NASA
Office of Inspector General

Audit of NASA's Deep Space Network

July 12, 2023

IG-23-016

Office of Inspector General

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Results in Brief

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Why We Performed This Audit

NASA relies on its Deep Space Network (DSN) to provide communication links that guide and control spacecraft and bring back images and other data from missions. The DSN consists of three communications facilities located near Goldstone, California; Madrid, Spain; and Canberra, Australia. The complexes use antennas to communicate with spacecraft located from between 10,000 miles from Earth to the edge of the solar system and beyond. NASA's Space Communications and Navigation (SCaN) program office manages NASA's space communication activities, including the ground-based facilities and services provided by DSN and collaborates with the Agency's mission directorates to identify communication and navigation requirements for current and future missions. The DSN is managed by the Jet Propulsion Laboratory (JPL) and funded by NASA through a contract with the California Institute of Technology. NASA's Office of JPL Management and Oversight oversees the contracts that NASA has with the Australian and Spanish governments to manage day-to-day operations at the foreign DSN sites.

DSN antennas are currently operating at capacity and are oversubscribed—meaning more time is requested by missions than the network's current capacity can provide—with demand exceeding supply at times by as much as 40 percent. The Agency's upcoming crewed Artemis missions to the Moon will require increasingly higher amounts of bandwidth and further constrict the network's ability to meet growing mission demands. In 2010, NASA initiated the Deep Space Network Aperture Enhancement Project (DAEP) to provide upgrades and capacity expansion to ensure continued operation and meet new mission needs. The DAEP planned to build six new antennas to replace existing antennas, equip each new antenna with a 20 kW transmitter, and add six additional high power 80 kW transmitters. Prior OIG reports identified challenges in DSN's ability to maintain levels of performance and complete upgrade projects on time and on budget. Successfully completing this upgrade and expansion project is integral to NASA's future missions as interplanetary spacecraft become more complex and human exploration of the Moon will require the movement of vast amounts of data to track the health and safety of astronauts.

In this audit, we assessed NASA's progress towards upgrading the Agency's DSN and the network's ability to support current and future mission requirements. To complete this work, we analyzed NASA studies of projected growth in DSN demand, financial and project management data, and contractual and international agreement documentation. We also met with SCaN officials, mission managers, and other NASA representatives. In addition, we conducted a site visit to JPL and the Goldstone Complex to hold discussions with project managers and assess the Agency's construction progress.

What We Found

NASA's DSN is currently oversubscribed and will continue to be overburdened by the demands created by an increasing number of deep space missions, including crewed and robotic missions. Presently, the Agency's DSN is responsible for communication and navigation support for nearly 60 NASA and international space missions. According to Agency internal capacity and loading studies, demand for DSN support will increase dramatically in the coming decade with excess demand for hours on the DSN reaching about 50 percent by the 2030s.

Limitations on the DSN's capacity have already impacted Agency missions' ability to fully meet objectives and achieve full return on investment. In the past 5 years, NASA missions have received between 8,500 and 15,000 less DSN tracking hours than requested. Going forward, the DSN will face an even greater strain when the network's largest capacity users—the Mars Perseverance Rover, James Webb Space Telescope, and Artemis missions—will be in the same part of the sky vying for the same antennas. As NASA pivots toward extended human exploration of the Moon, the Agency may need to give DSN capacity to priority missions in critical phases, such as launches, while other missions make do with limited or no data during those periods.

Currently, NASA mission managers use the DSN scheduling process to negotiate with each other to use unmet DSN capacity and they described the process as largely sufficient to meet existing mission objectives. However, as capacity challenges grow and issues such as unforeseen outages occur, missions' have expressed frustration with the process for scheduling and rescheduling DSN support. The DSN scheduling process involves time consuming negotiations among missions to develop a baseline schedule, which then must be managed to accommodate changes agreed to by all parties. While other networks such as the Near Space Network use mission priority lists—where missions are ranked in priority order that helps drive scheduling—no such list exists for the DSN.

NASA's primary solution to address the DSN's capacity issues is to construct additional antennas and make upgrades to existing infrastructure. However, the Agency's efforts to complete the DAEP are behind schedule and over cost. As of the end of fiscal year 2022, NASA had only partially completed the first two phases of construction. Changes to the DAEP's scope increased the expected costs from $419 million to $706 million, a 68 percent increase. Moreover, the Agency does not expect to have each of the three sites equipped with fully functional antennas until at least 2029, nearly 5 years behind schedule.

NASA continues to face challenges in completing DAEP on cost and schedule while working under international agreements and contracts. According to NASA officials, the Agency has lacked insight into the selection of contractors and work performed at the sites in Australia and Spain, leading to issues with the quality and timing of work performed. In addition, NASA has yet to install 80 kW transmitters on antennas at the Australia and Spain sites and will need to obtain clearances from the Australian and Spanish governments prior to installation. Finally, the Agency is exploring other options to increase capacity to the DSN. This includes the development of Lunar Exploration Ground Sites (LEGS), which are intended to offload services from the DSN through a series of antennas that will be located at three sites around the Earth. However, LEGS will only be able to address a portion of the excess demand and the Agency is continuing to work with stakeholders to define requirements and award contracts for LEGS construction. Additional options NASA is pursuing include utilizing foreign partners and commercial communication assets and equipping existing antennas to send and receive data across additional frequencies.

What We Recommend

To ensure NASA's progress towards upgrading the Agency's DSN and the network's ability to support current and future mission requirements, we recommended NASA's Deputy Associate Administrator for SCaN: (1) explore more efficient options for DSN scheduling, such as maintaining a list of DSN users by priority that is updated in real-time and accessible to all users; (2) ensure completion of the DAEP's remaining antennas and transmitters and finalize requirements for the LEGS project; (3) finalize international agreements, obtain appropriate clearances for installing the remaining 80 kW transmitters, and establish mechanisms to allow for greater oversight of DAEP sites; and (4) explore options for utilizing commercial and international partners networks to offload excess demand from the DSN and to serve as backups in the event of network overages or outages.

We provided a draft of this report to NASA management who concurred with our recommendations and described planned actions to address them. We consider management's comments responsive; therefore, the recommendations are resolved and will be closed upon completion and verification of the proposed corrective actions.

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Acronyms

BWG	Beam Waveguide
CSIRO	Commonwealth Scientific and Industrial Research Organization
DAEP	Deep Space Network Aperture Enhancement Project
DSN	Deep Space Network
FY	fiscal year
HEF	High Efficiency
INTA	Instituto Nacional de Técnica Aeroespacial
JWST	James Webb Space Telescope
JPL	Jet Propulsion Laboratory
LEGS	Lunar Exploration Ground Sites
NSN	Near Space Network
OIG	Office of Inspector General
SCaN	Space Communications and Navigation

INTRODUCTION

From Explorer 1—the first successful U.S. satellite launched in 1958—to the James Webb Space Telescope (JWST), launched in December 2021, NASA has relied on its Deep Space Network (DSN) to provide two-way communication links that guide and control spacecraft and bring back images and other scientific data they collect.[1] The DSN consists of three deep-space communications facilities located approximately 120 degrees apart on the Earth's axis near Goldstone, California; Madrid, Spain; and Canberra, Australia. The complexes utilize arrays of 34-meter and 70-meter antennas to communicate with spacecraft located 10,000 miles from Earth (about one-tenth of the distance to the Moon) to the edge of the solar system and beyond.

DSN antennas are currently operating at capacity and are oversubscribed—meaning more time is requested by missions than the network's current capacity can provide—with demand exceeding supply by about 40 percent at times. The Agency's upcoming crewed Artemis missions to the Moon will require increasingly higher amounts of bandwidth and further constrict the network's ability to meet growing mission demands. Moreover, DSN's infrastructure, some of which was built in the 1960s, is outdated and characterized by extensive deferred maintenance that is becoming increasingly difficult and costly to maintain.

In the 2005 NASA Authorization Act, Congress directed the Agency to develop plans for updating its space communication infrastructure for deep space exploration to meet mission needs over the next 20 years. In 2010, NASA initiated the Deep Space Network Aperture Enhancement Project (DAEP) to provide required upgrades and capacity expansion to ensure continued operation and meet new mission needs. Our prior work has identified challenges in DSN's ability to maintain levels of performance and complete upgrade projects on time and on budget.[2] We also previously found that NASA did not adequately secure the DSN's information technology and physical infrastructure or ensure that contractors provided detailed support for expenses. Successfully completing this modernization and expansion project is integral to NASA's future missions as interplanetary spacecraft become more complex and human exploration of the Moon will require the movement of vast amounts of data to track the health and safety of astronauts.

In this audit, we assessed NASA's progress towards upgrading the Agency's DSN and the ability of the network to support current and future mission requirements. See Appendix A for details on the audit's scope and methodology.

Background

NASA's DSN is an international array of giant radio antennas that support communication and data exchange for interplanetary spacecraft missions. The DSN also provides radar and radio astronomy

[1] The JWST is a large orbiting infrared observatory operating a million miles from Earth that is studying the origins of the universe.

[2] NASA OIG, *NASA's Management of the Deep Space Network,* (IG-15-013, March 26, 2015).

observations that are intended to improve understanding of the solar system and universe.[3] The strategic placement of DSN sites equally distant across the Earth permits constant communication with spacecraft as the planet rotates by allowing forward sites to pick up signals and carry on communicating with spacecraft that have sunk below the horizon at previous sites. The DSN is managed by the Jet Propulsion Laboratory (JPL), a federally funded research and development center in Pasadena, California, under contract with NASA. Figure 1 displays the DSN's three sites located near Goldstone, California; Madrid, Spain; and Canberra, Australia.

Figure 1: Locations of Primary DSN Communication Complexes

Source: NASA OIG presentation of NASA information.

