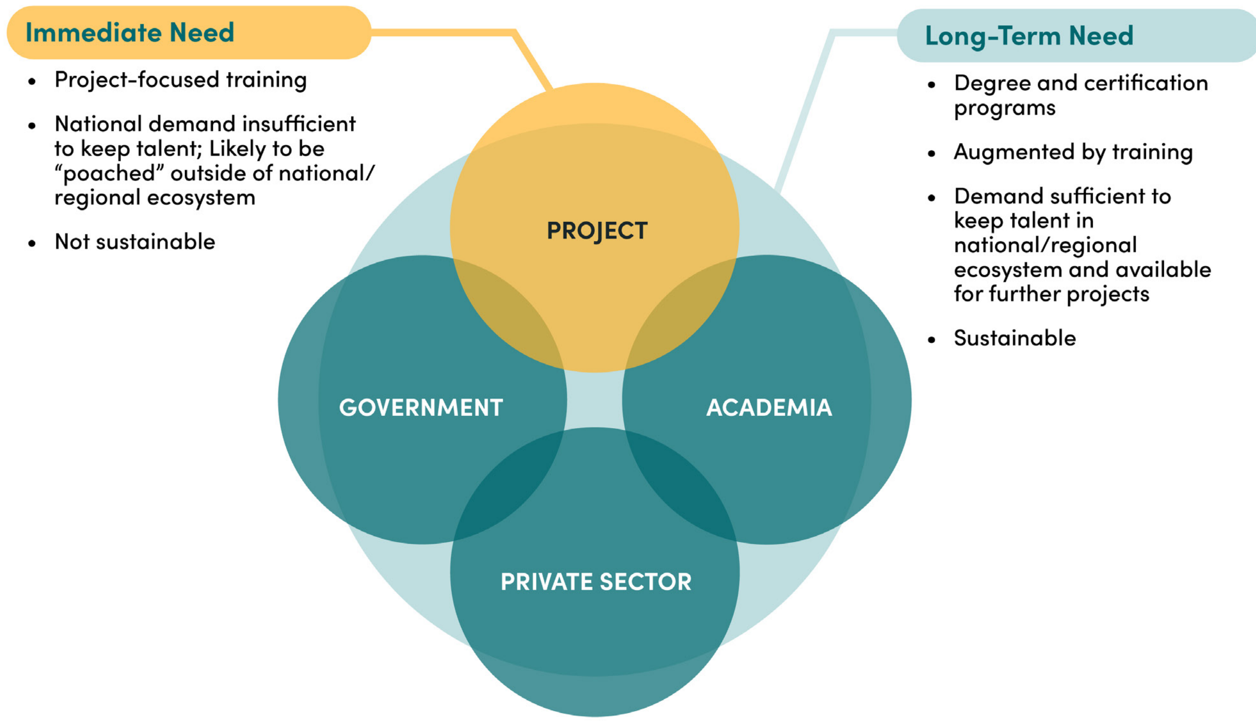
A particular project may need a team of only ten workers for a short term of a few months to years, but the government should consider nurturing and encouraging the growth of the available talent pool that will be needed for long-term sustainability of that project and others that will follow. A multi-week gap between one project and the next, or other appropriate, progressive employment, may force hard-won talent to look abroad for work. A space program should actively support and promote opportunities for skilled talent to transition to new space-related projects of interest to the state, or to other local academic, civil or private sector opportunities.

Reaching out to space and technology professionals that are working abroad is another way to infuse a space program with seasoned professionals. The types of technical skills needed for a space program include familiarity with geospatial information systems and platforms; an understanding of the attributes of various sensors, PNT, and communications satellites; and experience in satellite operations (and radio-frequency spectrum use) in general.

A new space program will also need to plug into a greater human capital development program that enables it to bring new leadership, science, technology, and engineering personnel and to rotate (permanently or temporarily) a multidisciplinary mix of skilled workers who can advance the use of space (Figure 3.6). For example, a lawyer from the Ministry of Justice may be detailed to a space program for a few years to lead the drafting of national laws that determine the rules for using remote sensing data as evidence in a court of law, or aid in establishing contracting standards to normalize government purchase of various space services.

The Vietnam National Space Center (VNSC) found success deliberately growing its human capability and capacity through its "Dragon Roadmap." Starting by working with Japan through an academic connection (first the University of Tokyo and then a consortium of universities), VNSC developed CubeSat in 2013 and SmallSat in 2019. Using these projects, VNSC was able to train and employ about one hundred engineers and scientists. To keep them within the Vietnam space ecosystem, VNSC proceeded to collaborate with the Japanese private sector (a Japanese satellite manufacturer, NEC) to develop progressively more complex satellites (Verspieren et al. 2022). In this case, the agency focused on the development of satellites, but the same pattern could be used to expand any aspect of the space and data ecosystem.

FIGURE 3.6 Advantage of long-term focus on human capacity needs to retain and grow national talent



Space program component: Policy and regulatory framework

International, bilateral, and multilateral treaties and agreements are key mechanisms for countries' integration into the global space sector and contribute to the body of material that is a nation's policy and regulatory framework. *The Handbook for New Actors in Space* (Johnson 2017) provides an overview and discussion of the five main space treaties, starting with the essential "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies," more common signatories as the "Outer Space Treaty" (OST). The UN Committee on the Peaceful Uses of Outer Space (UNCOPUOS) monitories the status of signatures and ratifications of the international agreements relating to outer space; UNOOSA posts ongoing updates.[16] It is important to note that OST signatories bear international responsibility for national activities in outer space, whether carried on by governmental agencies or by non-government entities, and require authorization and continuing supervision by the state (Article VI). Additionally, Article VII stipulates that treaty members are internationally liable for damage to other states should its space object damage another members' property in orbit or on Earth. Domestic regulations, therefore, should take care to address launches of satellites from both domestic territory or facilities and those that are procured abroad.

A national space policy, however, codifies domestic goals and priorities for space-related activities and provides a critical reference point, a North Star, for complementary actions at multiple levels of government. A national space policy ideally allocates roles, responsibilities, and resources between various agencies and entities to clear the way for intragovernmental, public, commercial, and international cooperation on specific programs or projects. For example, it assigns responsibility for core space-related functions, such as administrating and licensing radio frequencies used by satellites, or

16 UNOOSA, "Status of International Agreements Relating to Activities in Outer Space," https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/status/index.html.

purchasing, using, and storing remote sensing data. Domestic policies can facilitate growth by lowering barriers to participation. For example, to encourage the private sector, the US government provided liability indemnification as a catalyst; this indemnification reduced insurance costs and requirements to a manageable level for new ventures. Such domestic policy establishes a foundation for international dialogue and formation of international norms and law through such bodies as the UNCOPUOS and ITU. The process of developing a policy itself can also be useful as an organizing (or forcing) function that brings together intra-governmental and other stakeholders to develop a clear rationale and intent that is, in turn, cemented through national leadership approval.

A space strategy traditionally follows a policy, translating national intention into action over a set period of time, often five or ten years. In the case of a new program, an early function of a developing space program may be to support the design of a policy as well as a strategy. A strategy is the key result of systems mapping and SWOT analysis and is where analysis, actions, and plans to monitor and evaluate progress are documented.

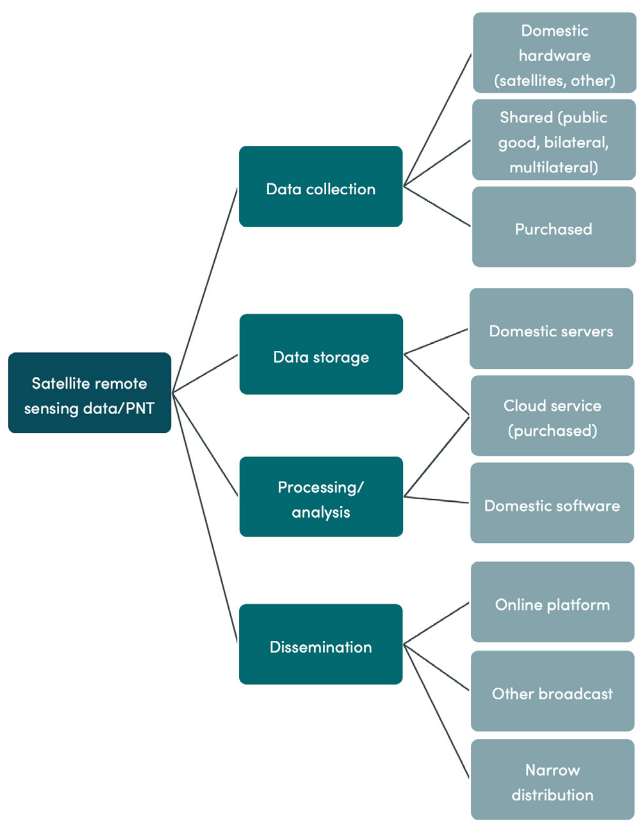
Space program component: Institutional support

A space program and organization, like any government program and organization, will need basic institutional support. This includes facilities, computers, internet, structure, oversight, and financing. The space office must account for how it will integrate into state bureaucracy and be ready to provide inputs to policy and state activity, and to request and manage its allocated resources.

Some space-specific needs include support for the acquisition, storage, processing and analysis, and dissemination of remote sensing data. A space program must decide how and if it will accomplish these functions, because they require different kinds and levels of institutional support. A space program may just draft guidelines and set standards for the government's use of remote sensing and PNT data, or it may run such a project itself. Regardless, the space office should be the government's repository of expertise on the topic of remote sensing and PNT data.

The space office will need to discover where its activities overlap with other organizations and policies. For example, is there a national data privacy and storage policy? Are there, therefore, restrictions on how domestic data are stored, processed, combined, and shared? A program must consider options for acquiring remote sensing data (Figure 3.7), with decisions such as using sensors on satellites or alternative technology such as pseudo satellites, drones, aircraft, or more traditional techniques (surveys, census, samples, etc.). Remote sensing data can also be acquired through open-source, online data sources (NASA SPIRE, ESA Copernicus, UN-SPIDER, WMO, Digital Earth Africa, etc.), shared through bilateral or multilateral cooperation (BRICS, NATO, etc.) or purchased (Maxar, Planet, among others). As the data market matures, "data marketplaces" like Arlula will likely become more common,

FIGURE 3.7 Decision tree to support use of remote sensing data



making it easier to compare data sets, their unique attributes, and price.[17] For quick reference, one can divide remote sensing data resolution into three rough categories: low resolution, with imaging over 30 meters per pixel; medium resolution, 10–30 meters per pixel; and high to very high resolution, with 30 centimeters to 5 meters per pixel. In general, data are more expensive if recently collected, frequently collected, collected using a higher resolution, or a combination of these.

Data processing occurs when data are collected and translated into usable information. It is notable that remote sensing data storage and processing require significant computing power. For a country that has unstable or costly power and internet access, or that lacks an existing data center, it may be more cost-effective and reliable to use cloud storage and processing than to build, operate, power, temperature control, and generally maintain a local data center. A user just needs an internet connection to gain immediate access to a cloud-based system. The cloud still uses physical servicers to store and process data, which are typically located in large data centers in the US, Europe, India, or China. Some disadvantages to using the cloud include (a) the users' connection can still be interrupted by power and internet outages; (b) it limits national control and flexibility of backend infrastructure and security protocols; and (c) it creates a degree of dependency on a particular vendor (Larkin 2019). Many online commercial GIS services like GoogleEarth Engine, Microsoft Planetary Computer, and software like ArcGIS, will allow users free or inexpensive access to learn and experiment, and then sell annual subscriptions, charge fees for computer processing use, or both.

There are also several nonprofit geospatial platforms that provide processed remote sensing data and tools that can be used to conduct themed analysis (on common interest topics such as agriculture and water availability), such as DE Africa Platform and the US Famine Early Warning Systems Network (FEWS NET). Additionally, a robust community of developers, researchers, and users shares processed data, use cases, and best practices on topics such as soil properties, land cover, oceans and shoreline, hydrology, utilities, weather, and global events. Such communities share information on social media (LinkedIn, Facebook, Reddit), on forums (GIS Stack Exchange, ESRI's GeoNet), at conferences (Global Conference on Space for Emerging Countries, Geospatial World Forum, International Astronautical Federation Conference, NewSpace Africa Conference, etc.), and through professional associations (Institute of Electrical and Electronics Engineers, University Consortium for Geographic Information Science, etc.).

Using a project-specific lens to prioritize

It is difficult and expensive to build all the components needed for a robust space capability at once. One possible way to focus a space program's resources is to build capability around a shorter-term space-related project that also addresses a national priority or concern. This option has two effects. It shortens and prioritizes the requirements for space capabilities and illuminates which capabilities need to be developed first, while also contributing to the overall effort to build greater space capability. For example, having reviewed materials that define and prioritize national needs, completed a systems map, and made initial recommendations based on opportunities and strengths, a country may select "chronic flooding" as the national priority or concern to address. A space program can then focus on using remote sensing data to identify at-risk, low-lying areas, the soil's capacity to absorb water, and the likelihood of severe weather over a set period. A space program can also contribute to use of satellites to support disaster response efforts via satellite-enabled communications and location data.

Designing a short-term project

A good space project can

- Produce an outcome that can be measured and widely understood.
- Expose various government agencies to how space capabilities are useful to their mission.
- Be a catalyst for establishing a domestic workforce's capability to acquire, analyze, and apply remote sensing and PNT data, and/or satellite communications.

