Transformation of the Space Surveillance Telescope into a Dedicated Sensor in the Space Surveillance Network

Jonathan Hutfilz
Space Domain Awareness Division

James "Chris" Higgins
Space Domain Awareness Division

ABSTRACT

The Space Surveillance Telescope (SST) is a large ground-based optical system capable of rapid un-cued search, detection and tracking of dim objects in deep space. Originally produced by the Defense Advanced Research Projects Agency (DARPA) as an advanced technology demonstration, SST has been improved so that it can begin operations in 2022 as a dedicated sensor in the Space Surveillance Network. At that time, it will start surveying the skies above the Indo-Pacific Region, from its new home in the southern hemisphere. The original location for the evaluation of this telescope was from a DARPA-built facility on the north end of White Sands Missile Range, in central New Mexico. As a prototype sensor, SST achieved its first "first light" in 2011, and immediately began breaking records for discovery of new objects. Its performance was so good that it became the subject of a 2013 agreement between the U.S. Secretary of Defense and the Australian Minister of Defence, agreeing that the two nations would partner on operating SST from a new facility which Australia would build near Exmouth, in Western Australia. This presentation will describe that transformation, spanning 2 decades, 2 continents and one very-strong international partnership.

1 INTRODUCTION

The Space Surveillance Telescope is one of the world's most exquisite space domain awareness sensors, capable of searching (in seconds) an area the size of either the U.S. or Australia, surveying one-quarter of the sky several times each night. The number of earth-orbiting objects will continue to grow while the size of those objects shrinks. Effective catalog maintenance requires sensors with high sensitivity, resolution and capacity. The Space Surveillance Telescope is the first operational sensor of its kind, and is ready to effectively monitoring the growing population of man-made objects in deep space. In doing so, it will fill a critical gap in the Space Surveillance Network's coverage of the skies above Earth. Under DARPA's leadership, SST was developed by Massachusetts Institute of Technology's Lincoln Laboratory. The design includes a 3.6-meter diameter aperture matched to an f/1 optical prescription, and a unique camera composed of 96 million pixels positioned along a curved surface. The telescope was designed and built by L3 Technologies, Brashear Division, now part of L3 Harris. The camera was designed and built by Lincoln Laboratory.

To satisfy the 2013 agreement between the U.S. and Australia's defense departments, an international collaboration was forged between 2 separate Program Offices, one assigned to the U.S. Space Force and the other to Australia's Defence Department. Through closely-integrated but separate acquisition activities conducted by both System Program Offices, the transformation of SST began. Over a 9-month period in 2017, SST was slowly disassembled in New Mexico, allowing for documentation of procedures, inspection and repair of components and assessment of improvements required so that SST could eventually meet reliability and SSN performance standards. 232 tons of SST hardware were then shipped over 14,000 miles in 17 crates, safely arriving in Australia. Australia designed and constructed a marvelous facility for SST, fit for the purpose of maintaining high operational availability of this new sensor. Finally, the re-assembly of SST commenced in parallel with completion of that facility's construction. The U.S. Chief of Space Operations, General Jay Raymond, publicly announced that the re-built SST achieved "first light" in Australia in March of 2020.

In addition to understanding resident space objects, the Space Surveillance Telescope is well-suited to detect natural space objects, such as asteroids and comets. Between 2014 and 2017, SST contributed more than 3 million observations to the Minor Planet Center, including discoveries of over 500 new asteroids. Once operational in

DISTRIBUTION STATEMENT A. Approved for public release: Distribution unlimited.

Copyright © 2021 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com

Australia in 2022, SST data will provide NASA's Near-Earth Object discovery programs with access to the southern hemisphere sky, and increase the detection of asteroids which could be threatening to life on earth.

2 OPERATIONALIZATION

The activities transform SST to a dedicated sensor were seemingly straight forward: relocate the system, operationalization, test, and integrate the final product into the Space Surveillance Network. As one begins to ponder what all this means, part of the assignment is a crazy nebulous term of operationalization or operationalizing. What was truly meant by that term and why not a more common term such as standardization or normalization? In order to answer that question, once must start at the end…what does the day-to-day operations look like? What is the vision?

Sources of U.S. DoD prototype transition writings available at the time to the program office may have been useful, such as the U.S. DoD's *Manager's Guide to Technology Transition in an Evolutionary Acquisition Environment*, for a normal or standard transition. Outside of generalities, such as financial and risk management, the written material lacks granularity level detail to execute. In particular, the "what" was available for standard cookie-cutter programs – there is nothing normal or standard with transitioning SST - however, the "why" is completely skipped in order to tailor out the products to the minimum required. Operationalization encapsulated the final, tailored end-product in the vision to reach operational acceptance in conjunction with relocating the system to Australia.