NASA's three DSN sites utilize various size antennas that are designed to enable continuous radio communication between multiple spacecraft and Earth. Each site consists of at least four antenna stations and ultra-sensitive receiving systems capable of detecting incredibly faint radio signals from distant spacecraft. Specifically, each site has one 70-meter (230-foot) diameter antenna, the network's largest and most sensitive, capable of tracking a spacecraft traveling tens of billions of miles from Earth. The sites also have multiple 34-meter (112-foot) diameter antennas, including high-efficiency (HEF) and beam-waveguide (BWG) antennas.[4] Figure 2 illustrates the BWG versions, which have five precision

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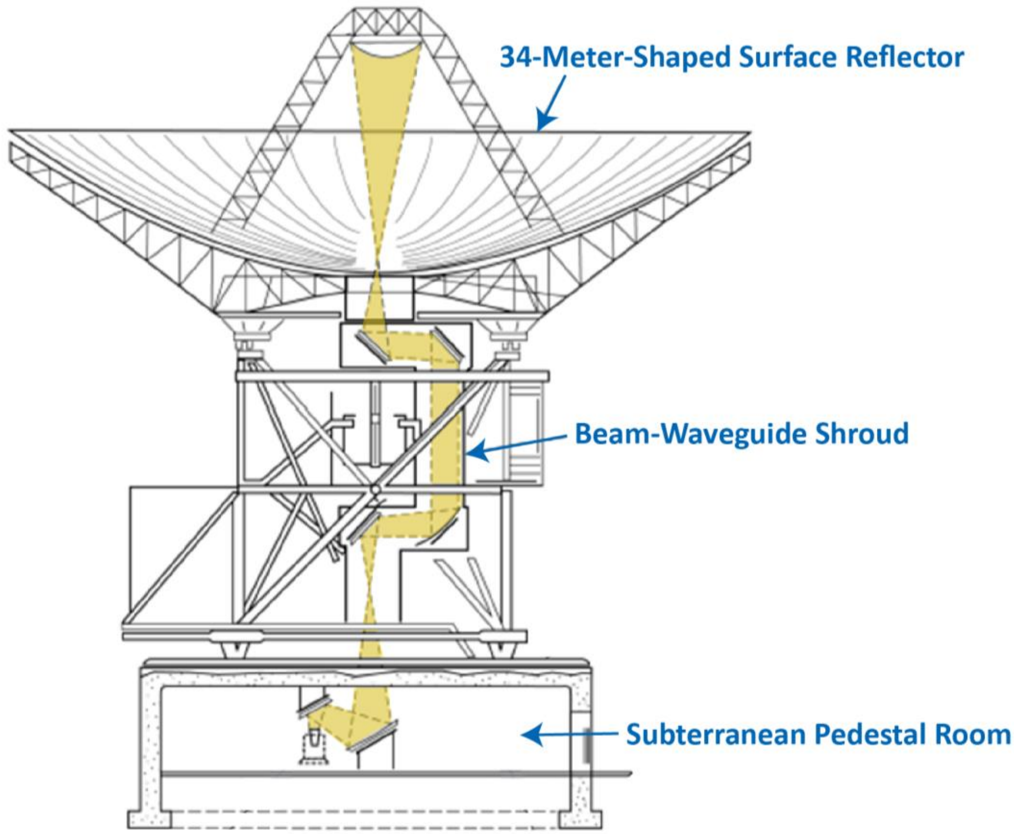
3 Radar astronomy studies objects in outer space by reflecting radio waves off objects and analyzing the reflections.

4 The HEF antenna was introduced in the mid-1980s as a dual-shaped reflector antenna to receive frequencies simultaneously. The high-efficiency antenna allows for the maximum possible illumination efficiency available for the given aperture size. NASA decommissioned HEF antennas DSS-45 at Canberra in 2016 and DSS-15 at Goldstone in 2018 while DSS-65 at Madrid remains operational.

radio frequency mirrors that reflect radio signals along a tube from the antenna to a below-ground room, allowing sensitive electronics to be housed in climate-controlled equipment rooms instead of outdoors at the center of the antenna dish. This configuration also simplifies maintenance and modification of the equipment as new technologies are developed. Lastly, each site contains one 26-meter (85-foot) diameter antenna that were used to track spacecraft orbiting between 100 and 620 miles above the Earth. The 26-meter antennas were originally built to support the Apollo missions, which sent human explorers to the Moon between 1967 and 1972. While still on-site, NASA decommissioned these 26-meter antennas in August 2009.

Figure 2: 34-Meter Beam-Waveguide Antenna



Source: NASA OIG presentation of NASA image.

Each complex's antennas are operated from signal processing centers located at each site. The processing centers house electronic systems that point and control the antennas, receive and process data, transmit commands, and generate spacecraft navigation data. Once the data is processed, it is transmitted to JPL for further processing and distribution to teams over a ground communications network.

NASA utilizes the DSN for commanding, tracking, and monitoring the health and safety of spacecraft at many distant planetary locales including Jupiter and Saturn. The DSN also enables powerful science investigations that probe the nature of asteroids and the interiors of planets and moons. Some of the many functions the DSN performs for NASA missions include:

- Radio Science. DSN antennas are used to perform science experiments utilizing the radio signals sent between a spacecraft and Earth. Changes in radio signals between transmission and receipt can provide information about far off places in the solar system, including probing the rings of Saturn, revealing the interior structure of planets and moons, and testing the theory of relativity.
- Science. The DSN is used as an instrument for scientific research, including radio astronomy and radar mapping of asteroids.
- Spacecraft Command. The DSN is used to control the activities of spacecraft. Commands are sent as coded computer files that the craft or crew execute.
- Telemetry. DSN acquires, processes, decodes, and distributes telemetry data. This data is composed of science and engineering information transmitted to Earth via radio signals from spacecraft as they explore the far reaches of the solar system.
- Tracking. The DSN provides two-way communication between Earth-based equipment and a spacecraft, making measurements that allow flight controllers to determine the position and velocity of spacecraft with great precision.

NASA Management of the DSN

NASA's Space Communications and Navigation (SCaN) program office, organizationally located within the Space Operations Mission Directorate, manages and directs all of NASA's space communication and navigation activities, including the ground-based facilities and services provided by DSN.[5] SCaN acts as the central agent for the acquisition and management of space communication and navigation services and fulfills these requirements through a portfolio of U.S government-owned assets, partnerships, and services. SCaN collaborates with the Agency's mission directorates to identify future communication and navigation requirements, resolve technical capability gaps, and plan for and support space communication and navigation requirements for all current and future missions.[6] The DSN is managed by JPL and funded by NASA through a contract with the California Institute of Technology. NASA's Office of JPL Management and Oversight oversees key activities in support of the DSN, including acquisition strategy development and implementation, execution, management of JPL-sponsored agreements, requirements definition and planning, contract negotiation and award, post-award contract administration, and contract oversight.

State of NASA's DSN

By the early 2000s, much of the DSN's infrastructure had become dated with ground stations, some of which were originally built in the 1960s, marked with extensive deferred maintenance and becoming increasingly difficult and costly to maintain. As a result, NASA missions were suffering from insufficient communications capability and occasional failures as the networks aged and limitations on bandwidth restricted the return of data. In 2006, the Government Accountability Office reported that the sustainability of the DSN's infrastructure was unknown because the poor condition of much of the

[5] SCaN also manages the Near Space Network, a composition of the former Near Earth Network and Space Network supporting commercial and government-owned space communications in near space, which extends to more than 1 million miles from Earth.

[6] NASA has six mission directorates: Aeronautics Research, Exploration Systems Development, Science, Space Operations, Space Technology, and Mission Support.

network's equipment was leading to operational disruptions.[7] Specifically, the report outlined disruptions that occurred in 2005 due to infrastructure deterioration such as failing network servers and corrosion of dishes, which caused outages and affected the Deep Impact, Mars Reconnaissance Orbiter, Mars Odyssey, Mars Global Surveyor, and Stardust missions.[8]

At the same time, NASA's missions were transitioning from the era of deep space "fly by" exploration to sustained missions with probes and spacecraft collecting data at targets for many years and utilizing more advanced scientific instruments that require increased bandwidth. Since Explorer 1 in 1958, space missions have gone farther and have demanded more data return to enable far more ambitious science goals. This is particularly so for probes in deep space. In the 1960s and 1970s, the missions were planet flybys, which typically had short encounter periods as they followed continuous solar orbits while never entering planetary orbits for extended observation. These missions ranged from Mariner 4 that captured the first images of the Martian surface in 1965 to Voyager 1 that launched in 1977 to study Jupiter and Saturn. Missions progressed in the 1980s and 1990s to planet orbiters, which had long and sustained scientific observations—often years of continuous operation. During this period, missions such as Galileo and Cassini orbited and studied the planets Jupiter and Saturn. In the 2000s, NASA missions landed rovers that moved around on the surface of a planet to engage in scientific investigations. In 2020, the Perseverance Rover landed on the surface of Mars and is slated to provide years of continuous scientific investigations returning reams of data.[9]

The DSN currently supports nearly 60 NASA and international partner missions ranging from ground-based radio astronomy to deep space missions such as the JWST. The oldest missions date back nearly 50 years with the DSN continuing to support Voyager 1 and Voyager 2 that launched in 1977 and are now both more than 12 billion miles from Earth. DSN also is supporting the Artemis missions, beginning with the uncrewed Artemis I that launched in November 2022 and utilized more than 900 hours of DSN support during its 25-day test mission.[10] In fiscal year (FY) 2022, the DSN provided roughly 77,000 antenna utilization hours to NASA and international partner missions. Figure 3 displays the DSN's top 10 users by their total hours of use in FY 2022.