17 See, for example, the Arlula Archive Catalog, https://api.arlula.com/catalog.

- Spur the acquisition of appropriate hardware, software, and related skills.
- Provide a context through which a space program can interact with stakeholders (disaster management personnel, leadership of villages at risk, policymakers, concerned NGOs, etc.).
- Produce positive spill-over effects.

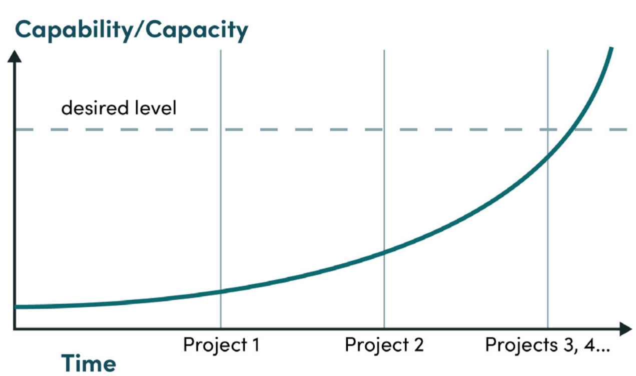
The action of capturing the results of such a project are vital, as they provide a concrete snapshot of a near-term return on a government's investment in space capabilities, especially for a nascent space program. It is harder and takes longer to measure the development of a space ecosystem and its impact. A space program can use these projects as building blocks and continue to establish new projects every year or two, especially as earlier projects are completed or transition to permanent home offices. It can harness the projects' spillover effects, leaving in its wake a more skilled workforce, new cooperative patterns, more knowledgeable and appreciative customers, and so on. A space program can stack projects methodically as a way to sustainably expand its foundational space capabilities and capacity, building toward upstream space activities, if so desired (Figure 3.8). A country could, for example, transfer the (now routine) function of using geospatial data to support emergency planning to its disaster management office (a new geospatial-support office), contract the work to a local small business (thus encouraging the private space sector and overall space ecosystem), or keep it as a function of its national space program.

Determining and prioritizing a space program's activities

In addition to running specific space projects, a space office should act as a catalyst, designed to set or encourage good conditions for the development of a domestic space ecosystem (good regulation, business practices, etc.). A space program can focus space-related inputs (funding, manpower, facilities, data, and so on) and action (provide technical advice, complete a space-related project, award scholarships, expand space-related infrastructure, and so on). These activities will have immediate outputs that are usually quantifiable. The long-term effects, the outcomes, of these activities will be harder to predict or measure since they also depend on other organizations and actions that fall outside a space program's ability to control. A space program can help a government understand how systems work together as they relate to space capabilities. A space program, for example, can advise the telecommunications industry (system) about its use of communication satellites (another system), for a beneficial outcome (broader public access to the internet). This bigger picture supports coordination between systems, and it can highlight potential leverage points to further encourage more positive outcomes in the short, medium, and long term.

In other words, a space program and its strategy ideally analyze, plan, organize, and integrate various systems into a space capability that is greater than its parts. For example, a space program may work with a university to ask why geospatial data aren't being used in research and continue to ask "why" until root causes are identified. These causes could be a lack of awareness, a lack of demand from future employers, lack of geospatial experience in the university system, lack of internet access or sufficient data storage, or other reasons. A "logic model" facilitates the process of breaking down a complex system into manageable pieces to support thinking, planning, and communications about program objectives and actual accomplishments over time.

FIGURE 3.8 A country can use projects to develop its space capabilities and infrastructure, while also providing concrete benefits for stakeholders and the public



Using a logic model

A “logic model” is defined as a graphic showing how a space organization will do its work and identifying the theory and assumptions that underlie the program (Innovation Network 2010). A model helps the planning team connect the program’s process (invested resources, specific activities, immediate results) to intended outcomes. It encourages articulation of any related analysis and assumptions, so if these change (and they often do over time), it can prompt a reevaluation of the logical progression from resource to action to outcome.

The first step in using a logic model for program design is to establish a workable problem statement. A problem statement is the problem or challenge (or a subset of this problem) the program will be designed to address. This step leverages the results of the systems map and SWOT analysis and tests the resulting hypothesized recommendations. The following template identifies the national priority or concern to be addressed as well as related analysis or assumptions and external factors. It is read from left to right, so that if certain processes happen, then they will result in certain outcomes. If resources are invested in a space program, then activities will happen with certain outputs. If those outputs occur, then planners can expect certain outcomes in the short, medium, and long term. (Figures 3.9 and 3.10).

A logic model can run “forward” from left to right, from activity to outcomes (Figure 3.11). It can also be run in reverse, from right to left, called a “reverse” logic model (Figure 3.12). A reverse logic model starts with the greatest long-term goal and asks, “but how?” to tease out needed intermediate and short-term outcomes. The model asks again, “but how?” to determine what sort of outputs would be needed, and again, “but how?” to find appropriate activities and resources.

Logic models use a linear process, rooted to a single problem statement at a time. However, multiple logic models can be run to explore and test possible activities. Again, it’s useful to circle back to the Pareto principle: Which 20 percent of possible activities or projects would potentially result in the best outcomes? Which would (also) advance the establishment of a healthy space ecosystem?

The planning team will likely need to develop several programmatic lines of effort (also called “thematic groups,” “clusters,” and “pathways”) to best organize its approach to achieving desired outcomes. As an example, in its 2022 Strategy, India defined six distinct “Areas of Capacity Building” (in addition to projects and other activities), each with its own set of activities and results, driving toward greater outcomes of a more developed space ecosystem (ISRO 2022):

- Academia research collaboration
- Infrastructure building
- Industry promotion
- International cooperation
- Human resource development
- Student engagement

TAKING ACTION, OR IMPLEMENTING THE STRATEGY

A critical shift happens during the *taking action phase*. Once program design is complete, the planning team must hand responsibility to the permanent space program office that will be responsible for implementing the strategy. Ideally some of the planning team will transition to the space office as well, to provide continuity and insight into the strategy formation. Others may join an oversight board, or they may return to their primary offices and careers as knowledgeable actors in the overall space ecosystem. Regardless, it’s important that the space program office fully understands the analysis done during the evaluation phase and the theory of change underpinning the program design itself. This background provides critical context for the planned activities and sequencing. The space program office will be responsible for acquiring and applying the logic models’ inputs, such as leadership, advocacy, funding, administrative support, communication, and expert advice as well for launching the strategy’s activities and

FIGURE 3.9 Example of a logic model

Problem Statement: The problem or challenge (or subset of this problem) the program is designed to address.

Analysis/Assumptions: Root cause, or assumed root cause, of the problem or challenge.

(If) Process (...then)					Outcomes		
(If) Inputs		**(If) Activities**	**(If) Output**		**Short**	**Medium**	**Long**
Resources invested in a program: funding, labor, facilities, supplies, policy development, advocacy...	(then)	• What actions will be taken? • These are the products, tools, advocacy, and other actions that are used to bring about a program's intended changes or results	• Who or what is affected? • These are the direct products of activities, usually quantifiable. Includes the number and type of stakeholders attending events, receiving services, using tools, etc.	(then)	• What will be different within one year of participation? • "Expect to see" • Expect changes in: Awareness, Knowledge, Attitudes, Skills, Opinion, Aspirations, Motivations	• What will be different within 1-5 years of participation? • "Want to see" • Expect changes in: Actions, Behaviors, Practice, Decisions, Policies	• What will be different 5+ years of participation? • "Hope to see" • Expect changes in: Social Economic, Civic, Environment

External Factors: These are conditions in the environment in which the program exists over which one has little control, but they can influence the program's success. For example: the political climate; social, economic, and demographic changes that may affect participation; media coverage; local or national events that may influence public support, changes in laws; changes in organization's or the funding organization's policies and priorities; or, changes in leadership

FIGURE 3.10 Example of a logic model specific to a space program

Problem Statement: There is a lack of capability to use remote sensing data to predict and manage flood zones.

Analysis/Assumptions: There isn't much local awareness of, or demand for, space and data skillsets by government disaster management office. There are no domestic training programs.

Process					Outcomes		
(If) Inputs		**(If) Activities**	**(If) Output**		**Short**	**Medium**	**Long**
• Advocacy • Funds • Administrative support • Expert advice	(then)	• Offer 12 scholarships per year • Provide 2 short "orientation" events on data & space applications to universities & open to the public/private sector • Sponsor/offer 8 internships per year • Government leader supports in speeches	• 12 students participate, 8+ graduate with space and data relevant degrees, each year • 2 intern at regional disaster management office, 2 at GIS-using businesses, 2 at local telco, 2 in gov space program, per year • 300 students and general public learn about space applications	(then)	• Modest increase of domestic space & data workforce • Government/private sector/civil society experiments with using space applications using "free" interns	• Disaster management office identifies likely flood zones • Government/private sector/civil society normalizes use of space applications, develops demand • Space & data-curricula is updated to meet demand; new research produced • Workforce grows	• Government issues routine and accurate flood warnings. • Space & data-related material incorporated into many disciplines, normalized, increased research output • Businesses/Government/civil society expands use of space applications. Grows demand. • Workforce grows without scholarships or sponsorship

External Factors: These are conditions in the environment in which the program exists over which one has little control, but they can influence the program's success. For example: the political climate; social, economic, and demographic changes that may affect participation; media coverage; local or national events that may influence public support; changes in laws; changes in organization's or the funding organization's policies and priorities; or, changes in leadership

FIGURE 3.11 An example of a "forward" logic model

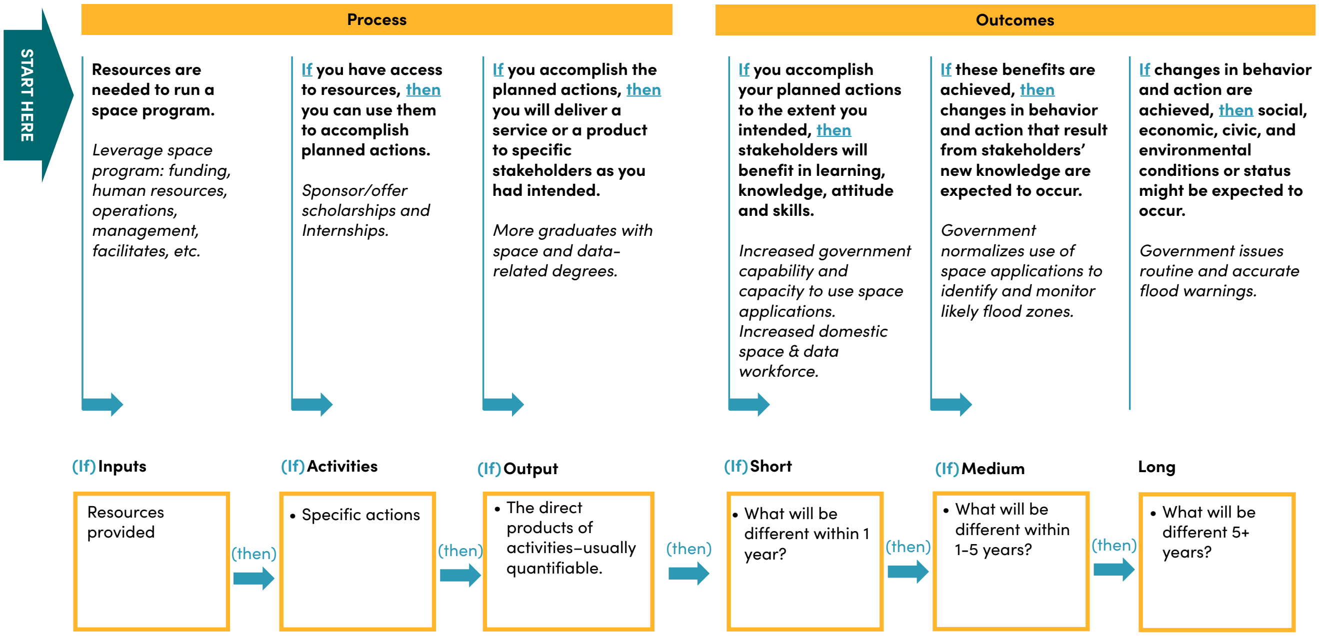
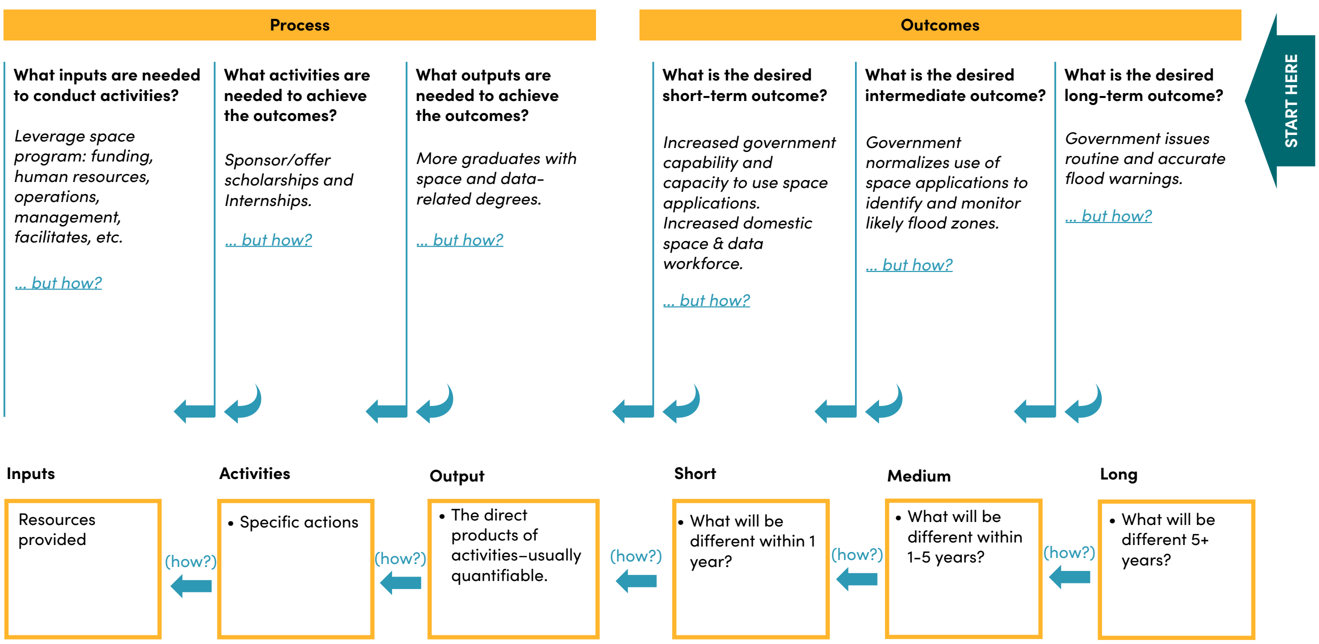


FIGURE 3.12 Example of a "reverse" logic model



projects. While the initial plan to monitor, evaluate, and learn from activities would be drafted by the planning team, the space program office is responsible for partitioning enough internal capacity to successfully complete that monitoring, evaluation, learning, and strategy adaptation as a critical component to overall program success. The space office may break the strategy into more detailed action plans that are bound by a shorter period of time, typically 12 months. An action plan addresses specific initiatives, key objectives, concurrent and supporting activities, specific monitoring and evaluation activities, who will carry them out, and a timeline for doing so.