For the Space Surveillance Telescope, the referenced vision is not one you would normally see as part of a company or an organization's purpose and what it is trying to achieve. In the case of SST, it is actually visualizing day-to-day operations, picturing who is doing what and when as a day progresses into the night when SST operates. Expanding that view to include the sustaining engineering functions and activities necessary to ensure the enduring capability. Once that is visualize, breaking down that visualization into discrete elements that can be acted upon, either through a contractual relationship, internal to the program office, or to our Australian partner. The operationalization visualization on a piece of paper would look like:

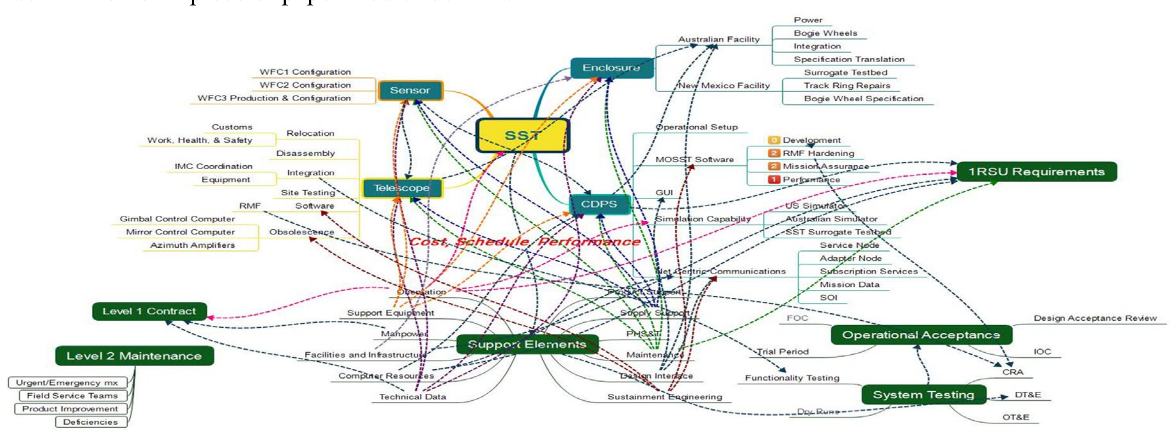

Fig 1. SST Initial Operationalization Mind Map

If Fig. 1 is confusing, in order to operationalize SST, the Space Domain Awareness Division is accomplishing the following high-level operationalization activities:

1) Upgrade hardware and software
2) Create a technical baseline (specifications, interface documents, requirements, etc.)
3) System support with spares and instructions
4) Provide training and instructions to operate the system
5) Institute a communications path for data to the Command and Control Centers
6) Establish a cyber-resilient product
7) Test and evaluate the system for the Space Domain Awareness mission

In addition to moving the telescope and integrating SST in the new Australian purpose-built facility, the aforementioned list was seen as the minimum activities necessary to transition SST from a prototype system to a

Copyright © 2021 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com

dedicated Space Surveillance Network sensor. Essentially, procure the products and services to operationalize the SST system to ensure the continued supportability and sustainability in Western Australia.

2.1 TECHNICAL BASELINE

In acquisitions, technical baseline contains the functional, allocated, and product baselines [1]. Generally, it contains requirements and product information such as specifications, interface documents, drawing, and architectures. As an inherited DARPA advance technology demonstration system, only some of the artifacts were available. Therefore, one has determined what is really important, and what would be considered gold-plating. To have this understanding, the first step in the operationalization effort not just understand what the system does but, more importantly, what is in the system. What are the components from a hardware and software perspective that when one thinks 25-years into the future, what needs the care and feeding or what bolt needs tightening? A supportability-type analysis was required to establish what was transferred. Basically, a logistics planning and supportability analysis activity for the SST system, subsystems, Line Replaceable Units (LRUs) and components to aid in the identification of sustainment, obsolescence issues, and mission systems impacts. In addition, we sought a provisioning parts listing identifying critical, non-critical and long lead items required for sparing the system allowing the program office sufficient time to align financial resources into the correct pots of money [2]. Especially important is obsolescence; the repair parts that are no longer available to maintain the system. From this aspect, the knowledge of the products specifications, its interface and role in the system is important in order to make the correct decisions regarding a replacement. While a time-consuming process, it is not a difficult task to accomplish for products available from a commercial vendor, however, a complete custom subsystem, such as the SST camera, creates its own unique challenges.