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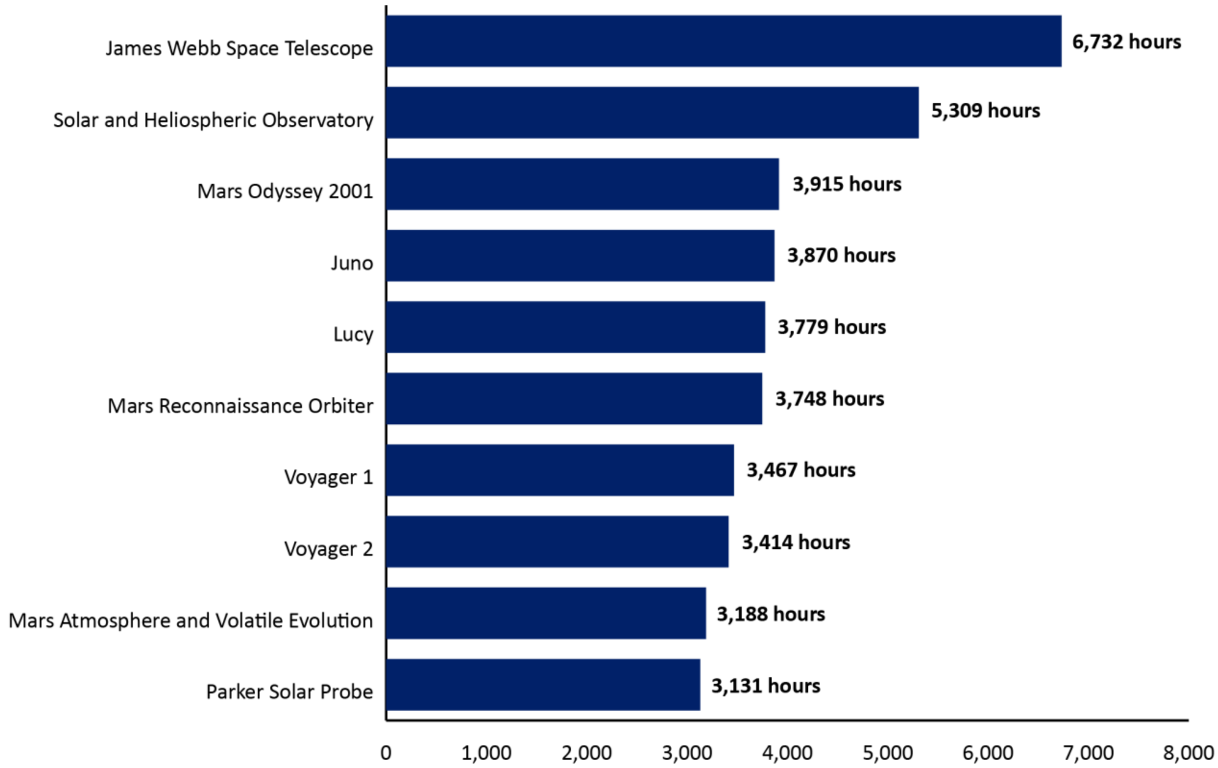
[7] Government Accountability Office, *NASA's Deep Space Network: Current Management Structure is not Conducive to Effectively Matching Resources with Future Requirements,* (GAO-06-445, April 2006).

[8] The Deep Impact Mission (2005 to 2013) investigated the surface and interior composition of comets and captured images and observations of planets and stars. The Mars Reconnaissance Orbiter (2005 to present) carried six scientific instruments to examine the surface, atmosphere, and subsurface of Mars. Mars Odyssey (2001 to present) is a spacecraft designed to detect water and ice on the surface of Mars. The Mars Global Surveyor (1996 to 2006) was the first successful mission to Mars to study the surface, atmosphere, and interior. NASA's Stardust (1999 to 2006) returned a sample and extraterrestrial material to Earth from outside the orbit of the Moon for detailed study.

[9] The Mars Perseverance Rover, which launched in July 2020 and landed in February 2021, seeks to better understand the geology of Mars, identify evidence of ancient life, collect Martian surface samples, and test new technologies.

[10] Artemis I, launched in November 2022, was an uncrewed test flight for the Space Launch System rocket and the Orion crew capsule. Future flights include Artemis II, which will fly four astronauts to the Moon's orbit and back while Artemis III will dock with the pre-positioned Human Landing System Starship that two astronauts will use to travel to the lunar surface.

Figure 3: DSN Antenna Utilization Hours for FY 2022 by Mission



Source: NASA OIG presentation of NASA data.

Note: Solar and Heliospheric Observatory, launched in 1995, is studying the Sun. Juno, launched in 2011, is a space probe orbiting Jupiter. Lucy, launched in 2021, is the first space mission to study the Jupiter Trojan asteroids. Mars Atmosphere and Volatile Evolution, launched in 2013, is studying the Mars upper atmosphere and interactions with the Sun and solar wind. Parker Solar Probe, launched in 2018, is making observations of the Sun's outer corona.

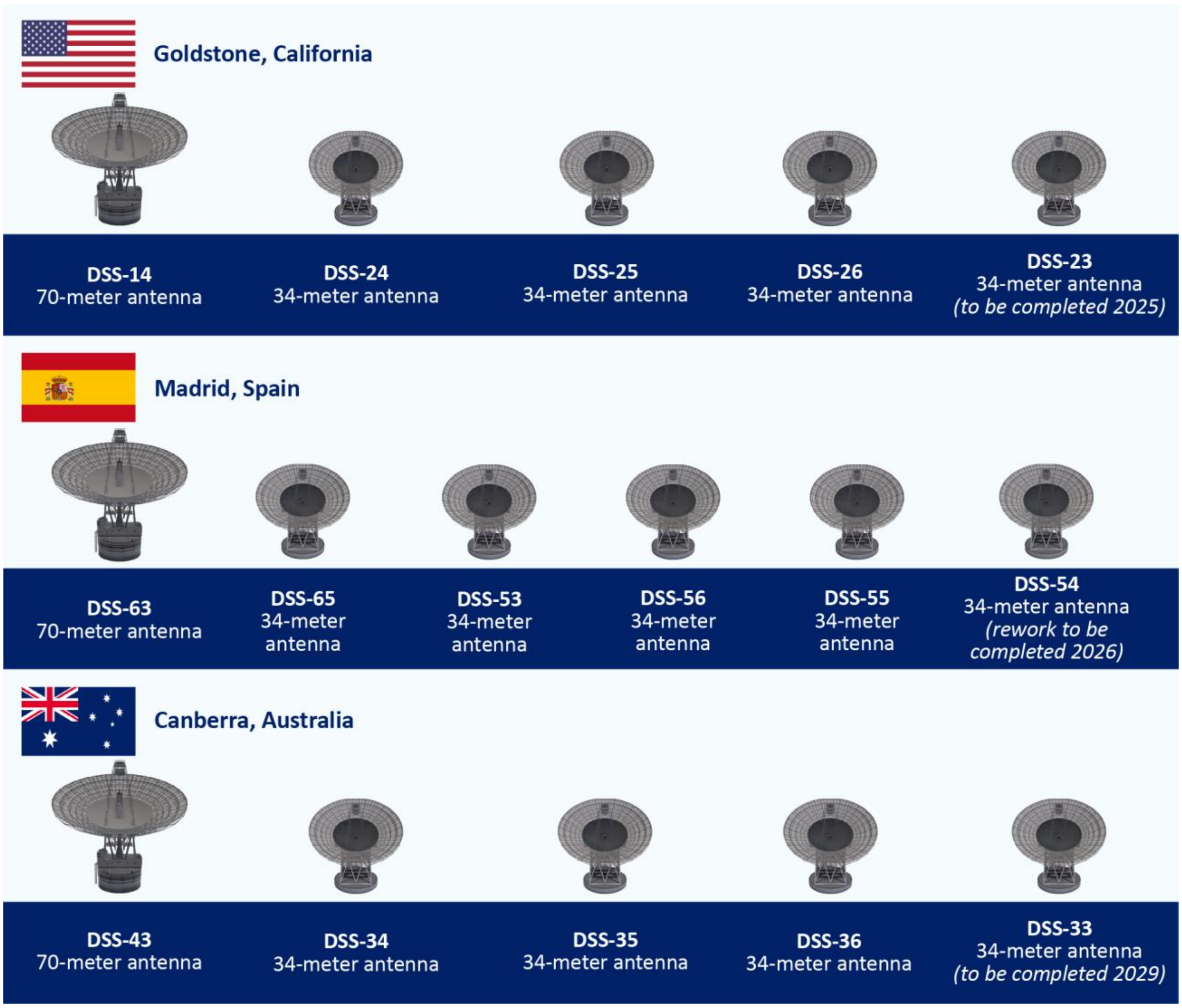
Deep Space Network Aperture Enhancement Project

NASA initiated DAEP in 2010 to provide required upgrades and capacity expansion to ensure continued operation and to meet new mission needs such as the Agency's Artemis missions. NASA's DAEP planned to build six new 34-meter BWG antennas to replace existing 70-meter antennas. Each new antenna was to be accompanied by a new 20 kW transmitter and six additional high power 80 kW transmitters. With the new antennas, DSN would be able to array the 34-meter BWG antennas to supply downlink capabilities (sending data and images from spacecraft back to Earth) like the 70-meter antennas that the new antennas will replace.[11] Similarly, installation of an 80 kW transmitter in the 34-meter antennas would provide uplink capability (sending instructions to a spacecraft) comparable to the 70-meter antennas. All systems are expected to be upgraded to have X band uplink capabilities and both X and Ka

[11] Antenna arraying combines the signals received by multiple antennas at different locations to function as a single large antenna. Arraying is beneficial in deep space communications where the signal transmitted by a spacecraft becomes very weak as it travels across vast interplanetary distances.

band downlink capabilities.[12] NASA planned to construct the six new antennas and transmitters in phases with the first two antennas built at the Canberra site; the third and fourth at the Madrid site; and the fifth and sixth at the Goldstone and Canberra sites. Figure 4 depicts the DSN's current and planned antennas by site.

Figure 4: DSN Current and Planned Antennas by Site



Source: NASA OIG presentation of NASA data.