As discussed in Section 2, there is no one kind of structure required to house a space program. Broadly, however, it should be optimized to execute the established strategy in the short and perhaps medium term. Too large, too fast, and the program may get bogged down in bureaucratic minutiae, or find it difficult to justify the investment in resources before some results can be realized. Early space programs are often more loosely departmentalized, with less specialization, since a small pool of personnel may be called upon to support multiple aspects of foundational space capabilities. As a space program grows, more formalized structures, with stricter parameters for roles, responsibilities, and authority, will become necessary. To determine the necessary size and composition, planners will find that useful questions to ask are "Is the space office organized to provide the necessary inputs, conduct these near- and mid-term planned activities, and monitor outcomes (results)?" "Is it clear who is responsible for each action, and are they, in turn, supported?"

Turning the strategy into action will require frequent communication, both internally and externally. A space program, even a very modest one, should institute reporting structures to make sure the flow of information is effective, efficient, and accessible. A communications plan or protocol is a useful way to document key stakeholders, what data will be communicated and to whom, the frequency of communications, and where information will be posted or stored as well as who holds the internal responsibility to implement the communications plan. Internal communications can manifest as biweekly or monthly meetings, reports, or online dashboards for individuals within the office, among stakeholders, and in collaborating offices. A project status report is a document or tool that records the status of projects and provides general updates on their progress. A more succinct and less frequent executive version should flow to senior leadership to keep them informed and engaged as the space program develops. The communications plan should also account for external reports—those that go to other governments or international organizations and the public at large. This communication, or publicity, can be in the form of newsletters, fact sheets, website updates, speeches, press releases, and social media posts.

MONITORING A PROGRAM

Monitoring and evaluation together help program managers (and national leadership) know if their program is successful. The task consists of a systematic approach to collecting and understanding information about the program's activities and progress toward achieving desired outcomes. No program, anywhere, is perfectly planned or perfectly executed. Monitoring and evaluation, therefore, are key to learning and, most importantly, improving the program's ability to produce desired outcomes. The "NewSpace" private space industry movement especially is characterized by a preference for rapid iteration, which accepts some failure but is also organized to quickly detect problems and adapt to try again (Figure 3.13).

The process of methodically monitoring the results of activities provides information about how well a program activity was performed and measures progress in executing the strategy or derivative plan. Measuring results includes questions like, "Was remote sensing successfully integrated into the university curriculum? Was a Continuously Operating Reference Station (CORS) system installed, and is it operational?"

FIGURE 3.13 Process to monitor, evaluate, and adapt

Monitor Activities ›

- Gather **data** on outputs and outcomes

Evaluate & Learn »

- Are the results and outcomes (thus far) **desirable**?
- **Why** or why not?
- How can we do this **better**?

Adapt Activities & Stategies

Activity:

- Should we change **how** the activity is run?

Strategy or Plan:

- Does the **theory of change** still make sense?
- Should we **add**, **subtract**, or **modify** activities?
- Should we change the **sequence** or **timing** of activities?

Monitoring *outcomes* provides information about the short-, mid-, and long-term impacts of one or many activities. For example, noting the addition of remote sensing coursework into the curriculum and seeking to measure its short-term outcome, a program manager may ask, “How much original research using remote sensing data has the university produced in the past two years?” Noting the new CORS system (combined with other activities and projects, like building new ground control points, or establishing a digital geodetic reference frame), a program analyst seeking to understand outcomes may ask, “What surveying projects referenced the CORS system the past two years, to what effect?”

Development of indicators

An important aspect of monitoring is deciding what, exactly, to monitor. Monitoring specific activities is usually measured immediately or soon after an activity is complete. It asks questions like, “Did the training occur? How many students passed the exit exam?” This provides useful information on how well the program is completing actions. However, the more important (and more difficult) things to measure are the outcomes. Are the program activities resulting in desired short-, medium- and long-term effects? How can one tell? “Indicators” are specific, observable, and measurable trends or facts that shows a level of capability or capacity (Table 3.3). Measuring the same indicator over time illuminates progress made (or not) toward achieving a specific output or outcome in the logic model. A negative or positive result is equally valuable, as each is a signpost indicating where the program needs to focus time and resources in order to make concrete progress.

A worthwhile planning effort is defining a short list (say, one to three indicators) for each output and outcome, and

TABLE 3.3 Indicator types

INDICATOR ELEMENTS	DESCRIPTION AND EXAMPLE
Specific	Provides a clear description of what is measured: “Geospatial data training materials have been developed and provided to university staff.”
Observable	Focuses on an action or change: “5% of syllabuses include geospatial data familiarization in undergraduate courses at regional universities.”
Measurable	Quantified change that is generally reported in numerical terms, such as counts, percentages, proportions, or ratios: “There has been a 25% increase in original research using remote sensing data published since the start of the program.”

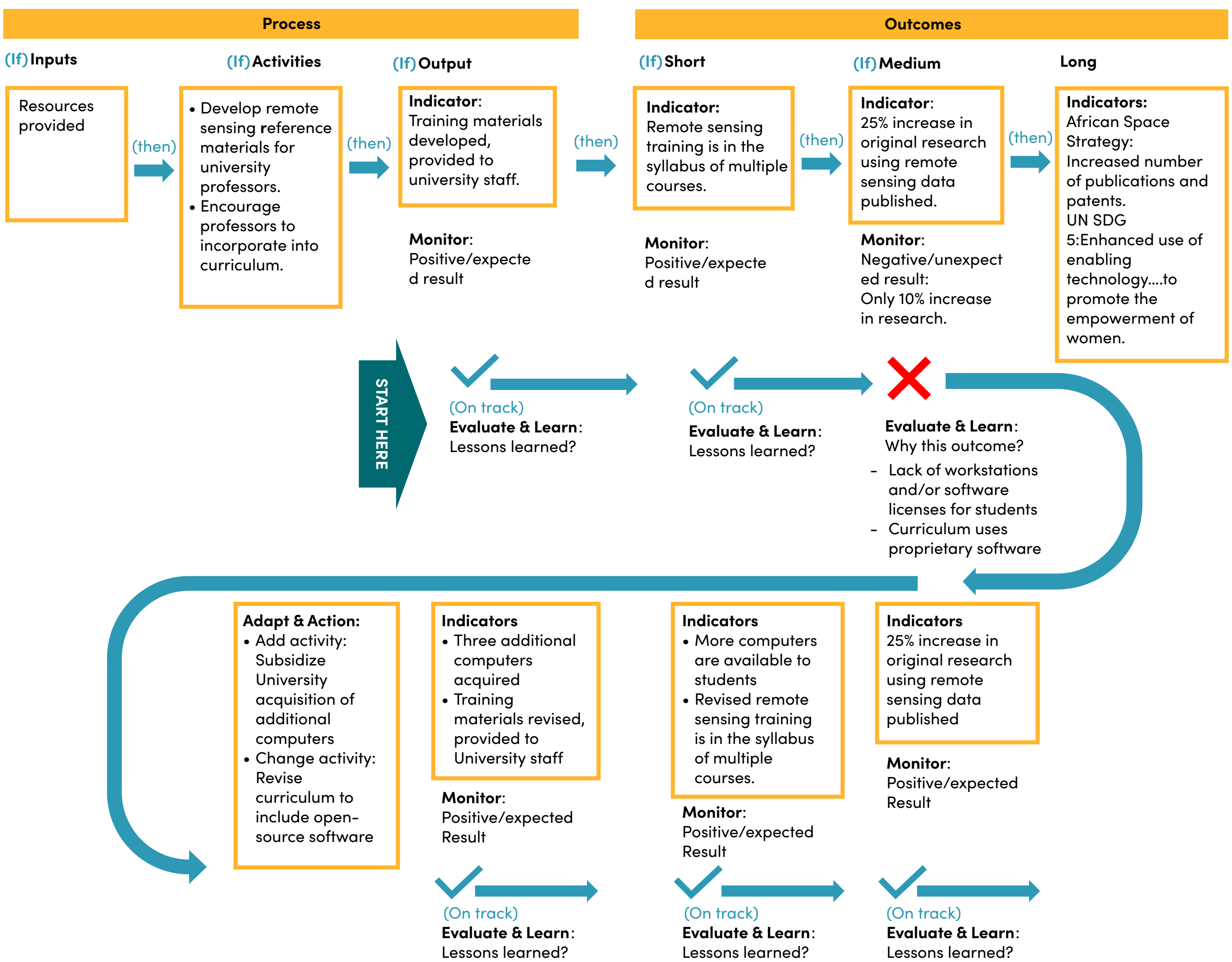
documenting specifics about who, how, and when these data would be collected for a particular purpose. Choosing too many indicators or indicators that are too difficult to monitor will eat up staff time. Not having enough indicators or relying on nonspecific or untracked indicators leaves the team without enough data to evaluate the program's efforts so far and will lose the team the opportunity to obtain useful, relevant evidence of progress. Of note, the definition of medium- and long-term outcomes may already be defined and monitored by other strategies or programs. For example, the African Space Strategy includes a list of suggested indicators for its objectives, and the World Bank provides standardized indicators by country for the Sustainable Development Goals.[18]

EVALUATING AND LEARNING

Evaluate and Learn

Evaluation is making sense of the data collected thus far. Evaluation asks why an action was successful or not, and why it resulted in a desired outcome or not. If the actions have (the intended) positive results and are combining successfully with other actions for desired short-term outcomes, then the program is probably on track. There are still lessons learned or

FIGURE 3.14 Process to monitor, evaluate, and adapt



18 See African Union 2019 and World Bank, "World Development Indicators: Sustainable Development Goals," dashboard, https://datatopics.worldbank.org/sdgs/.

best practices that can be documented and shared (and celebrated). If the actions have negative results (outputs), then the activities themselves may need change.

All new and complex capability development efforts will have setbacks and the need to reassess the approach from time to time. Planners can use the structure of a logic model to unpack a shortfall by asking why and working backwards from the problem. Was the activity (training material) inadequate in some way? Are there new external factors to consider? Perhaps there aren't enough geospatial software licenses or computers available for students to use in their research? If the desired outcomes aren't achieved—or worse, had a negative result—then the program design for that effort may need to be reworked. Perhaps the underlying theory of change needs to be adjusted owing to new external factors. Perhaps the sequence or types of activities need to be changed. Regardless, it is far better to return to the start than to persist in activities that don't contribute to the desired program goals.

This cyclical monitor-and-iterate approach to program management shows why it is so vital to have a proactive, engaged management team for your space program.

ESTABLISHING A PROGRAM CYCLE

It may be helpful to hold an annual review at which space program members and key stakeholders reunite to evaluate the data gathered through monitoring designated indicators throughout the year. These data can be used to understand if the completed activities have indeed resulted in the desired outputs and outcomes. If so, why did an activity work? If not, why not? Are there lessons learned in resourcing, the execution of the activities themselves, in the process of monitoring? Are there new opportunities or threats that need to be considered and worked into the program? Do the original program design theory of change and logic models still hold true?

A program manager may want to link the phases of this cycle (Figure 3.15) to the greater national annual rhythm so that, for example, an annual report of space-related activity and outcomes, demonstrating a return on investment, is ready for policymakers and the public just as future budget allocations are being planned.

Space capabilities and the space and data ecosystem itself will build over time, but progress will not manifest in a straight line. Activities and projects can serve as a fulcrum, as a forcing function, to develop the components of space capabilities. As these activities change or are completed, and as personnel change over and hardware and software are reassigned or redesigned, it is normal for capability and capacity to fluctuate (Figure 3.16). Over the long run, however, the space program should see a steady improvement. This is again why it is so useful to establish some early, key indicators to help managers measure real change over time (Figure 3.17).