The MIT LL custom built wide-field camera, winning a R&D 100 award from R&D Magazine [3], had to be thought through on how the camera and its associated components was to be maintained and serviced throughout the program lifecycle. With few exceptions, most of SST camera components are commercially available, but they are arranged in such a manner that subsystem as a whole a custom piece of equipment. As with the entire system itself, the camera was relocating to an environment that it was not originally design for. A modernization effort had to be launched to ensure SST camera and its associated components could handle the hot, humid, and dusty environment it was about to enter.

2.2 CYBERSECURITY

"When developing software, what are your main sources for security best practices?" asked the Linux Foundation and The Laboratory for Innovation Science at Harvard as reported in their 2020 FOSS Contributor Survey [4]. They found FOSS developers spend a little over 2% of their time responding to security issues with around the same for the time developers *would like* to spend on building-in security [4]. A couple of responses [4]:

"I find the enterprise of security a soul-withering chore and a subject best left for the lawyers and process freaks. I am an application developer."

"I find security an insufferably boring procedural hindrance."

One can chuckle, with tossing your head back-and-forth in eventual, begrudgingly agreement. However, for a military-use system, such as SST, protection and mission assurance are important factors in today's network security environment to protect against malware, denial of service, and ransom cyber-attacks. This meant the entire software code baseline, to include the anxiety-driven FOSS, required a 100% audit for the program office to have an understanding of what it accepted. In the case of SST, the starting point is an operational system that includes a mix of prototype software and re-used operational software from other telescope systems. The planned process for "operationalizing" this software is an iterative process of assessing weaknesses, debugging or rewriting pieces that need improvement, and isolating code that is not specifically used by SST so it can be removed from operations. The first iteration addressed the largest and most significant issues; successive iterations addressed more minor issues. This activity was driven by National Institute of Standards and Technology Risk Management Framework process.

The Risk Management Framework (RMF) provides a process that integrates security, privacy, and cyber supply chain risk management activities into the system development life cycle. RMF will categorize the system based

Copyright © 2021 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com

upon perceived mission risk leading the process to implement security controls in not only the software, but also the hardware for eventually authorization to operate by the senior security officials in the USSF.

2.3 COMMUNICATIONS

Under DARPA development SST communicated directly with MIT LL in order to prove its utility. With SST becoming a dedicated SDA sensor, data from SST required bringing in the outside world in the form of United States and Australia C2 centers. In order to accomplish this, both the physical data pipes and the message formats must meet the current data exploitation expectations.

Since data formats were evolving in the SDA community, SST benefited from the previous work done under the Space Fence program. Space Fence led the charge in developing the modern formats that are still evolving within the community today. However, with Space Fence being a radar, not everything was equal in the application of their formats to SST. SST being the first optical system was able to leverage Space Fence, but still had to adjust the formats to meet the optical data requirements. With the formats for data understood, SST set out next to understand the bandwidth was required to properly report all this data.

First, with the help of The MITRE Corporation, SST modeled a cascading space incident based upon an ASAT destruction with a corresponding secondary incident where the debris from the ASAT collided with another satellite exasperating the situation. Taken the file sizes from the aforementioned data formats, and the model data from the simulation, The MITRE Corporation was able to calculate the amount of required bandwidth to the C2 center to report such an incident. These numbers then form the basis for both the Australian and US program offices to work with their respective communication service providers ensuring the appropriate bandwidth from SST to the C2 centers in near real time.

In addition, SST is to be remotely operated. Additional analysis had to be conducted by MIT LL to ensure that connectivity between the SST site and the Australian operation center met the bandwidth and latency requirements in order to successfully perform operations. While the sound simple, this took several months to resolve with constant tweaking of the communication protocols, again for real-time control and operations of SST.

2.4 UPGRADES

While it’s been hinted that throughout this paper, all the previous sections reference a major upgrade that SST had undertaken in order to transform the prototype system to a dedicated sensor. One piece of information to keep in mind is that the original SST for light in the United States was in February 2011. The program office not receiving any funding until 2015 had to analyze the entire system that was being used and realized it was nearly a decade old. With the full knowledge and understanding that this was a DARPA prototype, it must be understood by program offices inheriting such a system that the rigor the acquisition community puts in such a product, was not on the forefront of DARPA’s development.