NASA funded DAEP from a "funding wedge" it created within the DSN budget through project reserves, reprogramming efforts, and shifting priorities that made funds available for the project. The Agency also

[12] DSN antennas communicate with spacecraft over radio frequency bands including S band (2–4 GHz), X band (8–12 GHz), and Ka band (27–40 GHz). The earliest and most widely used DSN frequency is S band. NASA later added X band and Ka band, which can send more data per second. In the future, the DSN is expected to support optical communication in the infrared frequency band. Optical communication elements will be installed on 34-meter antennas and are expected to allow faster data downloads using less power.

utilized Construction of Facilities funds for portions of the project.[13] Beginning in FY 2010 and extending through FY 2022, NASA committed $363.2 million to completing the project. That amount includes $184 million from the funding wedge created from the DSN budget and $179.2 million of Construction of Facilities funds.

As outlined in JPL's DSN Implementation Plan, the Agency expected to build six new 34-meter BWG antennas in three phases (three at Canberra, two at Madrid, and one at Goldstone), six new 80 kW transmitters (two at each complex), and six new 20 kW transmitters (one on each new 34-meter antenna) for $362.3 million (see Table 1).[14] The 80 kW transmitters were to be added to DSS-26 at Goldstone, DSS-35 at Canberra, and DSS-55 at Madrid during Phase 1; DSS-36 at Canberra and DSS-56 at Madrid during Phase 2; and DSS-23 at Goldstone during Phase 3. NASA expected Phase 1 to be completed by September 2018, Phase 2 by September 2022, and Phase 3 by September 2024. NASA also planned to replace each site's 34-meter HEF antenna (DSS-15 at Goldstone, DSS-45 at Canberra, and DSS-65 at Madrid) for an additional $56.4 million by September 2025. The overall project was expected to cost nearly $419 million.

Table 1: 2010 DSN Implementation Plan (Dollars in Millions)

Item	Location	Phase	Expected Completion	Expected Cost
DSS-33 Antenna and 20 kW Transmitter	Canberra	Phase 1	September 2018	$47.3
DSS-35 Antenna and 20 kW Transmitter	Canberra	Phase 1	September 2014	$44.8
DSS-36 Antenna and 20 kW Transmitter	Canberra	Phase 1	September 2016	$46.1
80 kW Transmitters	Canberra, Goldstone, Madrid	Phase 1	September 2017	$35.0
DSS-53 Antenna and 20 kW Transmitter	Madrid	Phase 2	September 2022	$52.4
DSS-56 Antenna and 20 kW Transmitter	Madrid	Phase 2	September 2020	$49.9
80 kW Transmitters	Canberra, Madrid	Phase 2	September 2020	$20.0
DSS-23	Goldstone	Phase 3	September 2024	$55.2
80 kW Transmitter	Goldstone	Phase 3	September 2024	$11.6
34-meter HEF Antennas	Canberra, Goldstone, Madrid	Phase 3	September 2025	$56.4
			Total	**$418.7**

Source: NASA OIG presentation of NASA data.

To complete DAEP, NASA added work to its existing prime contract with JPL–responsible for the operation and maintenance of the Goldstone Deep Space Communication Complex–and awarded a series of firm-fixed price subcontracts to design, build, and deliver the antennas and transmitters (with General Dynamics SATCOM Technologies, Continental Electronics Corp, and Aerodyne Industries). The Agency also has agreements with the governments of Australia and Spain to oversee the sites located in their respective countries. The Commonwealth Scientific and Industrial Research Organization (CSIRO),

[13] NASA's Construction of Facilities program makes capital repairs and improvements to the Agency's infrastructure and provides NASA projects and programs with the test, research, and operational facilities required to accomplish their missions. Funding for the program comes from the Agency's Construction and Environmental Compliance and Restoration appropriation.

[14] JPL, *DSN 70m Antenna Replacement Task Implementation Plan (Through 2025),* (September 2010).

an Australian Commonwealth Government Statutory Authority, established the CSIRO Astronomy and Space Science Division to manage the day-to-day operations, engineering, and maintenance activities of the Canberra Deep Space Communications Complex. Ingenieria de Sistemas para la Defensa de España S.A., a subsidiary of the Instituto Nacional de Técnica Aeroespacial (INTA) and a part of the Spanish Department of Defense, operates and maintains the Madrid Deep Space Communications Complex.

NASA's Deep Space Network Is Oversubscribed and Delayed Upgrades Could Impact Communications for Key Missions

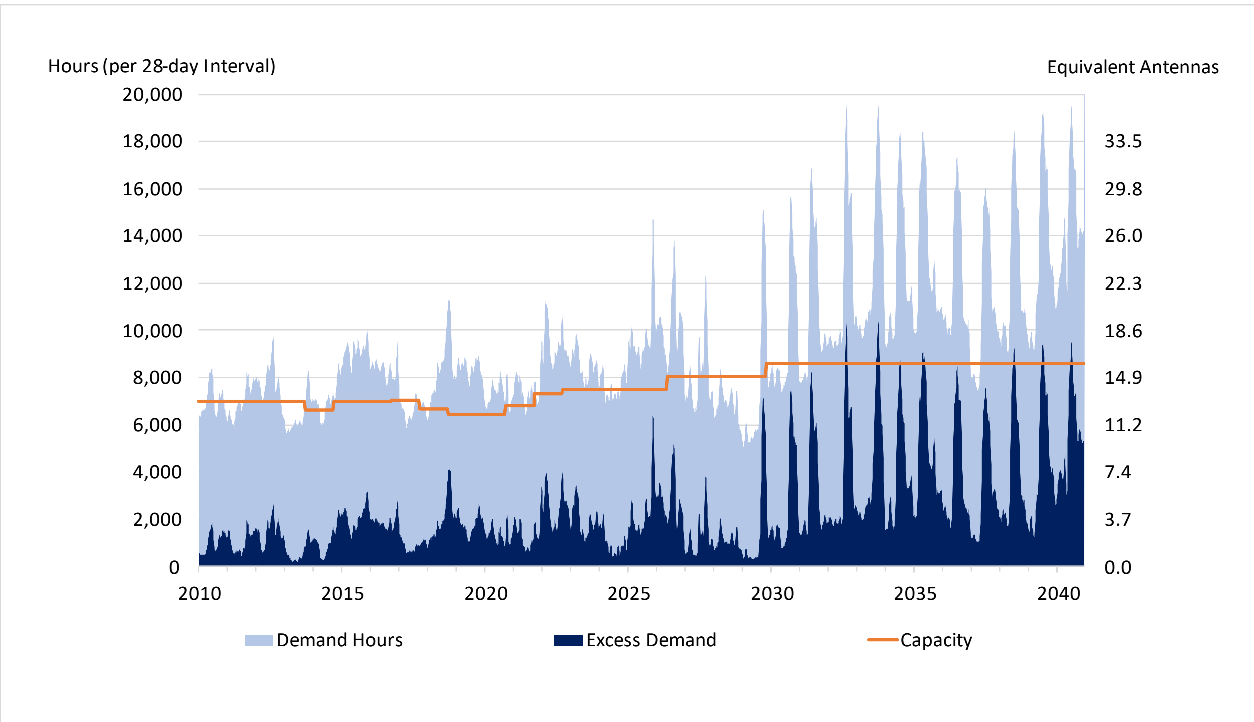
NASA's DSN is currently oversubscribed and for the foreseeable future will continue to be overburdened by the demands created by an increasing number of deep space missions, including crewed and robotic missions. Capacity remains a challenge because the Agency has made limited progress towards upgrading the DSN. As of September 30, 2022 (end of FY 2022), NASA completed the installation of four of the six 34-Meter Beam Waveguide antennas, but the Agency does not expect the fifth and sixth antennas to be complete until 2025 and 2029, nearly 4 years behind its initial schedule. In addition, the Agency does not expect to have each of the three sites (Canberra, Goldstone, and Madrid) equipped with 80 kW transmitters, which are required to make the antennas fully functional, until at least 2029, nearly 5 years behind schedule. Changes to the DAEP's scope, including adding elements such as a rebuild of the pedestal of one dish and deferring construction of another dish to a later date increased the project's expected life cycle costs from $419 million in 2010 to $706 million by 2033, a $287 million or 68 percent increase. In addition, the Agency will continue to face challenges with completing the project as it works to address issues with international agreements and project oversight. Finally, as crewed Artemis missions come online and receive priority over uncrewed missions such as the JWST and Mars 2020 Perseverance Rover, missions will be challenged to schedule DSN time and may not receive the full amount of capacity they require for timely navigation and data transfer.

NASA's DSN Is Oversubscribed, Leading to Mission Impacts and Scheduling Challenges

NASA's DSN is operating at capacity with demand exceeding supply by 40 percent at times, an amount that is expected to grow as the Artemis missions advance. The Agency's DSN is currently responsible for communication and navigation support for nearly 60 NASA and international space missions. Most of these missions rely on the DSN to provide the links necessary for commanding spacecraft and for receiving images and scientific data. For more than 30 years, demand on the network has been greater than its capacity with oversubscription sometimes reaching 40 percent. The Agency's internal DSN capacity and loading studies show that demand for DSN support will increase dramatically in the coming decade, projected at a factor of ten by the early 2030s. According to the studies, the tremendous growth in demand for the network is driven by the increase in the number of deep space missions, increases in uplink and downlink data rates and volumes, and the complexity of Artemis and future human exploration missions that will involve multiple, independently functioning elements with human-rated tracking requirements. Additionally, the amount of data collected and transmitted has significantly increased over the past 30 years. For example, missions like JWST collect and transmit data at roughly 50 times the rate of its predecessor, the Hubble Space Telescope.[15]

Figure 5 shows the projected growth in DSN demand through 2040. The total DSN time available for missions to download data is shown on the left, with the equivalent number of antennas needed to provide support (for the hours) on the right. The light blue shading shows the amount of time missions have or will request, and the dark blue shading shows how much of the requested time is outside of the DSN's capacity. The orange line represents actual DSN capacity. The excess demand for hours on the DSN is projected at about 50 percent by the 2030s. According to the DSN capacity and loading studies, the estimate of needed DSN capacity will double when factoring in the Artemis missions. Over the next 10 years, the average data rate needed to be processed on the downlink (spacecraft sending images and data back to Earth) will be six times what it was in 2021 while the volume of data will increase by a factor of 37. The studies show that as the average data rates continue to increase, future unmet demand will result in very large data volume shortfalls on the DSN.