FIGURE 3.15 Program cycle

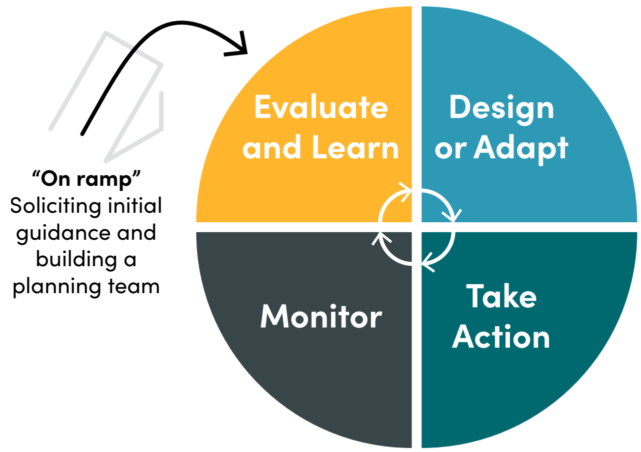
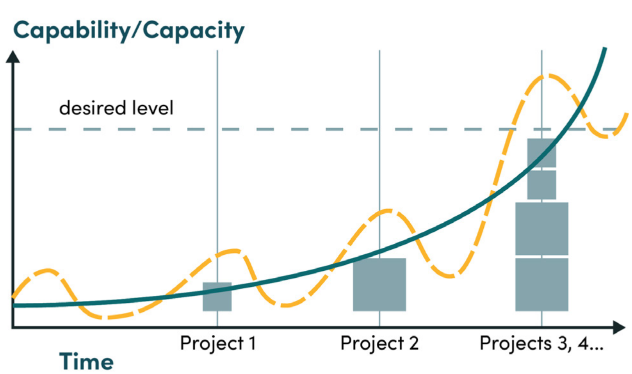
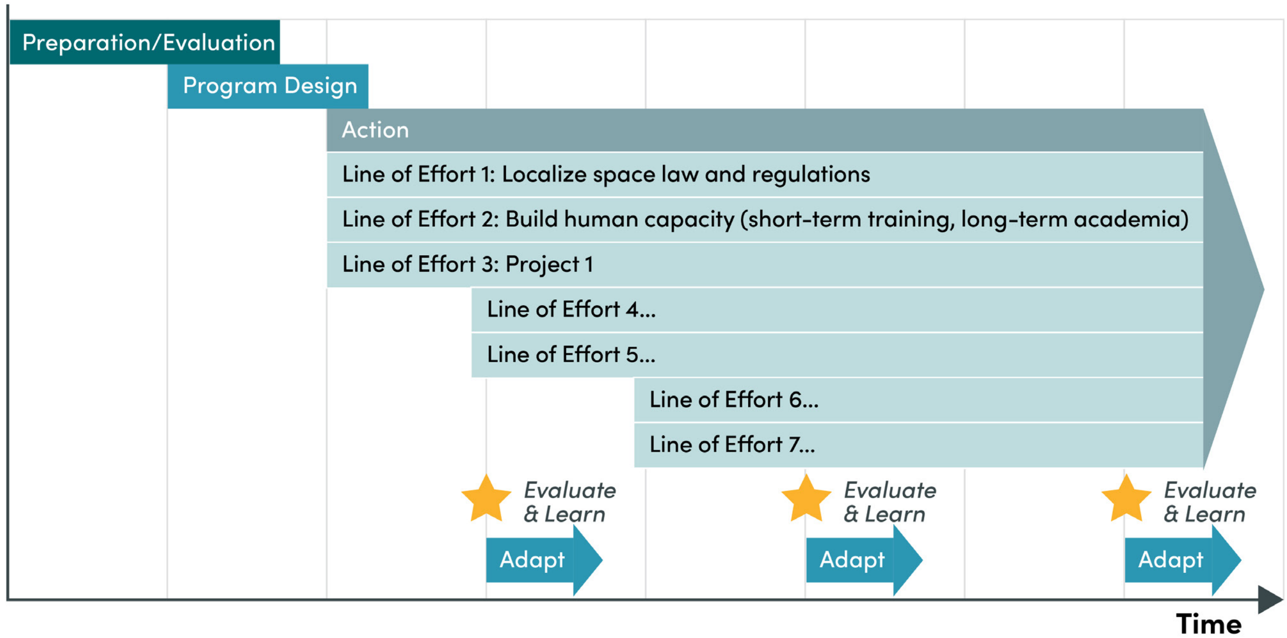


FIGURE 3.16 Capability and capacity progress



Note: The dotted line symbolizes realistic progress toward a desired level of space capabilities versus the "planned" progression in green.

FIGURE 3.17 Program timeline with multiple lines of effort of focus areas, showing increasing activity over time and accounting for "Design/Adapt, Action, Monitor, and Evaluate & Learn" program phases



IDENTIFYING FUNDING AND ADVISING SUPPORT

There are two major approaches to thinking about funding and support for foundational space capability development. The first is the space program and office itself, to include its personnel, facilities, management, internet connection, computers, and so on. It is rare that foreign, private, or philanthropic funding will defray these overhead costs, so a government-sponsored space program will need a funding line in a national or ministerial budget. The proactive engagement of government bureaucracy—building understanding and support with policymakers and the public, submitting and championing a budget request and supporting laws, and maneuvering through many country-unique requirements—all demand considerable skill and persistence. It took Indonesia ten years to go from its an academic draft to signing its first national space act (Verspieren et al. 2022). A successful space program will include a mix of personnel with good management, political savvy, and strong communication skills, in addition to science and technology credentials, between them. The suggested approach of incorporating shorter-term projects into the overall program arc provides regular opportunities to show policymakers and the public a concrete return on their investment, thereby building support for the less tangible, but equally important, longer-term development of the space and data ecosystem.

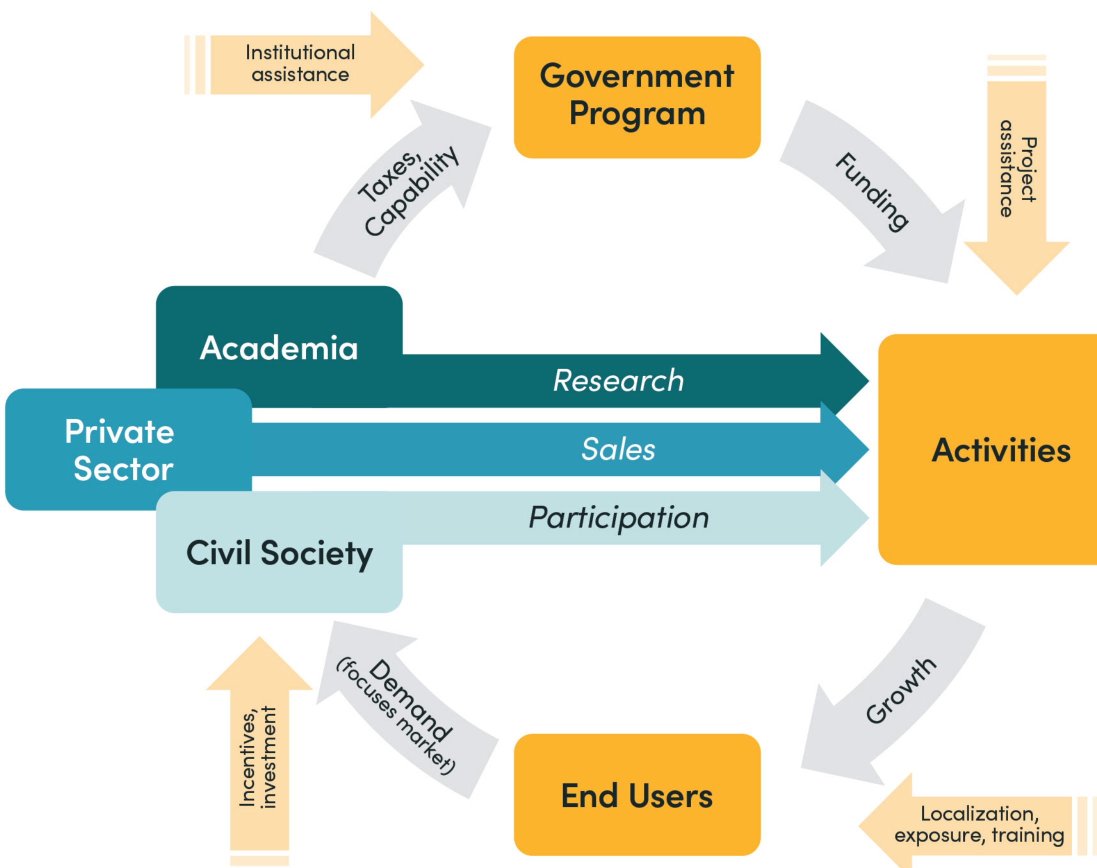
The second approach is funding and support for space-enabled functions, the use of remote sensing, and PNT and satellite communications as enabling components of other state activities. The systems map (see Figure 3.2) shows an example of where space activities may overlap with other programs' activities. Space capabilities should be considered and, if appropriate, woven into other programs (and their funding). For example, if a local government decides to build a new tax cadastre (perhaps aided or funded by an NGO or the UN), and it determines that a cost-effective approach is to use remote sensing data to assess property values, then that capability should be included in the project plan, skills transfer plan, and budget. As an example, a geospatial budget may include a technical advisor, three local geospatial analysts' salary for six months, two computers, a geospatial software license, commercial remote sensing data, data storage on the cloud, a 5G internet connection, and project management and oversight. The space office's role would be to support the teasing-out of space-related needs, support the development of space-related activities (using remote sensing data to survey an area over time), facilitate access to existing capabilities and infrastructure (flag the national spatial reference system and connect "reservoirs" of expertise in the government, private sector, academia, and civil society) and costing (leverage standardized or pre-arranged contracts to acquire data, advise on type of computers needed with sufficient processing power, help define the skills and software required to accomplish the task).

Domestic tools

A state can broadly offer incentives, reduce barriers, and encourage sustainability in the space ecosystem or act as a direct catalyst.

Acting directly, a state may initiate a project that provides a localized service, thus growing awareness and demand for further space-related services and capabilities. For example, a government initiates an e-governance insurance program that tracks drought damage to crops using remote sensing data and then facilitates aid delivery via digital finance (e-finance) to remote farmers by using satellite broadband internet. This naturally captures the interest of farmers, who potentially had never before considered the use of space applications in daily life. They may now proactively look for ways to leverage localized space applications for other areas, such as health, education, and market access. This type of end-user demand should trigger new activity from the private sector (services), academia (projects, research, curriculum development), and the civil sector (participation, use). This growth in research, sales, and participation in turn enhances the space and data ecosystem, making more capability and capacity and (ideally) tax revenue available to the government, which enables improved support to the space sector and other users of space infrastructure. In short, a positive feedback loop is formed (Figure 3.18).

FIGURE 3.18 Ways in which financing and advising support can be used to spur the space ecosystem



To reduce barriers, a state should foster well-coordinated policies on topics that affect the use of satellite applications like satellite broadband, such as those regulating the use of the radio spectrum. In general, many low-income countries tend to have policies that sell access to national spectrum to maximize state revenue, but this tends to dampen the growth of affordable services and private sector network investment. Policies that provide competitive, predictable, and transparent access to sufficient radio spectrum are an important component of thriving space and data ecosystems (Agnoletto, Butler, and Castelis 2022).