Old hardware, software that was reused, a bunch of free and open-source software, new requirements to meet the mission need all contributed to the modernization effort that had to be undertaken. Working with the original developers, SST set the course for upgrading all the hardware computer components and software for cybersecurity needs. In addition, SST was developed as a PhD-like system. Meaning at the way the operator interacted with the system needed to change drastically in order for it to be upon by Australian operators who have never run an optical system before. Again, with the system developer, how operations are to be run in Australia, required the assistance of the Austrian operators in their basic understanding of the SDA mission in order to manipulate the code and the displays from a script-based aspect for more modern look of today’s Internet with pushbutton graphical user interfaces and easier to interpret data displays for quick responses. With the end user and maintainer in mind for operating the system the program office one about modernizing SST to marry the mission with the operators in the maintainers.

2.5 ORIENTATION

Orientation in the context of SST simply means training. Training for the Australian operators and their maintainers. SST leveraged heavily on the C-Band radar program which was established in the same area as SST a couple years

Copyright © 2021 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com

prior. Lessons learned from C-Band recognize the need for a more robust training program than the previous effort. In order to accomplish this more robust training effort, SST set out to find system experts from the developer would actually be willing to move to Australia and work side-by-side with the operators and maintainers. This portion of the program was set up is known as an extended detachment. In all, seven personnel from MIT LL relocated to both the SST sensor site and its control center. This has allowed the Australians to learn directly from the system experts and how SST is to be operated and cared for.

However, one piece that was missing to enable this effort to be properly conducted was the leave behind material that once the systems experts left Australia and Australia was on their own to perform these activities without the oversight of MIT LL. This missing material as the technical manuals necessary to operate and maintain the system. Rightfully so under the DARPA development, very limited operations and maintenance material was transferred to the program office. This was perfectly acceptable. As DARPA is on the leading edge of technology development, the program office was more suited for the task of creating the technical manuals in accordance with the proper regulations and standards.

Anyone who's been involved with creating technical manuals for system knows this is not a trivial task. Much effort is giving to breaking down the system piece by piece, part by part, to develop a maintenance concept for each and every single component. Once that is established, this is called provisioning the system, program office was able to develop a technical order program in conjunction with the eventual sustainment contractor. This proves beneficial in a couple different ways. First, the sustainment contractor will eventually be responsible for the level of maintenance that is beyond what the Australians capability can provide. Second, as they will be the ones who keep the manuals updated for technical accuracy, safety, and applicability, this insured there would be no conflict as the system transitions from development to operations and sustainment. There have been several instances as a program transition from the prototyping world to the operations world, or even from one program office to another, or conflicts have arisen in the transfer of technical data to include the manuals used for operations and maintenance. The method employed by SST was the most effective process to ensure continuity entering a new type of operations.

2.6 CONOPS

Traditionally, legacy space surveillance network sensors were task-based. DARPA's foresight into the needs recognized the value and search-based operations. SST shifts the paradigm from traditional tasking to this new concept of operations. While can perform the legacy receive a tasking respond to a tasking, SST is bread-and-butter is searching the southern hemisphere several times a night. This is a piece that's missing that SST is providing is the capability to resolve and discriminate space objects and debris to accurately assess space events and make informed decisions in response. SST's unique location combined with its ability to see dim objects enhances the ability of the network to improve detection, safety of flight, separation, conjunction assessment, and proximity operations. Both the US and Australia recognize that space systems are part of the national infrastructure, and their national defensive and economic security are dependent upon the free use of space. As the barriers for entry to space lower, more and more actors have gained access. This trend will lead to the emergence of greater congestion and competition. The number of earth-orbiting objects will continue to grow while the size of the objects will decrease through advances in technology, requiring sensors to provide higher sensitivity, resolution, and capacity. SST with its unique capabilities is able to meet these requirements for deep space objects.

SST will operate in an autonomous search mode with little or no direct tasking, allowing SST to operate as a synoptic survey sensor detecting and tracking viewable objects which pass within its field of view. SST operators can schedule preset synoptic search patterns for future observation periods. The SST system will autonomously detect, track, and characterize space objects while still responding to the traditional legacy tasking mode of operations. However, SST through its synoptic search is expected to satisfy any potential tasking request from the C2 center.

3 PERSONNEL

While part of the problem was understanding the exacting nature of what needed to be done to transform SST, establishing the cooperative relationships with the "who" can perform the activities was tougher. According to Schoemaker [5], "Having consistency in the individuals in the project, and avoiding turnover shows to be a factor in transitioning prototype projects." While Schoemaker's research was published after commencing with the SST

DISTRIBUTION STATEMENT A. Approved for public release: Distribution unlimited.

Copyright © 2021 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com

program, his work validates the approach the program office, as well as HQ SpOC, system developers, and potential sustainment team in organizing personnel resources to manage the program. Consistency is the key in championing the project. Vital program office personnel have been involved with SST since 2009, while HQ SpOC came in earlier, in 2005.