Figure 5: Projected Growth in DSN Demand



Source: NASA.

Note: DSN capacity fluctuates based on the number of operational antennas. Each operational antenna has approximately 540 hours of capacity for a 28-day interval (28 days multiplied by 24 hours multiplied by a factor of 0.8 to account for maintenance time that is required to keep the antennas functioning).

[15] The Hubble Space Telescope is a large, space-based observatory launched in 1990 that continues to make observations of stars, galaxies, and other astronomical objects.

Capacity Limitations Leading to Mission Impacts Are Expected to Increase with the Onset of Crewed Artemis Missions

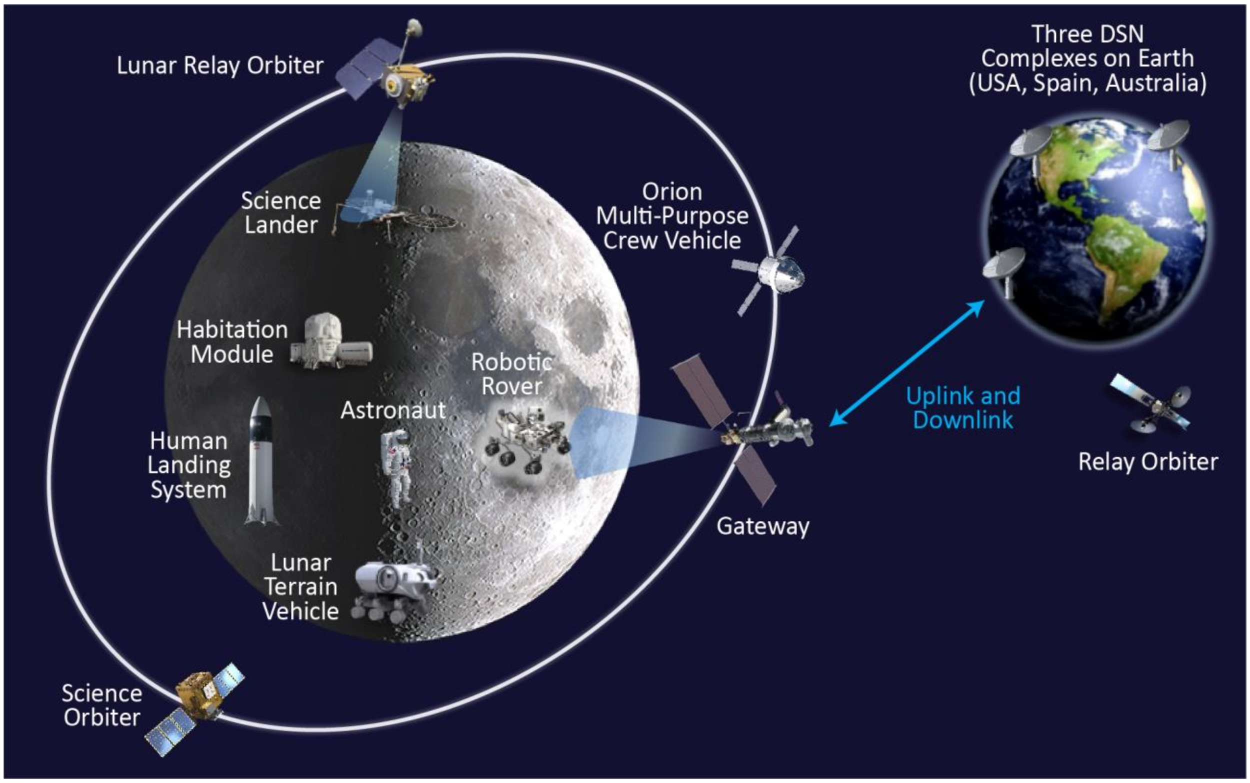
Limitations on the DSN's capacity have already impacted Agency missions' ability to fully meet objectives and achieve full return on investment. In the past 5 years, NASA missions such as Mars Odyssey, Voyager 2, and New Horizons received between 8,500 and 15,000 less DSN tracking hours than their missions requested.[16] We met with the managers of ten missions that described events with the DSN being oversubscribed and the corresponding effects the events had on their missions, including data loss and the inability to send commands including those needed to initiate movement. For example, mission managers for the Mars 2020 Perseverance Rover stated that their mission was impacted by DSN oversubscription at least seven times in a 21-month period. During these events, the mission was not able to retrieve data from the Rover necessary to determine the vehicle's next movements. As a result, the mission had to wait until the next opening to receive and review location data, determine the Rover's next location and pathway, and transmit commands telling the vehicle where to go and how to get there. Mars 2020 mission managers said missed opportunities to send commands such as these delayed the Rover's progress. In another example, mission managers for JWST that launched in December 2021 described the DSN's ongoing challenge to balance limited supply and growing mission demand as a key contributor to space communication and navigation challenges faced by the mission in its early operations, such as frequent failures to establish a connection between the spacecraft and the DSN.

The DSN faces an even greater "contention period" in the next 4 to 5 years, when the pressure on DSN capacity will be further compounded because the network's largest capacity users—Mars missions such as the Mars 2020 Perseverance Rover, JWST, and Artemis—will be in the same part of the sky vying for the same antennas every 2 years.

While space communication and navigation requirements for Artemis missions are still in development, high-bandwidth activities such as 4k video communications, telemedicine, remote operations of vehicles such as rovers, and tracking the health and safety of the astronauts clearly will be necessary. As shown in Figure 6, besides landing astronauts on the Moon using landers such as the Human Landing System Starship, Artemis missions will also include biannual robotic and scientific missions to the lunar surface that will utilize their own landing systems and orbiting satellites that will require DSN support. NASA will also establish an orbiting lunar outpost called Gateway and develop ground infrastructure on the Moon such as habitation modules, lunar terrain vehicles, rovers, and infrastructure to support astronaut extravehicular activities. All of this infrastructure will require communication support and significant amounts of data processing through the DSN's relay orbiters and ground stations on Earth.

[16] NASA launched the New Horizons mission in January 2006 to study the dwarf planet Pluto, its moons, and the Kuiper Belt, a region of the solar system that extends from the vicinity of Neptune to the Sun.

Figure 6: Artemis Systems that Will Require DSN Support



Source: NASA OIG presentation of NASA information.

As NASA moves into this busy period of human exploration of the Moon, the Agency may need to allocate DSN capacity to priority missions in their critical phases, such as launches, while other missions make do with limited or no data during those periods. For example, JWST (already in orbit) had limited DSN capacity during the Artemis 1 launch in November 2022, forcing the mission to collect lower quality data during that period. Although JWST was able to collect limited data during the Artemis 1 launch window, JWST officials said that the DSN capacity during that period would not have been sufficient to meet mission requirements that required higher-quality data. While in this instance JWST mission managers were able to schedule events that required the transmission of less data, future Artemis missions could prevent missions such as JWST (which cost over $10 billion to develop and deploy) from receiving data as frequently or in as much detail as needed to ensure the mission is meeting its objectives and delivering the expected return on investment.

Capacity Limitations, Lack of Readily Available Backups, and Laborious Process Present Challenges to Scheduling Time on DSN

NASA mission managers currently use the DSN scheduling process to negotiate with each other to “borrow” unmet DSN capacity and described the process as largely sufficient to meet mission objectives to date. However, as capacity challenges grow and issues such as unforeseen outages occur, missions are beginning to express frustration with the time- and labor-intensive process for scheduling and rescheduling DSN support. The DSN scheduling process begins months in advance and is conducted on a weekly basis. Typically, the DSN will have about 500 scheduled activities a week (the total across all antennas at the three DSN Complexes). Users submit requests for projected network usage, which must be integrated and deconflicted among the missions leading to what managers described as the most labor-intensive and time-consuming aspects of DSN scheduling. Because the DSN scheduling process involves peer-to-peer collaborative negotiation, the process consumes significant time and resources to reach a baseline version of the schedule, which then must be managed to accommodate changes agreed to by all missions. Despite best efforts, unexpected changes can result in process delays that are exacerbated by high levels of DSN oversubscription and unforeseen events.

For example, in December 2022 the DSN went offline due to a hardware failure at Goldstone. According to SCaN officials, a failure in systems that control tracking passes at Goldstone and enable communication with the Canberra and Madrid Complexes resulted in the tracking for all missions and operations from Goldstone to cease for a 33-hour period. SCaN officials stated that during the event, missions that utilized the DSN lost a total of 9,090 minutes (151.5 hours) of command, tracking, and telemetry data; and there was not enough time to arrange coverage from backup sources such as international partner networks. Compounding the issue, as the DSN resumed operations, users had to negotiate with each other to reschedule DSN time to communicate, navigate, transmit commands, or retrieve data from their spacecraft.

While other NASA networks such as the Near Space Network (NSN) make use of mission priority lists—where missions are ranked in priority order that drives scheduling—no such list exists for the DSN. The NSN has more than three times the number of antennas but is utilized half as much as the DSN. For example, in 2020 the DSN had 12 antennas compared to the NSN's 38 and provided about 83,000 contact hours to the NSN's 43,000. Although having to schedule more contact hours across fewer assets makes it more difficult to maintain a priority list, without such a list the scheduling process becomes much more complex and burdensome and can lead to decisions that do not consistently make the most sense for the Agency. For example, the Artemis 1 mission launched in November 2022 included 10 CubeSat secondary payloads with more than half experiencing significant problems during launch including the Lunar Polar Hydrogen Mapper that was unable to achieve lunar orbit due to a stuck valve in the CubeSat's electric thruster.[17] However, due to the complicated DSN scheduling process, the CubeSats that experienced issues during launch received priority for DSN usage. SCaN officials stated that they are working on improvements to the scheduling process to ensure that similar incidents do not occur in the future. In our view, without more efficient and pragmatic options for DSN scheduling such as user priority lists, the Agency risks encountering similar problems in the future.