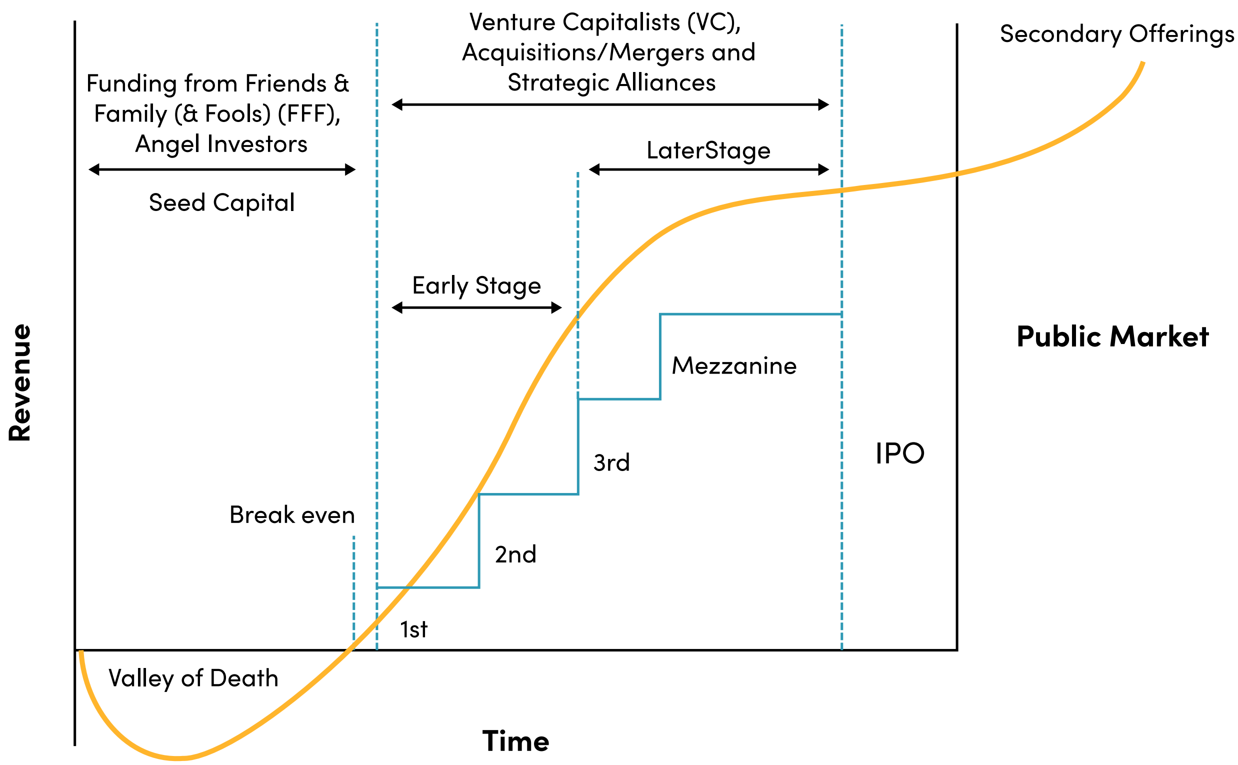
A state can also support its domestic space ecosystem through tax incentives, subsidies, public-private partnerships, prizes, and contracts. Specifically, governments can contract for the delivery of goods to include data, space-related services, and advising. Common contracting types include "fixed-price" contracts and "time and materials" contracts. Prizes can be used to accelerate the pace of innovation and localization. Prizes can do this by offering an award (cash, access to greater support like mentorship and technical assistance), a chance to establish credibility, and free publicity. In turn, prize sponsors have the potential to gain low-risk and low-cost technology development, localization, procurement, or a combination of these with no payment required until the technology is successfully demonstrated. In turn, a space program is able to entice new companies, individuals, and ideas into the space ecosystem and encourage new connections and partnerships ("densifying" the space ecosystem). Prizes also often capture the public's imagination, encourage excitement, and increase awareness of science, technology, and space, thus spurring support for space programs and stimulating greater interest in science and engineering. Prizes do have their limits; that is, solutions are not guaranteed and there is risk for those who compete but do not win. Wealthier competitors may have a greater advantage over those who need to spend time and resources to recruit investors or work without guaranteed pay. Peter Diamandis, chairman of the X–Prize Foundation, recommended incorporating the following: (a) a prize purse and contest time that are well matched to the degree of difficulty, (b) clear and simple rules, (c) an exciting objective, and (d) a potential follow-on market (Culver et al. 2007). A recent example of a prize program designed to "drive entrepreneurial activity in the African space industry and promote awareness of the value of earth observation" is the 2022 Africa Earth Observation Challenge, sponsored jointly by the South African Space Agency, Rwanda Space Agency, and Kenya Space Agency, among others.[19]

States can also provide favorable loans through their national development bank or equivalent institution. A government can sponsor grants for scholarships, research and development, technology accelerators, and incubators. Of note, accelerators and incubator programs are typically competitive and can be sponsored by the government as well as by investors or other companies, or they can be sponsored by an independent for-profit or nonprofit organization. Accelerator programs usually have a set timeframe, generally several months, during which startups work with a group of mentors to build out their business, culminating in a pitch competition or demo day with potential investors, which provide funding often in exchange for a small amount of equity in the future business. For incubator programs, a new company pays an open-ended, month-to-month lease for shared workspace, where it will obtain mentoring, refine its ideas, network, build out a business plan, and work on its product (Kenan Institute of Private Enterprise 2020).

Private sector companies, both domestic and international, can seek seed funding, support from friends and family, crowdfunding, small business loans, and "blended" financing (Figure 3.19). "Blended financing" includes various instruments to "crowd in" commercial investment for development, and includes collective investment or pooled vehicles, such as facilities and funds. More developed space sectors have access to larger for-profit funding, like angel funding, venture capital, or an initial public offering (IPO). Nongovernmental and philanthropic organizations, like the Space Foundation, Secure World Foundation, and the International Astronautical Federation, often convene, share information, and sometimes

19 See "What Is the Africa Earth Observation Challenge?," https://eochallenge.africa/about/.

FIGURE 3.19 Startup financing cycle



Source: Kmuehmel 2009.

support domestic civil society space organizations. Many non-space-focused civil organizations use space applications as a matter of course and thus also represent a significant resource. Examples include organizations focused on geography, cartography, climate, weather, and general science. Some large private companies with a social mission build community and training into their business models. A few examples of such public-benefit corporations include ESRI, Planet, and Google Earth Engine (Legal Information Institute 2020).

Regardless of the types of tools a state decides to use, they aren't useful if people do not know they exist. Good communication is key. Space agencies, like NASA, ESA, and ISRO, routinely post calls for proposals for research, collaboration, goods and services, and host guidance, tutorials, and standards to support the general development of their space ecosystem.

Regional or local governments interested in growing their tech and space industry often do the same. For example, the city of Shenzhen, China, published a list of available subsidies and support measures for companies developing satellite-related technology, which included support for reaching international certification, subsidies for internal market access, and subsidies for joint ventures with foreign companies in related industries.[20] The US state of Virginia hosts a website for its spaceport, lauding its tax incentives to locate and headquarter space flight launch and training business operations in Virginia, its liability law, and trade zone status.[21]

Ideally, as the nongovernment elements in the space and data ecosystem grow, more services and benefits will flow to activities and end users that are not specifically driven by a government space program.

20 "A Rising Chinese Space Sector: Expectations vs Reality | Satellite Markets & Research." file:///C:/Users/rose/Zotero/storage/6Z36VE9D/rising-chinese-space-sector-expectations-vs-reality.html

21 "Virginia Space and the Mid-Atlantic Regional Spaceport." https://visitesva.com/things-to-do/listings/virginia-space-and-the-mid-atlantic-regional-spaceport/

For startup companies, the early "valley of death" is the period when a business startup is doing research for and development of its product and has not yet started to generate revenue. As a business matures and is able to prove the viability of and demand for its product, it can attract larger investments as well as depend on increasing revenue.

Additional tools

Although the government must manage its own program overhead costs, it can leverage or support access to significant funding, technical advising support, or both, that are available through development finance institutions (DFIs), international cooperation, access to bilateral and multilateral forums and organizations, and the United Nations. These organizations tend to sit on a spectrum somewhere between "advising" and "financing" poles. It is useful to investigate their past activity and various programs to understand what mix of assistance or financing they are likely to provide. These organizations can support the development of the space office itself, the program's activities, or the development of the greater space and data ecosystem. This support may include but is not limited to loans, grants, technical advising, training, networking, acquisition of equipment, data infrastructure, and diverse forms of cooperation. International links can also make the space program itself more politically robust, as commitment to an outside organization tends to solidify domestic political commitment as well.

The foundational space capabilities of consulting, advising, and localization are a critical balancing factor when weighing possible collaboration or support. Every country has its strengths and ability to contribute, be it geographic attributes, its networks and geopolitical relationships, its technology, industry, or people.

Philanthropic organizations, civil sector organizations

There are many nonprofit organizations that can provide useful networking, reference material, training, advising, and, occasionally, funding. Some are explicitly space focused, like the International Astronautical Federation (established in 1951) and Space Frontier Foundation (founded in 1988), among others. These organizations excel in their ability to convene diverse elements of the space community and support networking and mentoring. The Space Generation Advisory Council (SGAC) is associated with the UN and has numerous national, regional, and international chapters that run workshops on all sorts of space topics but excels at developing youth leadership in the space sector. Non-space-focused philanthropic organizations frequently support efforts that include space applications and capability and capacity building. A land-reform-focused NGO could, for example, support the implementation of using remote sensing data in the development of property registers for the process of titling and registering land. Education-focused NGOs incorporate support for youth engagement with digital public goods, science, and technology, which connects to or can lead to the space ecosystem and helps build human capacity in the long term. If a country is clear about the tools it would like to consider for addressing its developmental goals, many development-oriented philanthropic organizations will take space applications more seriously when negotiating possible collaboration and support.

There are also many nonprofit organizations that focus on bridging space capabilities to development-related actions. OpenGeoHub (funded by the European Union) "aims to accelerate the uptake of key environmental data...[for use] in the field of research, decision-making, and practitioners, including landholders and citizens, in support of effective and impactful actions on the ground."[22] The Geo4Dev initiative is a collaboration between a private company (New Technologies Inc.) and two nonprofits (Center for Global Action and 3IE) and operates from the University of California, Berkeley, to "inspire novel research collaborations, share knowledge, and build capacity to utilize geospatial data, tools and approaches."[23] OpenStreetMaps, Ushahidi, and others provide user-friendly geospatial platforms. Nonprofit, license-free software, like QGIS, can be a useful way to remove cost barriers to accessing

22 "Open-Earth-Monitor Cyberinfrastructure," https://opengeohub.org.
23 "About Geo4Dev," https://www.geo4.dev/about.

and using remote sensing data. GSMA Mobile for Development (a charitable section within the GSMA trade association) and the Internet Society, among others, focus on closing the digital divide, to include the space segment of telecommunications infrastructure.

Academia and research community

Universities and research or education-oriented networks are another way to foster domestic, regional, and international cooperation to build foundational space capabilities. Partnerships can include a variety of activities such as (but not limited to) joint research, training, curriculum development, scholarships, and faculty and student exchanges. International partnerships can be structured to include applied field and laboratory work, research, publication, and internships to expose young professionals to a range of skills and material on science and technology subjects as well as humanities subjects such as leadership, commerce, management, and governance. High-quality, open-access, peer-reviewed journals like *Remote Sensing, Geosciences, International Journal of Geo-Information (IJGI)*, and *IEEE Communications Surveys and Tutorials*, among many others, are accessible via the internet.

Stepping back further, it is useful to recognize that a government has a primary role in preparing the country's population to participate in the space and data ecosystems starting in primary and secondary schools. Strong foundations in math, science, critical and problem-solving skills, creativity and innovation, research, communication, cooperation, interpersonal management, life skills, and lifelong learning are essential. A state can maximize the potential of its population by encouraging children of all backgrounds, races, ethnicities, genders, religions, and income levels to join and benefit from this growing and increasingly global knowledge-based economic community.

Development finance institutions

Major DFIs include the World Bank Group (International Bank for Reconstruction and Development, International Development Association, and the International Finance Corporation), African Development Bank, Inter-American Development Bank, European Bank for Reconstruction and Development, Asian Development Bank, (the China-led) Asian Infrastructure Investment Bank, Islamic Development Bank, and New Development Bank (formerly the BRICS Development Bank). These institutions offer policy advice, research and analysis, technical assistance, and financing to varying degrees. The World Bank, for example, often accounts for space applications like remote sensing when partnering with a country to address a state's (non-space) economic constraints. In 2011 the World Bank provided US$4.59 million in grants to improve water resource and agricultural management within Jordan, Tunisia, Morocco, Lebanon, and the Arab Water Council. This support provided hardware, software, and technical assistance needed for the application of various remote sensing and decision-support tools to address water resources and agricultural management (World Bank 2011). Another example is the Climate Risk and Early Warning Systems (CREWS) initiative that funds analytical and advisory services, technical assistance, investments, capacity building, and some operational support for "risk-informed" early-warning systems in least developed countries and small island developing states. This naturally includes leveraging various space applications, from remote communications to remote sensing data. The dividing line between types of assistance and organizations can be blurred—the fund's secretariat is hosted by the WMO, steered by eight member states, managed by the World Bank, and implemented by the World Bank's Global Facility for Disaster Reduction and Recovery (GFDRR), UN Office for Disaster Risk Reduction (UNDRR), and the WMO.[24] Explicitly space-focused DFI programs are harder to find but are becoming more common. In 2020, the Asian Development Bank provided US$50 million to Kacific Broadband Satellites International Ltd. to bring affordable and reliable internet to remote communities and island states in Asia and in the Pacific (ADB 2020). The case for leveraging DFIs to grow foundational space capabilities will strengthen as access to and use of space are increasingly recognized as important national infrastructure and a component of national development. Having policy and strategy that connect to broader national

24 See CREWS website, https://www.crews-initiative.org/en.

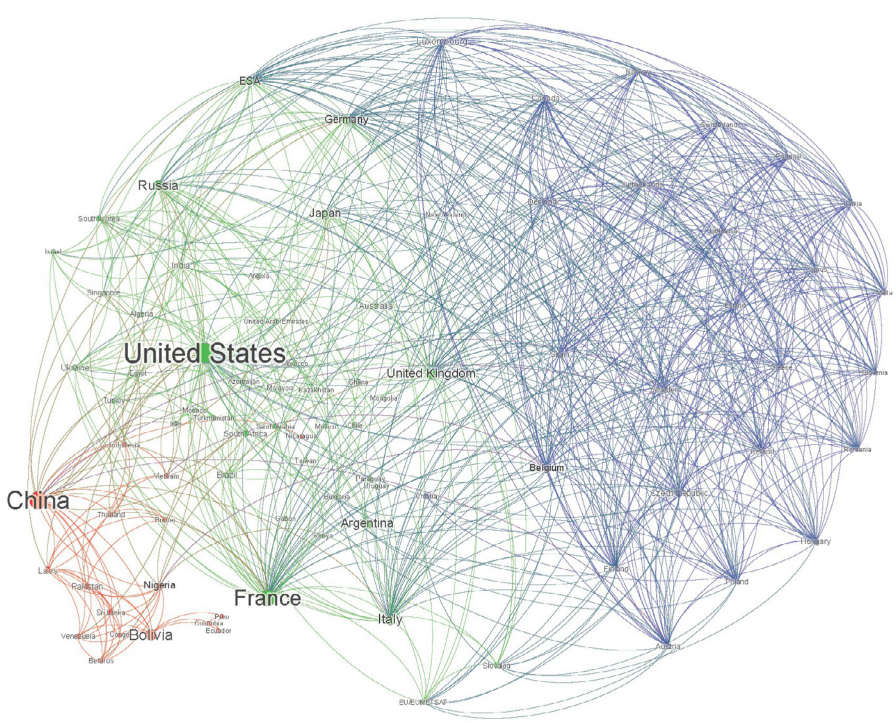
priorities for development as well as shovel-ready activities and projects in mind will greatly improve the likelihood of gaining DFI support.