With consistency being the key, trust is vital. Problems occur when organizations don't trust each other to get the job done. Program managers, engineers, logistics, and cybersecurity professionals must be able to clearly articulate the plans to accomplish work going forward. More importantly, is when the plan starts to go sideways as having the trust in not only your immediate team but your extended team as well. Being fully open and honest with the entire team regarding the problems that are occurring, and there will be problems, brings and ideas and solutions that a single individual alone may not have considered. This concept should not be hard. But for some it is seen as a failure. For SST, the team has been encouraged, and has demonstrated, the ability to solve issues and concerns as a whole team approach. This team consist of members of the program office, SpOC, system developers, system sustainers, maintenance personnel, the operations staff, and the Australian government.

SST is a true partnership with Australia. Costs are shared, problems are shared, and successes are shared. No one organization was able to do it alone and having a dependable partner, in this case partners, has made the successes sweeter and more enjoyable. Building this partnership takes time, takes patience, and takes practice. The more open, the more trust that is built.

4 CONCLUSION

The Space Surveillance Telescope (SST) is the most exquisite, ground-based optical telescope in the United States (U.S.) Space Surveillance Network family of systems. SST is designed for synoptic survey of deep space, collecting data on all viewable objects in that region whether or not the object has been previously cataloged. Developed by the Defense Advanced Research Projects Agency (DARPA) with Massachusetts Institute of Technology Lincoln Laboratory (MIT LL) serving as DARPA's lead integrator for the design and system integration, SST is capable of rapid uncued search, detection, and tracking of dim objects in deep space. In 2006, Headquarters Air Force Space Command (HQ AFSPC) signed a memorandum of agreement (MOA) with DARPA to evaluate the military utility of the SST prototype with the intent that AFSPC would operationalize the prototype in New Mexico. However, in 2010, the U.S. Secretary of Defense (SECDEF) and the Australian (AUS) Minister for Defence (MINDEF) signed a Statement of Principles establishing a space domain awareness (SDA) partnership to investigate the potential for jointly establishing and operating SDA facilities in Australia. Then in 2013, the two defense leaders furthered the international partnership in mutual SDA capabilities by signing a memorandum of understanding (MOU) to relocate, demonstrate, and operationalize SST in Australia. It is imperative for the U.S. and Australia partnership to have the capability to resolve and discriminate space objects and debris to accurately assess space events and make informed decisions in response. The successful relocation and operational acceptance of SST will provide capabilities to effectively improve detection and characterization of space activities; improve orbital safety of flight during maneuver, separation, conjunction assessment, and proximity operations; and improve SDA support to counter-space operations. In addition to relocating and operationalizing the system, the Royal Australian Air Force (RAAF) will operate and maintain the telescope. HQ AFPSC, now HQ Space Operations Command, a field command under the U.S. Space Force (USSF), charged the Space Systems Command, specifically Special Programs Space Domain Awareness Division, with the task of transitioning the DARPA prototype system to an operational sensor, implementing SST in Australia, and creating an enduring and lasting program for many, many years to come.

5 REFERENCES

[1] AcqNotes. *Systems Engineering*. https://acqnotes.com/acqnote/careerfields/technical-baseline accessed 22 July 2021.
[2] Office of the Under Secretary of Defense (Comptroller) / CFO. *Department of Defense Financial Management Regulation, DOD 7000.14-R*. https://comptroller.defense.gov/FMR/ accessed 19 July 2021.
[3] R&D World. *R&D 100 Archive of Winners,* 2012. https://www.rdworldonline.com/rd-100-archive/?YEAR=2012 accessed 19 July 2021.
[4] F. Nagle, D. Wheeler, H. Lifshitz-Assaf, H. Ham, and J. Hoffman. *Report on the 2020 FOSS Contributor Survey*, The Linux Foundation, 2020.

DISTRIBUTION STATEMENT A. Approved for public release: Distribution unlimited.

Copyright © 2021 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com

[5] M.D. Schoemaker. *Analysis of the Factors that Correlate with Transition Outcomes of Commercial Technology Prototype Projects*. Theses and Dissertations, 2020. https://scholar.afit.edu/etd/4345

The views, opinions, and/or findings contained in this article/presentation are those of the author/presenter and should not be interpreted as representing the official views or policies, either expressed or implied, of the Department of Defense, Department of the Air Force, or the United States Space Force.

DISTRIBUTION STATEMENT A. Approved for public release: Distribution unlimited.

Copyright © 2021 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com