Upgrades to NASA's Deep Space Network Are Behind Schedule and More Costly than Planned

NASA's primary solution to address the DSN's capacity issues is to construct additional antennas and make upgrades to existing infrastructure. However, the Agency's efforts to complete the DAEP are nearly 5 years behind schedule and costs have increased 68 percent. The project was expected to cost a total of $419 million when it began in 2010. However, as of the end of FY 2022, NASA had only partially

[17] A CubeSat is a type of miniature satellite used for research typically the size of a Rubik's cube (10 cm x 10 cm x 10 cm) and weighing less than 3 pounds. NASA selected 10 CubeSats for deployment from the secondary payload system during the Artemis 1 mission. The Lunar Polar Hydrogen Mapper—funded by NASA and developed by Arizona State University—was a CubeSat mission designed to orbit the Moon and determine the amount of water ice at the Moon's South Pole.

completed the first two phases of construction and expects the remainder of the work to cost significantly more and take significantly longer than initially planned.

Phase 1 Partially Complete with Antenna and Transmitter Deferred

NASA has only partially completed Phase 1 of its three-phase DAEP with construction of one antenna (DSS-33) and installation of one 80 kW transmitter deferred to the third phase of the project. In 2015, NASA deferred construction of DSS-33 until the third phase of the DAEP because cost estimates at the time were significantly higher than budgeted. In addition, installation of one of the 80 kW transmitters at Madrid was deferred from Phase 1 to Phase 3 due to delays in developing the prototype and rising development and construction costs. The Agency also cancelled one 80 kW transmitter originally planned for Canberra after deciding not to retire the three 70-meter antennas. NASA had expected to complete Phase 1 by September 2018 at a total cost of $173.2 million. However, as of FY 2022 the Agency had only completed construction of DSS-35 and DSS-36, installation of their 20 kW transmitters, and installation of one 80 kW transmitter at DSS-26 at a total cost of $120.8 million (see Table 2).

Table 2: DAEP Phase 1 (Dollars in Millions)

Item	Status	Completion Date	Amount Over/Under Schedule	Estimated Cost	Actual Cost	Amount Over/ (Under) Cost
DSS-33 Antenna and 20 kW Transmitter	Deferred to Phase 3	N/A	N/A	$47.3	N/A	N/A
DSS-35 Antenna and 20 kW Transmitter	Complete	October 2014	5 months	$44.8	$50.4	$5.6
DSS-36 Antenna and 20 kW Transmitter	Complete	October 2016	2 months	$46.1	$43.6	($2.5)
80 kW Transmitters	1 Complete, 1 Deferred, 1 Cancelled	June 2015	N/A	$35.0	$26.8	N/A
			Total	**$173.2**	**$120.8**	

Source: NASA OIG presentation of Agency data.

NASA mostly met cost and schedule estimates for construction of the two Phase 1 antennas and installation of their 20 kW transmitters. Specifically, construction of DSS-35 was completed in October 2014 and the antenna became operational in February 2015, 5 months later than planned with costs about $5.6 million more than estimated. DSS-36 was completed in October 2016 and operational in November 2016, 2 months later than planned but with costs $2.5 million less than estimated. According to JPL officials, the Agency was able to generally meet cost estimates for the two antennas by repurposing spare parts and reducing material costs. However, NASA spent $26.8 million to develop and install an 80 kW transmitter at DSS-26, nearly 77 percent of the $35 million it had estimated would be required to develop and install all three 80 kW transmitters at DSS-26, DSS-35, and DSS-55 during Phase 1 of the DAEP. The deferral of DSS-33 and one 80 kW transmitter to Phase 3 and cancellation of another 80 kW transmitter increased costs and left NASA without the expected complement of six fully functional 34-meter BWG antennas it had planned to support a growing number of communications-heavy missions.

Phase 2 Partially Complete with a Transmitter Delayed and Scope Added to Repair an Antenna

NASA has only partially completed Phase 2 of its DAEP with installation of one 80 kW transmitter deferred to the third phase of the project and scope added to repair an antenna. The Agency deferred installation of the 80 kW transmitter originally planned for Canberra during Phase 1 to Phase 3 due to delays in developing the prototype and rising development and construction costs. The Agency also cancelled one 80 kW transmitter originally slated for Madrid after deciding not to retire the three 70-meter antennas. NASA added scope and additional costs after discovering issues with DSS-54's pedestal and mechanical systems. Specifically, the foundation for DSS-54 being rebuilt at the Madrid site includes construction of a new pedestal (the underground base of the antenna) adjacent to the existing antenna, a 20 kW transmitter, and new systems and power equipment. The antenna structure, the visible part of the antenna above the ground, will be moved to the new site at the Madrid Complex and reused. NASA initiated construction at DSS-54 in July 2021 and expects the project to be complete by August 2026 at a total cost of $30.4 million. NASA expected to complete construction of the originally planned Phase 2 by September 2022 at a total cost of $122.3 million. However, as of the end of FY 2022 the Agency had only completed construction of DSS-53 and DSS-56 and installation of their 20 kW transmitters at a total cost of $103.2 million (see Table 3).

Table 3: DAEP Phase 2 (Dollars in Millions)

Item	Status	Completion Date	Amount Over/(Under) Schedule	Estimated Cost	Actual Cost	Amount Over/(Under) Cost
DSS-53 Antenna and 20 kW Transmitter	Complete	February 2022	(7 months)	$52.4	$50	($2.4)
DSS-56 Antenna and 20 kW Transmitter	Complete	January 2021	4 months	$49.9	$53.2	$3.3
DSS-54 Rebuild	Started	N/A	N/A	N/A	N/A	N/A
80 kW Transmitters	1 Cancelled, 1 Deferred	N/A	N/A	$20	N/A	N/A
			Total	**$122.3**	**$103.2**	

Source: NASA OIG presentation of Agency data.

During Phase 2, NASA was mostly able to meet its cost and schedule estimates for construction of the two antennas and their 20 kW transmitters. Construction of DSS-56 was completed in January 2021 and the antenna became operational that same month, 4 months later than planned with costs $3.3 million more than estimated. DSS-53 was completed in February 2022 and operational that same month, 7 months earlier than planned with costs $2.4 million less than estimated. According to JPL officials, the Agency was able to generally meet cost estimates for the two antennas because the contractor selected proposed a cost lower than expected. While additional work was necessary to complete construction of the antennas, the lower initial contract cost allowed NASA to cover the unexpected expenses and still remain slightly under budget. However, like Phase 1, NASA's cancellation and deferral of the 80 kW transmitters leaves the Agency short of the expected complement of six fully functional 34-meter BWG antennas to support a growing set of deep space missions.

Phase 3 Started but Expected to Cost Significantly More and Take Longer than Planned

NASA entered Phase 3 of its DAEP when construction on DSS-23 started in February 2021 at the Goldstone, California, DSN Complex. Original plans for this phase included construction of DSS-23, installation of the antenna's 20 kW transmitter, and installation of a sixth and final 80 kW transmitter at an estimated cost of $66.9 million with a completion date of September 2024. However, as of the end of FY 2022 construction had only begun on DSS-23 while construction on the remaining antenna (DSS-33) along with two 80 kW transmitters deferred from Phases 1 and 2 expected at a future date. The Agency also added additional scope and costs to outfit DSS-23 with optical communication capabilities, which will be critical to communicate with astronauts traveling to Mars.[18] By deferring DSS-33 and the two 80 kW transmitters and adding optical capability to DSS-23, NASA does not expect to complete the phase until October 2029 and the project's costs to increase from $66.8 million to $257.2 million (see Table 4).

Construction of DSS-23 Antenna at Goldstone Deep Space Communications Complex

Source: NASA OIG.

Table 4: DAEP Phase 3 (Dollars in Millions)

Item	Status	Initial Expected Completion Date	Current Expected Completion Date	Initial Expected Cost	Current Expected Cost
DSS-23 Antenna, 20 kW Transmitter, and optical	Started	September 2024	October 2025	$55.2	$157.4
DSS-33 Antenna and 20 kW Transmitter	Not Started	September 2018	September 2029	$47.3	$81.7
80 kW Transmitters	Not Started	September 2017 and September 2020	September 2029	$11.7	$18.1
				Total	**$257.2**

Source: NASA OIG presentation of Agency data.

NASA currently plans to complete construction of DSS-23 at the Goldstone Complex in October 2025, 13 months later than planned, and intends to outfit the antenna with optical capability by 2035. NASA also expects costs for the antenna to increase from the $55.2 million the Agency estimated in 2010 to $157.4 million, a $102.2 million or 185 percent increase. According to NASA officials, the projected costs increased due to the added optical capability and inflation in labor and materials. NASA plans to start construction on DSS-33 at the Canberra Complex in 2023 and have the antenna operational by 2029,

[18] NASA cannot use radio frequency communications to carry higher data rates like those required for Mars without increasing the size of its antennas or power of its radio transmitters. Therefore, the Agency is developing optical communications (use of light as a means of transmitting information through lasers) to address limitations of radio frequency communications, including bandwidth, spectrum, and overall size of frequency packages and power used.

nearly 11 years later than originally planned. The Agency also expects costs for the antenna to increase from the $47.3 million it projected in 2010 to $81.7 million, a $34.4 million or 73 percent increase. NASA officials stated that projected costs for DSS-33 will increase due to inflation in labor and materials. The Agency plans to complete the installation of the remaining two 80 kW transmitters on antennas at Canberra and Madrid by September 2029 for $18.1 million, 9 and 12 years later than originally planned.

Future DAEP Investments

NASA is also planning future DAEP investments totaling about $160 million, including site diversification work and refurbishment of each site's HEF antenna. Plans focus on diversifying sites around the world to support additional antennas to meet the Agency's goal of supporting future lunar missions and maintaining continuity of operations. The second investment will support the refurbishment of existing high-efficiency 34-meter antennas at the 3 DSN sites. NASA plans to start the site diversification work in FY 2028 with a projected budget of $92.6 million while the HEF refurbishment will begin in FY 2025 and is estimated to cost $66.8 million.