Bilateral and multilateral cooperation and assistance

Space actors with long-standing, developed programs, such as the United States, the European Union, Russia, and China, have a history of rich international cooperation. Such partnerships can provide rapid access to significant capability and a robust commercial space sector, as well as diplomatic prestige (space cooperation as a signifier of a strong relationship). Such a bilateral relationship tends to be asymmetrical, however, and geopolitics are an ever-present backdrop. When China built a satellite tracking and control center in Argentina in 2017, the US expressed concern that China was using it to spy on geostationary communication satellites that serve the US East Coast. In 2020, when countries began signing the US-sponsored Artemis Accords (a common set of principles to govern the civil exploration and use of outer space), China characterized the accords as an attempt to stymie Chinese space ambitions (Ji, Cerny, and Piliero 2020). However, these and other major space actors provide many core services, such as sharing PNT and weather data, without requiring any formal cooperation agreement (Figure 3.20). Looking forward, as the global space economy matures, space activity will probably gain increasing independence from state-driven strategic objectives and agendas (Lal et al. 2015).

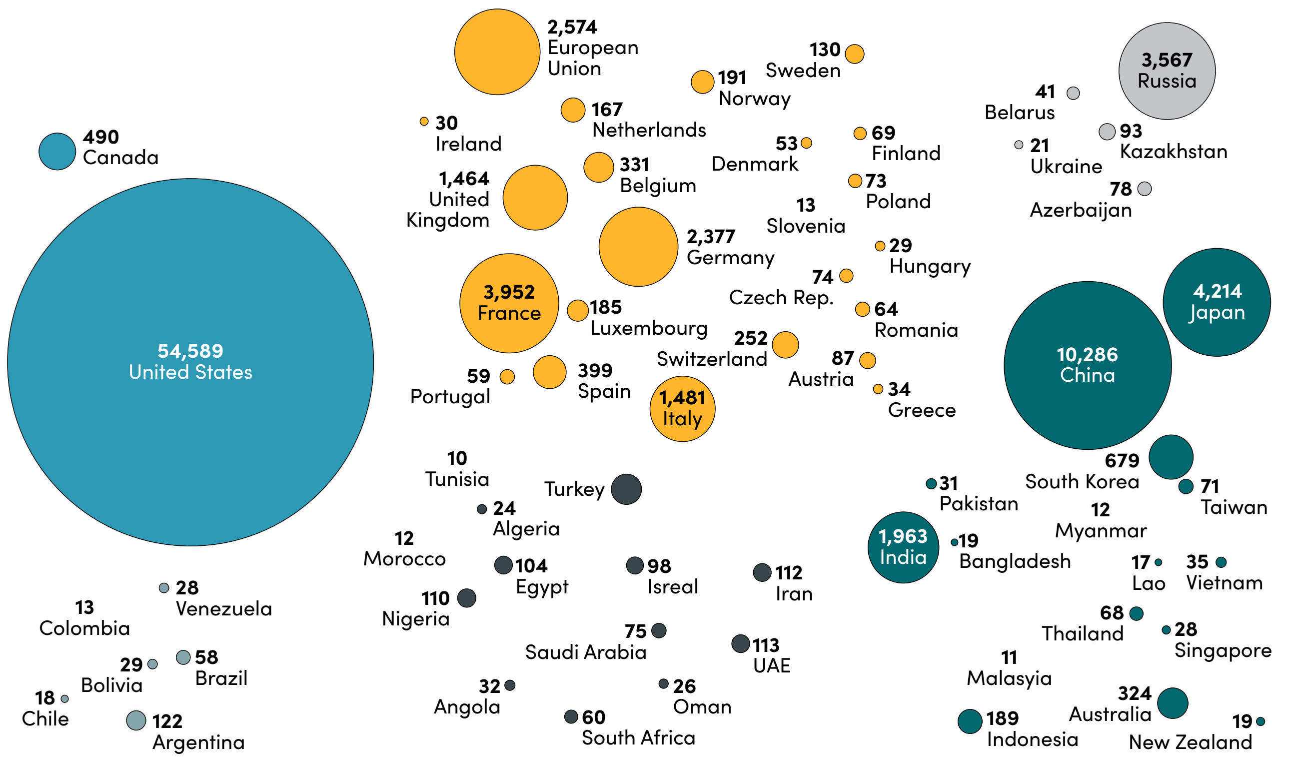
Figure 3.21 shows world government expenditures for space programs with a budget of over US$10 million, highlighting significant space actors such as the UK, France, Germany, Italy, India, Japan, South Korea, and Canada, among others (Berger 2022). These countries can offer other states a relationship with less charged (but not absent) political baggage, if not as much capacity for engagement as the US or China. Italy and Kenya, for example, have a multidecade history of cooperation, which includes exploring models for profit sharing (Space in Africa 2018). Brazil has leveraged its advantageous geography to work with France on stratospheric balloons, since Brazil is well placed for both balloon release and recovery. Japan is particularly adept at cooperating internationally through

FIGURE 3.20 Patterns in country-to-country collaboration



Source: Lal et al. 2015, 4–5. Reproduced with permission.

FIGURE 3.21 World government expenditures for space programs in 2021



Note: The total was US$92.4 billion. Budgets indicated for European countries include their contributions to the European Space Agency (ESA) and European Organisation for the Exploitation of Meteorological Satellites (Eumetsat). Only countries with a budget of at least US$10 million appear on the map.
Source: Berger 2022, from Euroconsult, Government Space Programs, 22nd edition, 2022.

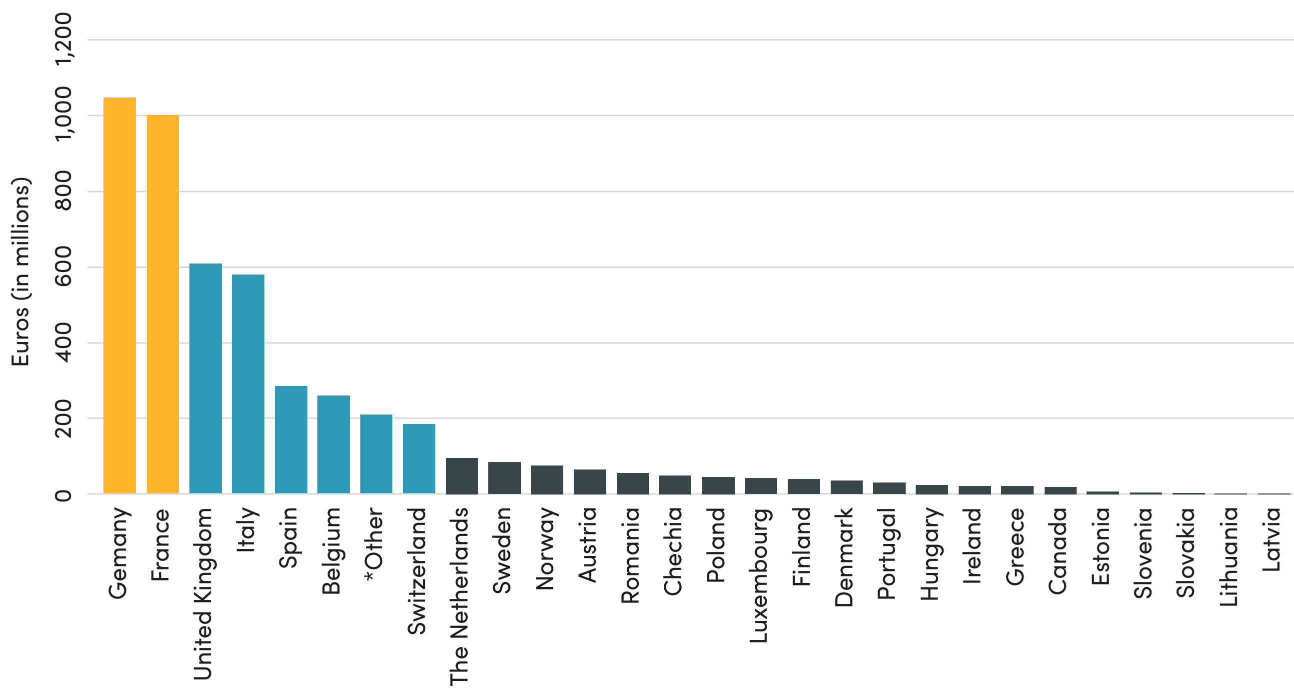
its academic institutions. As part of a collaboration program between two universities, for example, the Philippines' first two satellites, DIWATA-1 and DIWAT-2, were developed and manufactured by Filipinos and then produced in Japan. Further, there is no requirement that a state work with only one partner. Vietnam initiated its program with the Soviet Union focused on space science and then moved on to work with France and Japan on satellite development and applications (Verspieren et al. 2022). India credits its early success to ongoing cooperation with the US, Russia, and France combined with engaging the Indian diaspora and a systemic indigenous effort (Guruprasad 2018). Today, India has space cooperation agreements established with sixty countries and five multinational organizations (Sidharth 2022).

Regional space agencies

Regional space agencies offer countries the ability to pool resources and risk, though these efforts do require constant negotiation and compromise. The European Space Agency (ESA) has done this to great effect, building a twenty-two-member organization into one of the largest and most sophisticated space programs in the world, while also ensuring access to space technology and data at a sustainable cost for members that have the least resources. All ESA member states make mandatory contributions to certain core programs on a scale based on their gross national product (GNP). Members are free to decide on their level of involvement in other "optional" programs that may be of interest to only a subset of member states (Figure 3.22).[25]

25 "European Space Agency Funding," https://www.esa.int/About_Us/Corporate_news/Funding.

FIGURE 3.22 European Space Agency (ESA) budget 2022, in million euros



Source: "European Space Agency Funding," 2023 https://www.esa.int/About_Us/Corporate_news/Funding.

Other regional space agencies include the Asia-Pacific Space Cooperation Organization (APSCO) and the African Space Agency (AfSA). There is an effort underway to establish a Latin American and Caribbean Space Agency (ALCE) (Government of Mexico 2021). There are also numerous forums where nations can share information and best practices, collaborate on various themes, and participate in capacity building programs. The Asia-Pacific Regional Space Agency Forum (APRSAF) includes space agencies, governmental bodies, international organizations, private companies, and research institutions.[26]

United Nations

The United Nations Office for Outer Space Affairs (UNOOSA) is probably the largest and oldest platform for international space cooperation and capability building. UNOOSA was established in 1958 to support governments in building legal, technical, and political infrastructure to support global space activities. UNOOSA provides capacity building through training, workshops, conferences and knowledge-sharing portals, fellowships, and competitive programs for interested countries. In addition to capacity-building programs, UNOOSA provides advisory missions and emergency support to countries. Work is divided between various committees:

- Committee on the Peaceful Uses of Outer Space (UNCOPUOS) governs the exploration and use of space for the benefit of all humanity: for peace, security, and development. The committee is tasked with reviewing international cooperation in peaceful uses of outer space, studying space-related activities that could be undertaken by the UN, encouraging space research programs, and studying legal problems arising from the exploration of outer space. UNCOPUOS led the codification and entry into force of five "core" UN treaties related to outer space activities, as well as other international agreements and mechanisms vital to cooperation in space. Meeting annually in Vienna, Austria, UNCOPUOS is the primary forum whereby its (currently) one hundred member

26 "About APRSAF," Asia-Pacific Regional Space Agency Forum, https://www.aprsaf.org/about/.

states discuss issues including the regulation of space debris, safe (sustainable) space operations, "common good" space applications such as climate change mitigation and water management, and threats posed by asteroids, among other areas requiring discussion, consensus, and creation of international law. Most recently, UNCOPUOS negotiated the "Guidelines for the Long-Term Sustainability of Outer Space Activities."[27]

- UNCOPUOS Science and Technical Subcommittee (STSC) addresses scientific and technical aspects of outer space activity and international space cooperation, diving deep into topics such as space weather, orbital debris, and the long-term sustainability of outer space activity.
- UNCOPUOS Legal Subcommittee (LSC) helps countries understand the fundamentals of international space law and increase their capacity to draft or revise national space law and policy in line with international normative frameworks on space. This is particularly important as more and more actors enter the space arena.
- The International Committee on Global Navigation Satellite Systems (ICG) promotes the compatibility and interoperability of the GNSS and cooperation on matters of mutual interest related to civil satellite-based PNT and value-added services.

Major initiatives include the following:

- United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) Knowledge Portal. This portal offers links to open source (free) datasets of satellite imagery, elevation models, and land use and land cover maps as well as near real-time data products for different hazard types (floods, fires, earthquakes, etc.). Each month, the UN-SPIDER team compiles a list of applications of remote sensing data. Past topics include locust monitoring, soil erosion, and population and settlement data.
- "SPACE4SDGs" is a directory of sorts that matches space capabilities and initiatives (e.g., Space4Water, Space-4Climate Action, Space4Youth) to specific sustainable development goals.[28]
- "Access to Space for All" focuses on technical know-how, engineering processes. and infrastructure in the areas of hypergravity and microgravity, satellite development, and space exploration (UNOOSA 2022).
- "Space4Women" campaigns to increase women's representation in the space sector. In October 2022, UNOOSA launched a mentorship program for women in the aerospace sector.[29]
- "Space Law for New Space Actors" is a UN project to raise awareness of, and adherence to, the existing normative framework governing outer space activities. Upon request, the UN will facilitate a country's effort to draft national space law, policy, or both. This includes e-learning modules, advisory services, and capability building.[30]
- UN Register of Objects Launched into Outer Space. UNCOPUOS manages space object registration as a means of identifying which states bear international responsibility and liability for space objects—that is, satellites and associated debris.[31]

The UN Office for Disarmament Affairs (UNODA) also has a role for space, mainly focused on preventing an arms race in outer space; setting norms, rules, and principles for responsible behavior in space; and reducing the risk of misunderstandings and miscalculations in space.

Specialized agencies

UN International Telecommunications Union (ITU), established in 1865, is the UN's specialized agency for information and communication technologies. Originally organized

27 "Awareness-Raising and Capacity-Building Related to the Implementation of the Guidelines for the Long-Term Sustainability of Outer Space Activities," United Nations, https://spacesustainability.unoosa.org/.
28 "Space4SDGs: How Space Can Be Used in Support of the 2030 Agenda for Sustainable Development," UNOOSA, https://www.unoosa.org/oosa/en/ourwork/space4sdgs/index.html.
29 "Space4Women," https://space4women.unoosa.org/.
30 "Legal Advisory Project: Space Law for New Space Actors," USOOSA, https://www.unoosa.org/oosa/en/ourwork/spacelaw/capacitybuilding/advisory-services/index.html.
31 "United Nations Register of Objects Launched into Outer Space," UNOOSA, last modified December 13, 2022, https://www.unoosa.org/oosa/en/spaceobjectregister/index.html.

to regulate the telegraph industry, the ITU has evolved in step with the telecommunications and, increasingly, space industry. Today, through the implementation of radio regulations and regional agreements, the ITU works to ensure that radio-frequency spectrum and associated satellite orbits are used equitably, efficiently, and economically by states, and it prevents physical and electromagnetic interference in geosynchronous orbit.

The ITU has three technical sectors: T, R, and D. The ITU-Telecommunication Standardization Sector (ITU-T) is responsible for setting international standards (known as "recommendations") on issues such as interoperability and 5G technology. ITU-Radiocommunication (ITU-R) manages satellite ownership and spectrum allocation. ITU-Development (ITU-D) specializes in building human and institutional capacity, providing data and statistics, and promoting digital inclusion.[32] Each sector and region has its own set of study groups and conferences that build up to the ITU's Plenipotentiary Conference, held every four years.

Last, the UN has "DFI-like" components as well. The UN Technology Bank for Least Developed Countries focuses both on low- and middle-income countries. The UN Technology Bank's mandate is to strengthen science, technology, and innovation (STI) capacity in the least developed countries, including the capability to identify, absorb, develop, integrate, and scale up the deployment of technologies and innovations, as well as the capacity to address and manage intellectual property rights issues. The UN's Inclusive Digital Economy programs as well as the Least Developed Country (LDC) Investment Platform, both financed by the United Nations Capital Development Fund, provide flexible grants and loan instruments to least developed countries to finance a wide range of products and services in various sectors, including those that complement development of space and data ecosystems.

As of 2022, 193 states are members of the ITU, and one hundred states are members of UNCOPUOS. States must formally apply for membership in UNCOPOUS to participate. It can be difficult and expensive for countries to send delegates to UN space-related meetings and events, so many leverage their representatives posted to a permanent mission based in Geneva, Switzerland. The ITU convenes in Geneva, but UNOOSA and UNCOPOUS meet about 1,000 kilometers west, in Vienna, Austria. Most representatives will not have a deep background in space-related issues, so it's important that they are supported by a domestic space office. These representatives should be empowered to participate in international coordination, cooperation, norms setting, and so on, through tools such as information papers, white papers, and formal guidance from the member state.

SUMMARY OF SECTION 3

Space program design is essentially the process of writing highly localized instructions—a strategy—for methodically building foundational space capabilities and for setting the best conditions possible for accelerating the growth of a space and data ecosystem. A space office, no matter the size, gives a program an anchor within the government, a focal point capable of bringing together national priorities, organization, and resources—and those of the private sector, academia, and civil society—to achieve better access to and use of space and to engage the global community.

32 "About the ITU-D and the BDT," International Telecommunication Union, https://www.itu.int:443/en/ITU-D/Pages/About.aspx.

Annex 3A. Use Cases

Use Case 6. Drivers for a space program from a Philippine perspective

When the Philippine government evaluated its space needs, the main drivers to develop a space capability were identified as security and emergency communications, centered on the following significant experiences:

- The planning team found that, owing to a lack of domestic space knowledge, the Philippine government had, in hindsight, previously overestimated the risk of North Korean rocket bodies crashing into the Philippine Sea. This overestimate resulted in an unnecessary and economically damaging ban on all fishing activities on the eastern seaboard. Second, the Philippine government found it was unable to adequately patrol the large West Philippine and South China seas with the country's current number of aircraft and patrol ships. Subscription to commercial remote sensing data offered a more cost-effective option than buying, operating, and maintaining additional aircraft and ships. Thus the planning team determined that the development of sovereign space capabilities for defense and security is a priority need for the Philippines.
- In 2013, a super typhoon resulted in thousands of casualties and billions of US dollars in damages, and also destroyed the cellular transmissions towers in several provinces. In the words of Dr. Rogel Mari Sesi, "In the aftermath of the Typhoon, emergency responders, who mainly relied on cellular communications, lacked the capability to effectively assess the extent of damage on the ground. At that time, satellite phones were the only means of communications in the affected areas and the Office of Civil Defense (OCD). In the aftermath of [Typhoon] Haiyan, commercial satellite companies deployed mobile VSAT terminals, creating an ad-hoc communications network that enabled local government units, emergency responders and the military to coordinate their activities. This highlighted the need for a regular and emergency space-based communications capability, one that is not affected by weather and is constantly available" (Verspieren et al. 2022).

Use Case 7. The development and initial implementation of South Africa's national space policy

South Africa began its process to develop a space policy in 2003 with just a few dedicated individuals. South Africa's planning team weathered numerous challenges but eventually built a wide base of support in government for the space policy initiative, resulting in South Africa adopting its first space policy in 2009. Peter Martinez, drawing upon his time serving in the South African government, described the following development goals in rough chronological order.

- Raise the attention of policy makers to the fact that space is a policy issue.
- Find a champion for space in government.
- Identify or create a platform for space policy dialogue.
- Define a set of common goals to promote cooperation.
- Build a critical base of support in government.
- Make space a government-wide agenda.
- Build policy…coalitions.
- Build momentum and capacity in the space arena.

- Take stock of strengths, weaknesses, threats, and opportunities to inform policy development.
- Put it all together to formulate the policy.

"The process ... took some six years to run its course. It took that long because the process was, in a way, almost as important [as] the content of the policy. Through that process, we now have a well-grounded space programme that is modest, but which enjoys the support of a wide number of government Departments and also multi-party political support and is therefore likely to be sustained, unlike the previous military space programme. One of the central pillars of the National Space Policy is a cooperative governance approach to space activities. This has required (and will continue to require) concerted efforts on the part of civil servants to work across Departmental boundaries." (Martinez, 2016)

Use Case 8. The African Space Strategy's 2019 SWOT Analysis.

STRENGTHS	WEAKNESSES
▶ Political support for the growth and development of high-technology sectors, including the space sector.	▶ Disparities in space expertise and capabilities across the continent.
▶ Significant government support for the establishment of national and regional space programs.	▶ Wide range of African Challenges and societal needs.
▶ A significant number of space professionals committed to leveraging space for socio-economic development.	▶ African user needs are not well quantified and documented.
▶ Intra-continental partnerships fostering space science collaboration	▶ No governance structure to coordinate and manage continental-level space activities.
▶ Africa's strategic and geographic locations that are suitable for astronomical and space physics facilities.	▶ Inadequate core skills in several areas of space science.
▶ Exiting nodes of space expertise and in-situ capabilities.	▶ Limited number of space initiatives, so skills are lost.
▶ Established satellite assembly, integration, and testing facilities.	▶ Duplication of efforts and suboptimal coordination.
▶ Existing knowledge base and expertise in space engineering.	▶ Suboptimal investments in the space sector.
▶ Experience in the manufacture and/or operation of small satellites.	▶ Disjointed continental efforts because there are no data management or data sharing policies.
▶ Space physics capability that leverages its proximity to the Southern Ocean islands, the South Atlantic Anomaly, and the study of the Equatorial Electrojets.	▶ Limited access to libraries, journals and scientific and technical databases.
▶ Existing and established centers focused on the exploitation of geospatial data.	▶ Uncoordinated regulatory environments on matters such as immigration, and cross-border taxes and tariffs.
	▶ Fragmented space activities, not aligned with continental goals.
	▶ Limited funding on a continental scale that is allocated for space science and technology.

OPPORTUNITIES	THREATS
▶ Large rural communities whose needs can be supported by space products and services. ▶ A young population that could be trained to serve the requirements of an indigenous space sector. ▶ Maturing public awareness and knowledge of the societal benefits of space applications. ▶ Servicing the sustainable development needs of a population of 900 million people spread over 30.3 million km2. ▶ Natural resources that provide a significant socio-economic growth potential. ▶ Contribution of space products and services to the challenges of global change. ▶ Leveraging the skills and expertise of the African Diaspora. ▶ International partnerships for the co-development of space platforms, products and services. ▶ Potential to share infrastructure and other capacities among various African countries. ▶ Learning from existing satellite programs to strengthen continental capacity.	▶ Lack of a coordinated approach to international treaties and conventions. ▶ Political will for continental-level space initiatives not universally shared, amid other pressing national socio-economic priorities. ▶ Over-reliance on financial and technical support from outside the continent. ▶ Political instability. ▶ A weak financial base. ▶ Brian drain of core skills. ▶ Competition for radio frequencies allocated to Africa that could limit the future usage of such resources. ▶ National space programs not able to assimilate and adopt rapid technological advancements. ▶ Lack of a focus on user needs and innovation in delivering relevant space services and products. ▶ Limited collaboration and coordination owning to an exclusive focus on national priorities. ▶ Lack of a coordinated continental approach to multilateral space agreements and guidelines.

Source: African Union 2019, 11.

Use Case 9. SWOT analysis of the use of geospatial information in the United Nations system

STRENGTHS	WEAKNESSES
▶ Existing geospatial expertise and resources in many entities at headquarters, regional and country offices. ▶ Standards and policies to improve geospatial data management exist and are enforced in some entities. ▶ Existing geospatial capacity development programs (though limited and poorly funded).	▶ Senior management often lacks understanding of the specialized skill set required for geospatial experts ▶ External stakeholders do not conduct business with UN entities as one. ▶ Existing coordination mechanism is informal and on a voluntary, best-effort basis. ▶ Perception of geospatial information systems as just a tool for ad-hoc use and not viewed as a core asset to be integrated in decision-making. ▶ Not all agencies at same level of geospatial capacity, knowledge and resources. ▶ Limited awareness of the potential of geospatial application at all levels. ▶ Lack of corporate understanding on inefficiencies caused by the lack of a better use of geospatial information.
OPPORTUNITIES	**THREATS**
▶ Determination of respective entities to enhance coordination and collaboration through the Network ▶ Reporting to relevant and expert intergovernmental mechanism (UN-GGIM). ▶ Industry is providing more and more solutions, including innovative technologies. ▶ Leveraging existing UN-GGIM networks, working groups and frameworks such as for the integration of Statistical and Geospatial Information, Global Statistical Geospatial Framework, etc. ▶ Leveraging geospatial information and data with Member States for use/benefit of the Organization, through UN-GGIM. ▶ Emerging technologies (Big Data, AI and machine learning, etc.) can enhance conventional analysis.	▶ Difficulties to obtain or absorb costs related to infrastructure, software and environment. ▶ Poor recognition or unsustainable resources makes retention of expertise difficult. ▶ Lack of sustained or limited funding and resources (e.g. project-based approach). ▶ Lack of coordination leads to redundancy in initiatives and programs among entities. ▶ Lack of awareness, availability, and accessibility to existing geospatial services. ▶ Limited "bandwidth" in certain member States to access resources (data, tools, applications) ▶ Activities of the Network should not negatively affect United Nations entities with geospatial capabilities in the fulfilling of their mandates.

Source: United Nations Geospatial Network 2020, 10.

Handbook Conclusion

All countries use space applications daily. Those with a space program, however, are more prepared to absorb and magnify its benefits for the good of their economy and society. This Handbook's cases for *why* one should build capabilities, *what* capabilities to build, and *how* to go about it must be localized to be truly useful and sustainable for a particular state. One could say this process of localization is another name for iterative program design. The process of understanding satellites' function and applications, the inward examination of domestic use and expertise, the exploration of possible building actions nested within national priorities, the relentless asking of "why?" and "how could we do this better?" are all crucial elements to building foundational space capabilities and beyond.