When considering the actual costs for Phase 1 ($120.8 million) and Phase 2 ($103.2 million), expected costs to complete DSS-54 at the Madrid Complex ($30.4 million) and Phase 3 ($257.2 million), other future investments ($160 million), and an allowance for project reserves ($34.9 million); NASA plans to spend at least $706 million to complete DAEP. While the Agency made considerable changes to the project's scope over the last decade, costs have increased considerably from the 3-phase plan's original estimate of $419 million in 2010. Moreover, SCaN officials expect cost estimates to increase even further as more concrete budget estimates are developed for FY 2024 and future years.

Challenges with International Partners and Project Oversight

NASA continues to face challenges in completing DAEP on cost and schedule while working under international agreements and contracts. According to NASA officials, the Agency has lacked appropriate insight into the selection of contractors and work performed at the sites in Australia and Spain, leading to issues with the quality and timing of work performed. Specifically, the Agency's agreement with Spain does not specify who is responsible for management oversight during major construction activities at the DSN Complex. In addition, the agreements require that local subcontractors and labor be used to the maximum extent possible for construction activities at the Madrid Complex. As a result, contracts were awarded to Spanish companies that NASA officials stated did not always have the knowledge and experience to perform the job appropriately. For example, a contractor poured cement for DSS-56's pedestal improperly and refused to redo the work, which caused construction delays. Moreover, because Spanish officials oversaw the contract with limited NASA oversight, the Agency had limited ability to require the contractor to correct its deficiencies.

The Agency has also confronted multiple challenges in obtaining deliverables, assessing accomplishments, and resolving problems efficiently at the Australia DSN site. NASA officials stated that issues with contracts and oversight led to the site's excavation for construction of DSS-35 and DSS-36 taking longer than planned, the contractor having to redo DSS-35's pedestal, and antenna panels that were laid too close to each other. According to JPL officials, unclear contract language for the criteria to be used for reviews, milestones, and quality of deliverables provided limited leverage to mandate compliance. In addition, repeated contractor delays caused JPL to cancel planned trips to the antennas' construction site, thereby limiting officials' ability to inspect and verify crucial deliveries.

Lastly, NASA has yet to install 80 kW transmitters on antennas at the Australia and Spain sites and will need to obtain clearances from the Australian and Spanish governments prior to their installation. According to Agency officials, there is a potential issue with receiving the clearances due to concerns over radio frequency radiation that slow-moving aircraft could experience if passing through the DSN's beams. As NASA works to complete construction at the sites in Australia and Spain, the Agency remains in negotiations to obtain the clearances for the 80 kW transmitters.

NASA Exploring Options to Increase Capacity

NASA's primary solution to address the DSN's unmet demand is the additional antennas and upgrades ongoing and planned under the DAEP. However, as previously stated, DAEP is nearly 5 years behind schedule and Agency officials have stressed that even with those planned upgrades DSN capacity will be insufficient to meet current and future mission demands. According to internal studies, the Agency may need at least two more 34-meter antennas at each of the three sites to meet projected demand by the 2030s. Other options the Agency is exploring include the development of Lunar Exploration Ground Sites (LEGS), utilization of foreign partners and commercial providers communication assets, and equipping existing antennas to send and receive data across additional frequencies. The main goal of the LEGS project is to offload services from the DSN through a series of 18-meter, tri-band antennas that will be strategically located at three sites around the Earth to always keep the Moon in view. NASA officials say it will take less time to construct the 18-meter dishes than it takes to construct the 34-meter dishes for DAEP.

NASA plans to build the first LEGS ground station at its White Sands Complex in Las Cruces, New Mexico, and a second in Matjiesfontein, South Africa, while it evaluates locations for a third station somewhere in Australia. However, according to SCaN's internal studies, the LEGS project will only be able to address a portion of the excess demand the Agency is projecting. Moreover, the LEGS project is currently only entering the implementation phase with the Agency continuing to work with stakeholders to define requirements and award contracts for construction. NASA estimates that the three ground stations will not be complete and operational until January 2027. NASA is also planning to procure additional LEGS sites through commercial sources, but details on the locations, contractors, and timing have yet to be determined. The use of such sites would also present security challenges to ensure NASA requirements are met. NASA's option to utilize partner assets also remains uncertain with international partners such as the European Space Agency predicting that their networks will also be oversubscribed during the DSN's most demanding periods.[19] Lastly, equipping antennas to send and receive additional frequencies will require additional upgrades to existing infrastructure and will mostly only benefit upcoming missions that are willing to equip their spacecraft to send and receive those frequencies.

[19] The European Space Agency is an international space agency comprised of 22 member states, including founders such as Germany, France, Italy, Spain, and the United Kingdom.

CONCLUSION

NASA's DSN is vital to providing the communication links for the Agency's most complex and expensive space exploration missions such as the JWST and the Agency's Artemis lunar campaign. Nevertheless, the network is at times more than 40 percent oversubscribed and has suffered from outdated infrastructure for decades. These deficiencies have led to missions not consistently receiving the DSN support they require, thereby reducing their return on investment. NASA has sought to revitalize the DSN by upgrading existing infrastructure and building new antennas, but efforts have been slow to materialize and are not likely to keep pace with the Agency's growing number of deep space missions and their increasing data demands. As the Agency looks to the future and crewed missions to the Moon and Mars, maintaining a robust and reliable DSN is essential to meeting these missions' needs.

Key to revitalizing the DSN is completion of the Agency's DAEP and bringing online the project's full complement of antennas and transmitters. However, challenges remain to completing the project on time and on budget as the Agency navigates critical international agreements with its partners and works to gain further insight into the construction of antennas in Australia and Spain. In our judgment, making these efforts a higher priority could hasten their completion or at a minimum ensure that they do not fall further behind. Additional mechanisms that would allow for greater oversight of the construction projects would also help to ensure that antennas and support systems are constructed to specifications and not subject to costly and time-consuming rework.

NASA is also examining other options to increase its deep space communications capacity and offload excess demand, including the development of LEGS, tapping into commercial and partner assets, and equipping antennas and spacecraft to send and receive additional frequencies. However, these efforts are largely in their developmental phases and questions remain about their viability and timing. In our judgement, finalizing requirements for LEGS and hastening work with international and commercial partners to determine the viability of using their assets would provide greater assurance that the Agency will have the DSN capacity required to support its future missions.

RECOMMENDATIONS, MANAGEMENT'S RESPONSE, AND OUR EVALUATION

To ensure NASA's progress towards upgrading the Agency's DSN and the network's ability to support current and future mission requirements, we recommended NASA's Deputy Associate Administrator for SCaN:

1. Explore more efficient options for DSN scheduling, such as maintaining a list of DSN users by priority that is updated in real-time and accessible to all users.

2. Ensure completion of the DAEP's remaining antennas and transmitters and finalize requirements for the LEGS project.

3. Finalize international agreements, obtain appropriate clearances for installing the remaining 80 kW transmitters, and establish mechanisms to allow for greater oversight of DAEP sites.

4. Explore options for utilizing commercial and international partners networks to offload excess demand from the DSN and to serve as backups in the event of network overages or outages.

We provided a draft of this report to NASA management who concurred with our recommendations and described planned actions to address them. We consider management's comments responsive; therefore, the recommendations are resolved and will be closed upon completion and verification of the proposed corrective actions.

Management's comments are reproduced in Appendix B. Technical comments provided by management and revisions to address them have been incorporated as appropriate.

Major contributors to this report include Tekla Colón, Mission Support Audits Director; Mike Brant, Assistant Director; Gene Bauer; Mona Mann; Barbara Moody; and Rachel Pierre. Lauren Suls and Amanda Perry provided editorial and graphics assistance.

If you have questions about this report or wish to comment on the quality or usefulness of this report, contact Laurence Hawkins, Audit Operations and Quality Assurance Director, at 202-358-1543 or laurence.b.hawkins@nasa.gov.

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Paul K. Martin
Inspector General

APPENDIX A: SCOPE AND METHODOLOGY

We performed this audit from November 2021 through May 2023 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

In this audit, we assessed NASA's progress towards upgrading the Agency's DSN and the ability of the network to support current and future mission requirements. To complete our work, we analyzed NASA studies of projected growth in DSN demand and met with Agency mission managers from JWST, Mars 2020 Perseverance Rover, and Artemis to discuss challenges and access the impact that capacity shortages has on their missions. We also reviewed NASA's prioritization process for distributing DSN services and discussed options for increasing DSN capacity with JPL and SCaN officials.

To assess NASA's progress towards upgrading the DSN, we reviewed Agency financial data, project management materials, and contractual documentation related to the DAEP. We conducted a site visit to JPL and the Goldstone Deep Space Communications Complex to observe the Agency's construction progress and hold discussions with JPL project managers on the project's cost, schedule, and challenges. We also reviewed NASA's international agreements with Australia and Spain and interviewed officials from the Agency's Office of International and Interagency Relations and Office of the General Counsel to discuss the agreements and negotiations for their renewal.

Assessment of Data Reliability

We relied upon budget and cost data from NASA's financial system as part of performing this audit. We assessed the reliability of computer processed data by (1) performing electronic testing, (2) reviewing existing information about the data and system that produced them, and (3) interviewing Agency officials knowledgeable about the data. We determined that the data were sufficiently reliable for the purposes of this report.

Review of Internal Controls

We assessed internal controls and compliance with laws and regulations to determine whether NASA is effectively managing the DSN. Control weaknesses are identified and discussed in this report. Our recommendations, if implemented, will improve those identified weaknesses.

Prior Coverage

During the last 8 years, the NASA Office of Inspector General issued three reports of significant relevance to the subject of this report. Reports can be accessed at https://oig.nasa.gov/audits/auditReports.html.