The foundational space capabilities themselves—consult and localize, coordinate, manage, regulate, and represent—are a foundation upon which a nation can accelerate its access to and use of space. It enables a country to move from being a passive user of space to a thoughtful consumer and to a contributor. Contributions don't have to be in the form of a launch facility; rather, they can be in the form of research, materials, components, software, operations, and more that add value to the entire space ecosystem value chain. The principles of foundational space capabilities apply to developed and emerging space actors and to low-,middle-, and high-income countries alike.

All countries benefit at least indirectly from a well-ordered and peaceful space environment. The global space ecosystem itself is growing larger and more complex every day. As technology allows people to push more data through the radio spectrum and to more tightly pack satellites into orbit, issues like space sustainability, space traffic management, and the fair use of space resources concern every nation. These challenges need a fully engaged global community to navigate them successfully.

Building a space ecosystem is essentially building a new kind of infrastructure, a system of systems that can accelerate development through better connectivity, knowledge, and access to new markets. Establishing a space office and program to grow foundational space capabilities is an excellent place to start, within reach of every nation.

Additional Resources

SECTION 1 WHY SPACE?

Satellite services underpin other infrastructure.

United Nations Office of Outer Space Affairs (UNOOSA). www.unoosa.org

- Technical and policy guidance can be found at the International Committee on Global Navigation Satellite Systems (ICG).

"Sustainable Development Goals Data Pathfinders," United States National Air and Space Agency (NASA). www.earthdata.nasa.gov/learn/pathfinders/sdgs

- Examples, free data, and instructions to apply remote sensing to SDGs.

European Space Agency (ESA) and SDGs. https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Space_for_Earth/ESA_and_the_Sustainable_Development_Goals

- Provides a list of ESA programs as they apply to SDGs.

"Sustainable Development Goals Knowledge Platform," by the UN. www.sdgs.un.org/goals

- A deep dive into all seventeen Sustainable Development Goals.

"Broadband Strategies Toolkit," by the ITU and World Bank. https://ddtoolkits.worldbankgroup.org/broadband-strategies

- Robust discussion of telecommunications infrastructure and tools for capability and capacity building.

Space is a building block for the economy; Space expands the reach and depth of e-governance

"The Age of Digital Interdependence" (UN-Secretary-General's High-Level Panel on Digital Cooperation 2019) and Digital Economy Report 2021, (UNCTAD 2021). www.un.org

- Discusses frameworks to enable data "flows," with development objectives in mind.

"Digital Ecosystem Framework." (USAID 2022). www.usaid.gov

- Provides an orientation on the stakeholders, systems and enabling environment that make up a digital ecosystem, to include space capabilities and applications.

Principles for Digital Development. www.digitalprinciples.org

- In-depth discussion of the digital ecosystem, on-line training and list of additional guides and resources.

ESA Commercialization Gateway. https://commercialisation.esa.int

- An example of government proactively connecting the various sectors (government, private, civil, and commercial) to encourage the growth of its space sector and ecosystem. Also includes free training materials.

Space supports technology independence and improves security

Armed Conflict Location & Event Data Project (ACLED). **https://acleddata.com**

- ACLED is a US nonprofit disaggregated data collection, analysis, and crisis mapping project. Users can access an interactive dashboard, download data, and read reports and infographics.

Monitoring Border Conflicts with Satellite Imagery: A Handbook for Practitioners (American Association for the Advancement of Science). **https://www.aaas.org/sites/default/files/s3fs-public/reports/Handbook.pdf**

- Although slightly dated, (published in 2015), this handbook describes methods for monitoring cross-border conflicts using satellite imagery and multiple case studies.

"Remote Sensing for International Peace and Security: Its Role and Implications" (MDPI). **https://www.mdpi.com**

- Discusses the use of remote sensing for refugee relief operations, in armed conflicts monitoring, tracking acts of genocide, providing evidence in courts of law, and assessing contravention in human rights.

GEOGLAM Crop Monitoring, G20 Agricultural Market Information System (AMIS). **www.cropmonitor.org**

- Example of worldwide GIS platform supporting crop monitoring.

"Satellite Imagery" (to collect evidence of deforestation) and "Satellite Imagery for Human Rights Monitoring." (The Engine Room Library) **https://library.theengineroom.org/**

- Introduction to remote sensing for civil society using open-source tools and free data.

A space program contributes to the development of norms and laws governing space.

"Space Sustainability, A Practical Guide" (Secure World Foundation 2014). **www.swfound.org**

- A guide to ensuring that all humanity can continue to use outer space for peaceful purposes and socioeconomic benefit now and in the long term.

"Guidelines for the Long-term Sustainability of Outer Space Activities." **https://spacesustainability.unoosa.org/content/The_Guidelines**

- Formal guidelines issued by the UN.

SECTION 2 WHAT IS SPACE CAPABILITY?

Geospatial activity (remote sensing and PNT) in closer detail

"Mapping Rural Development: How to Use GIS to Monitor and Evaluate Projects" (IFAD 2022). **www.ifad.org**

- Funded by the International Fund for Agricultural Development, a UN specialized agency. Includes discussion of GIS terms and measuring and evaluation (M&E) standards, expands on how to do rural mapping, and provides checklists.

A Holistic Case-Study Approach to Applying Satellite Remote Sensing to Disaster Management (Kaku 2021). www.cambridgescholars.com

- Detailed discussion of using satellites to monitor disasters.

Examples of US PNT policy and infrastructure. www.gps.gov "Blueprint, Geospatial for a Better World" (United Nations Geospatial Network 2020). www.ggim.un.org

- Example UN strategy to improve use and coordination of geospatial data.

Short orientation on satellites' use of electromagnetic spectrum

Digital Economy Report 2021, Cross-Border Data Flows and Development: For Whom the Data Flow (UNCTAD 2021). https://unctad.org/webflyer/digital-economy-report-2021

Innovative Business Models for Expanding Fiber-Optic Networks and Closing the Access Gaps (World Bank Group 2018, Open Knowledge Repository). http://hdl.handle.net/10986/31072

- Reference to help policy makers and regulators assess alternatives for infrastructure deployment and adopt decisions tailored to their country's circumstances and needs.

ITU Telecommunications Development Sector (ITU-D), Telecommunication Development Bureau (BDT). https://www.itu.int:443/en/ITU-D/Pages/About.aspx

- Focuses on capability development and hosts the Digital Knowledge Hub and Partnerships for Digital Development Department.

"Radio Frequency Spectrum, Interference and Satellites Fact Sheet" (Weeden 2013). www.swfound.org

"Maximising the Socio-economic Value of Spectrum, A Best Practice Guide for The Cost-Benefit Analysis of 5G Spectrum Assignments" (Agnoletto, Butler, and Castelis.2022). www.gsma.com

"Satellite Communications in the New Space Era: A Survey and Future Challenges" (Kodheli et al. 2021). https://ieeexplore.ieee.org

- A well-illustrated survey of satellite constellation types, on-board processing capabilities, non-terrestrial networks, and remote sensing/data processing. It also discusses 5G integration, space communications, Earth observation, aeronautical and maritime tracking, and communication. It further provides a literature review across five axes: system aspects, air interface, medium access, networking, and testbeds and prototyping.

SECTION 3 HOW DOES A STATE DEVELOP SPACE CAPABILITY?

Tools to build a policy and strategy

"Space for Development," a knowledge hub managed by Caribou Space. www.spacefordevelopment.org

- Provides references and guides for space sorted by sector: Agriculture and Food Security, Climate Change, Forestry, Disasters, Extractives and Industry, Oceans (Blue Economy), Population Displacement, Conflict and Security, and Health.

"Big Data Systemic Map," by International Initiative for Impact Evaluation. https://gapmaps.3ieimpact.org/evidence-maps/big-data-systematic-map

- Compiles examples of research completed using data from satellites and sorts them into searchable categories, such as economic development and livelihoods, urban development, governance and human rights, among others.

"A Guide for Smart Communities: Using GIS Technology for Local Government Management," by the International City/County Management Association (ICMA) and software company ESRI (ICMA 2018). www.icma.org

- Explores a mix of remote sensing, PNT, and other data, as well as communications infrastructure, to increase civic engagement and develop tools to support (more local) government decisions.

"Mapping Rural Development: How to Use GIS to Monitor and Evaluate Projects," by International Fund for Agricultural Development (IFAD) (IFAD 2022). www.ifad.org

- This practical manual provides guidance on how to use geographic information systems (GIS) in the monitoring and evaluation of rural development projects.

"Why Information Matters: A Foundation for Resilience," by Internews Center for Innovation and Learning (Internews Center for Innovation and Learning 2015). www.internews.org

- Defines the "information ecosystem" and discusses program design to improve access to and use of data, to include satellite applications' data.

Planning considerations

"Systems Thinking Toolkit," by FSG, an NGO. www.fsg.org

- Provides guidance for additional assessment tools such as Actor Mapping, Appreciative Inquiry, Trend Mapping, among others.

Space program component: Skills

Regional Centres for Space Science and Technology Education, Program on Space Applications (PSA) (See UNOOSA 2008). www.unoosa.org

- Affiliated with UNOOSA, these Centres provide UN-certified training and education programs and are located in Mexico, Brazil, Morocco, Nigeria, China, India and Jordan. UNOOSA posts standardized curricula (though a bit dated now) on topics such as satellite meteorology and global climate, satellite communications, space and atmospheric science, remote sensing and geographic information systems, space law and global navigation systems in English, French, Spanish and (limited) Arabic.

Developing a Road Map for Engaging Diasporas in Development: A Handbook for Policymakers and Practitioners in Home and Host Countries, by the Migration Policy Institute. www.migratrionpolicy.org

- Highlights policies and programs that can magnify the resources, both human and financial, that emigrants and their descendants contribute to development. It gives examples of policies and programs that have been effective, and pulls out both useful lessons and common challenges associated with the topics at hand.

"Innovative Resources for Skills Development," (EO4GEO Alliance). **www.eo4geo.eu**

- Provides a body of knowledge, various open source tools, and materials for teachers, students, and professionals as well as access to webinars and workshops. It also provides tools to help more precisely define "data science" and "geospatial" occupations, linked to the UN's International Standard Classification of Education: Fields of Education and Training (ISCED-F).

NASA Capacity Building Programs. **http://appliedsciences.nasa.gov/what-we-do/capacity-building**

- Provides individuals and institutions with workforce development, training activities, and collaborative projects to strengthen the understanding of Earth observations and expand their use around the world.

Global Monitoring for Environment and Security and Africa Support Programme (GMES and Africa 2022). **https://gmes4africa.blogspot.com**

- A joint program co-financed by the European Commission and the African Union Commission. The program adapts and uses Copernicus Programme data and services in the African context, to include online courses, regional Africa events, shared curricula, and best practices.

Hour of CI (Cyberinfrastructure). **www.hourofci.org**

- Provides a curriculum model for educators that integrates cyberinfrastructure skill building and cyber literacy into domain-specific curriculum.

Internet Telecommunications Union (ITU) Academy. **https://academy.itu.int**

- Offers a wide range of general and specialized online courses and material on all aspects of information and communications technologies. Includes references such as "Digital Skills Insights 2021," "Digital Skills Assessment Guidebook," and "Digital Skills Toolkit," which address skills at the basic through advanced levels, in multiple languages. The ITU may also provide support in the development and/or updating of national training materials.

GSMA Capacity Building Courses. **www.gsmatraining.com**

- Free online courses on a range of topics such as "Competition Policy in the Digital Age" and "Leveraging Mobile to Achieve SDG Targets."

United States Telecommunications Training Institute (USTTI). **www.ustti.org**

- A US government-industry joint venture that provides free in-person training for those who regulate and oversee the communications infrastructure in developing countries.

Space program component: Institutional support

World Meteorological Organization, "WMO Guidelines on Emerging Data Issues" (WMO 2019). **www.library.wmo.int**

- Provides guidance for members navigating the rapidly changing world of data and data technologies, and especially to provide some insight regarding trends and emerging challenges in data and their use. Defines and addresses topics such as big data, cloud computing, dealing with large data volumes and diverse sources of data, analytics, commercial services, infrastructure, and networks.

Developing indicators; evaluation

"Evaluation Plan Workbook," by Innovation Network (2005). **www.innonet.org**

- In-depth discussion of how to develop and monitor indicators.

"International Partnership Program (IPP) in Review (2016 to 2022)" (UK Space Agency 2022). **www.spacefordevelopment.org**

- An example of the results of monitoring program activity and impact of a space-related program. This is a report on the United Kingdom's IPP designed to promote the use of space technology supporting the Sustainable Development Goals.

Domestic tools

Making Blended Finance Work for the Sustainable Development Goals (OECD 2018). **www.oecd-ilibrary.org**

- OECD report that explains blended finance, an approach that mixes different forms of capital in support of development. See especially the chapter, "Pooling Finance through Blended Finance Facilities and Funds."

"National Space Policy and Administration" section of Handbook for New Space Actors (Johnson 2017). **www.swfound.org**

- Discusses space-related contracting in more detail.

"Policies, Incentives, and Growth in the NewSpace Industry" (Culver et al. 2007).

- In-depth analysis of policy tools used by the US government to grow the NewSpace private sector.

United Nations.

United Nations Office for Outer Space Affairs (UNOOSA) annual reports. **https://www.unoosa.org/oosa/en/aboutus/annual-reports.html**

- Collection of annual reports describing UN space-related activity and programs since 2015.

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