NASA Office of Inspector General

NASA's Planetary Science Portfolio (IG-20-023, September 16, 2020)

NASA's Management of the Electromagnetic Spectrum (IG-17-012, March 9, 2017)

NASA's Management of the Deep Space Network (IG-15-013, March 26, 2015)

Appendix B: Management's Comments

National Aeronautics and Space Administration

Mary W. Jackson NASA Headquarters
Washington, DC 20546-0001

Reply to Attn of: Space Operations Mission Directorate

TO: Assistant Inspector General for Audits

FROM: Associate Administrator for Space Operations Mission Directorate

SUBJECT: Agency Response to OIG Draft Report, "Audit of NASA's Deep Space Network" (A-22-01-00-MSD)

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to review and comment on the Office of Inspector General (OIG) draft report entitled, "Audit of NASA's Deep Space Network" (A-22-01-00-MSD), dated May 23, 2023.

The report primarily focused on the impacts of Deep Space Network (DSN) support oversubscription and NASA's challenges with increasing network capacity through the DSN Aperture Enhancement Project (DAEP) to mitigate current and future mission needs.

The OIG makes four recommendations to NASA's Deputy Associate Administrator for NASA's Space Communications and Navigation (SCaN), intended to ensure NASA's progress toward upgrading the Agency's DSN and the network's ability to support current and future mission requirements.

Specifically, the OIG recommends the following:

Recommendation 1: Explore more efficient options for DSN scheduling, such as maintaining a list of DSN users by priority that is updated in real-time and accessible to all users.

Management's Response: NASA concurs with this recommendation. SCaN and the DSN have been investigating improvements to the current DSN scheduling process for many years. The scheduling process currently relies heavily on the DSN user mission community creating and adjudicating the schedule as opposed to the DSN project unilaterally scheduling the missions. In contrast, the Near Space Network (NSN) utilizes a priority list to ensure that each mission can achieve its mission objective. This approach is not directly translatable to Deep Space missions due to the unique nature of science observations, targets of opportunities, orbital dynamics, and the long data delivery dwell times required. However, a portion of the NSN scheduling concept can be used to provide a regularly updated schedule priority based on both science and human spaceflight objectives. This scheduling will not be achievable in real time due to the DSN constraints provided earlier.

To investigate this further and develop implementable recommendations, SCaN created a DSN prioritization working group to consider the options jointly with the user community. Through this working group, SCaN will work as a facilitator between stakeholders – i.e., Exploration Systems Mission Directorate (ESDMD), Science Mission Directorate (SMD), and Space Operations Mission Directorate (SOMD) – to create a mission prioritization list for the DSN, define an implementation approach for the new scheduling system, and determine how future prioritization challenges will be resolved consistently and effectively.

Estimated Completion Date: The DSN proposal for scheduling system improvements spans over three fiscal years (FY). If the funding request is approved, the first set of improvements is expected to be complete by September 30, 2025.

Recommendation 2: Ensure completion of the DAEP's remaining antennas and transmitters and finalize requirements for the LEGS project.

Management's Response: NASA concurs with this recommendation. The Lunar Exploration Ground Site (LEGS) project is a separate activity from the DAEP. LEGS is managed by Goddard Space Flight Center (GSFC), while DAEP is managed by Jet Propulsion Laboratory (JPL).

The DAEP schedule was updated in 2021 based on needed funding re-alignment to support the DSN Road to Green initiative. This realignment resulted in delivery date shifts; however, these were coordinated and socialized with the user mission community to ensure no negative mission impacts. SCaN remains committed to the completion of the final phase of DAEP which will result in four beam waveguide antennas per DSN complex. SCaN will investigate potential site diversity and refurbishment of the high-efficiency antennas to mitigate capacity constraints and address the capacity needs of the Agency.

SCaN continues to work with stakeholders and the mission community to ensure that all LEGS requirements are accurately captured. Any additional capability needs will be assessed on a case-by-case basis to confirm the need for a re-baseline of the requirements and potential cost and schedule impacts. The LEGS Project Plan is scheduled to be finalized in September 2023 and will provide a baseline for the full LEGS Project, including both the LEGS Government and LEGS Commercial initiatives. During the development of the project plan, SCaN is reviewing all required documentation and statuses. The LEGS development team completed significant milestones including the LEGS Site 1 System Requirements Review in May 2022, the LEGS Site 1 Preliminary Design Review in December 2022, and the release of the request for proposal (RFP) to select a vendor for the three Government LEGS antennas.

Estimated Completion Date: The DAEP radio frequency (RF) antennas and 80 kW transmitters are planned for completion in October 2029. Specifically, DSS-23 is expected to complete in March 2026, DSS-54 is expected to return to service in December 2026, and DSS-33 is expected to complete in October 2029. The LEGS Project Plan is planned to be finalized in September 2023.

Recommendation 3: Finalize international agreements, obtain appropriate clearances for installing the remaining 80 kW transmitters, and establish mechanisms to allow for greater oversight of DAEP project sites.

Management's Response: NASA concurs with this recommendation. SCaN has worked to re-baseline the schedule for the 80 kW transmitters after a shift in priorities due to the Road to Green initiative. Both the Canberra Deep Space Communications Complex (CDSCC) and Madrid Deep Space Communications Complex (MDSCC) have received directions to obtain the appropriate clearances for installing and operating the 80kW transmitters. NASA's foreign partners at CDSCC and MDSCC are responsible for working with local agencies and regulators to obtain the appropriate authorizations to meet the requested timeline.

SCaN has also taken measures to provide direct oversight of overseas sites and to facilitate closer communication with foreign partners. In 2022, SCaN appointed a Director of Overseas Operations whose responsibilities include providing greater oversight into operational and development efforts at overseas sites. Furthermore, for critical development activities, SCaN will be deploying DSN subject-matter experts (SMEs) to provide onsite technical oversight.

Estimated Completion Date: With the now projected delivery date of October 2029 for the 80kW transmitters, SCaN is working with foreign partners to complete the spectrum/aviation approvals.

Recommendation 4: Explore options for utilizing commercial and international partners networks to offload excess demand from the DSN and to serve as backups in the event of network overages or outages.

Management's Response: NASA concurs with this recommendation. Pursuing commercial and international partnerships is a high priority for SCaN to offload the DSN, specifically for lunar mission support.

NASA realizes the long-term strategic importance of maturing commercial market capabilities to support Deep Space missions. The NSN commercial services RFP (RFP Notice ID: 80GSFC22R0029, published Feb 20, 2023) will procure lunar direct-to-Earth (DTE) and lunar relay services to offload, to the extent possible, the current capacity requirements of the DSN. Additionally, NASA issued a request for information to allow interested parties to "shadow" the Orion vehicle during Artemis I to demonstrate lunar-capable commercial DTE capabilities. Multiple organizations participated in this activity and the resulting performance data is under evaluation by the Agency. Additional opportunities will be offered during subsequent Artemis campaigns to encourage broad market investment in lunar and deep space capable DTE services.

To leverage international partnership contributions, SCaN has been in active negotiations with other space agencies, including but not limited to the Japanese Aerospace Exploration Agency (JAXA), Korean Aerospace Research Institute, Italian Space Agency, European Space Agency (ESA), United Kingdom Space Agency, South African National Space Agency, and the New Zealand Ministry of Business, Innovation, and Employment. SCaN has already reached agreements with ESA and JAXA for DTE support for Artemis missions and is in the late stages of collaboration discussions with other partners for similar agreements. Additionally, for commercial DTE services, NASA has stood up a LEGS project with a commercial component that will procure commercial lunar DTE services as part of the recent RFP. These antennas will be utilized to address some of the current capacity requirements of the DSN.

Furthermore, NASA intends to offload the DSN for lunar mission support through the implementation of a lunar communications relay capability. The relay services will be acquired through commercial vendors, and the relay service vendor is required to provide their own ground stations for connectivity to the Earth. Also, the development of navigation services as part of the relay services will reduce the reliance on Earth ground stations for tracking data. At the same time, NASA has worked closely with ESA on a plan to employ their proposed Moonlight lunar relay services as part of a robust cooperative network to support NASA missions and ESA missions. NASA and ESA have prepared a preliminary description for a joint concept of operations for lunar communications and navigation services. Discussions with other international space agencies for possible future participation in a cooperative lunar network are ongoing. A key enabler for a cooperative lunar network is the LunaNet Interoperability Specification, which has been applied as a standard document for both the NASA and ESA lunar relay service procurements. It is also being proposed as an international standards reference.

SCaN is providing guidance to lunar missions in formulation or pre-formulation to plan for support from these non-DSN capabilities. DSN utilization will be constrained to critical mission events of limited duration, such as a lunar landing, that require additional DSN technical performance. Such guidance is also being employed for missions such as Gateway, Human Landing System, and Lunar Terrain Vehicle.

Lastly, the SCaN Mission Commitment Office manages a JPL Customer Interface Management Office (CIMO) which is responsible for coordinating with the DSN and ensuring international collaboration is in the best interest of NASA's needs and objectives. CIMO performs strategic, cross-support, and international/external relations functions for deep space communications demands. Additionally, CIMO executes technical assessments and agreements for NASA missions requiring non-DSN support from foreign or domestic facilities.

Estimated Completion Date: Awards for lunar DTE services, as a part of the LEGS project, are expected in early fall 2023 (no later than December 2023). Awards for lunar relay services are expected in summer 2023 (no later than November 2023). Some international support has already reached an agreement while others will be targeting support in time for Artemis III and beyond.

We have reviewed the draft report for information that should not be publicly released. As a result of this review, we have not identified any information that should not be publicly released.

Once again, thank you for the opportunity to review and comment on the draft report. If you have any questions or require additional information regarding this response, please contact Michelle Bascoe at (202) 358-1574.

Kenneth Bowersox
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Kenneth D. Bowersox
Associate Administrator for the
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cc:
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Associate Administrator, Office of International and Interagency Relations/Ms. Feldstein
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