Request for Information on Scope of Civil Space Situational Awareness Services: Stratagem Response

Submitted To:

The U.S. Department of Commerce (Department), via the Office of Space Commerce (OSC) in the National Oceanic and Atmospheric Administration (NOAA)

Submitted By:

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1. Stratagem Administrative Data

Data Universal Numbering System (DUNS) Number: 831508903

Commercial and Government Entity (CAGE) Code: 5NK85

Defense facility security clearance? Yes, TS for Storage/Possessing

Accounting system, & time keeping system audit info: 7 May 2019. Performed by: DCMA Denver, P.O. Box 25586 Denver Federal Center, Building 16, Denver CO 80225-0586

Interest: Stratagem is interested in leveraging proven technologies to support the Office of Space Commerce's mission with services that improve the quality of data required for safety of flight in multiple orbital regimes

OCI Concerns: Stratagem has no OCI concerns associated with this effort

2. Company Overview

Stratagem is a software development and R&D company that delivers purpose-built operational solutions for the Intelligence Community (IC) and Department of Defense (DoD). Our unique combination of experienced professionals who double as master technologists establishes us as an exclusive entity: *a boutique software house who crafts unique, special-purpose solutions tailored for our customers*. We specialize in pairing decades of Space Situational Awareness (SSA), SATCOM, GEOINT, and SIGINT domain expertise with advanced software techniques from the commercial sector and academia. Our operationally-ready products and services for SSA will enhance the Office of Space Commerce's (OSC) Traffic Management System for Space (TraCSS) program with automatic, near-real time monitoring, and assessment of third-party data that is critical to basic SSA safety services.

3. Scope of Stratagem Services to Improve SSA

We recognize that OSC is committed to evolving the space traffic management mission as changes continue to occur in the marketplace and in the underlying SSA technologies. Stratagem takes a measured approach to technology insertion, and we seek to meet initial operational capability with proven technologies with no disruption to other OSC TraCSS capability deployment. We accomplish this through a successful Stratagem Dev/Sec/Ops processes and policies, or in collaboration with customer defined development, testing and deployment practices.

Of the list of basic safety SSA services to be included in TraCSS, our Stratagem-developed Lumos capability independently and wholistically addresses two of them: (5) Data Quality Evaluation and (11) Conjunction Object Solution Improvements.

The Data Quality Service (DQS) was created to ensure bias sensor data is detected in near-real time. This baseline service would provide data quality assurance on par with that being deployed for DoD space-based sensors, with the capacity to expand a diverse set of sensors and providers being considered for use by OSC. In support of the OSC basic safety service, the DQS:

- Fuses data from multiple sources and suppliers, to include ground- and space-based sensors
- Alerts users to sensors with out-of-tolerance biases
- Prevents out-of-tolerance observations from entering critical SSA orbit determinations and propagation processes. This ensures that collision avoidance alerts and other safety of flight functions are not corrupted with biased observations
- Allows users to toggle out-of-tolerance sensors to prevent potentially anomalous sensors from being used

The Collection Recommender Service improves conjunction assessments through pre-planning and scheduling of sensor collection opportunities. The operational value of this service in the context of basic safety SSA services for the DoC mission include:

- Optimized collection geometry for reduced covariance of RSO(s) of interest
- Reduced number of sensors tasked for a desired (and user specified) accuracy
- Reduced quantity of observations purchased from 3rd parties to achieve desired effect

Stratagem offers these two services under an umbrella program called Lumos. Lumos was originally created for US Space Force 1St Space Operations Squadron (1SOPS) and could be integrated as a key baseline TraCSS component.

3.1 Lumos Data Quality Service (DQS):

To determine whether observational data is of sufficient quality for orbit determination and propagation for the TraCSS program to perform high-performance collision avoidance, the system must include a data quality evaluation of sensor observations. Erroneous or inconsistent tracking data leads to erroneous or inconsistent orbit determination (OD) and prediction products used for STM, RSO monitoring and SSA. Calibration of sensors for data quality assessment has traditionally been performed by tasking sensors to track reference RSOs, "calibration" satellites, for which highly accurate ephemerides are known, and from which accurate reference measurements are derived and compared to actual measurements for sensor noise and bias quantification.

Shortcomings of the traditional calibration process are that they are not real-time due to latency of available high accuracy reference satellite ephemerides, and "stove-piping" sensor calibration often results in incomplete or incorrect bias error determination due to incomplete error information (e.g., due to limited observing geometry). Independently procured and managed sensor systems remain an impediment to deployment of an enterprise data monitoring system. Our Stratagem Data Quality Service (DQS) developed to meet USSF/1SOPS requirements automates sensor data anomaly detection and reporting. This near real-time capability overcomes the limitations of traditional calibration approaches and fuses data monitoring from multiple sensors whether they be government, commercial or international (Figure 1). DQS does this by employing a multi-state Unscented-Schmidt Kalman Filter (USKF) that processes observations of well-known and well-behaved RSOs observed by multiple sensors. DQS is then able to detect sensor biases or potential RSO maneuvers by analysis of the resulting states and metrics of the USKF in near-real-time without the use of latent "calibration" satellite position and velocity data.

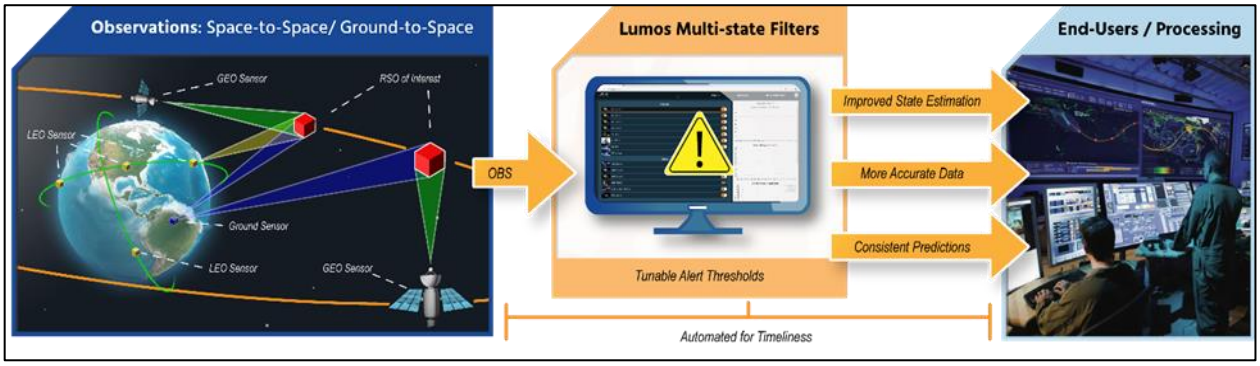

Figure 1: Multi-State Kalman Filter for Improved State Estimations and Data Accuracy

The DQS includes an UI (Figure 2) where an operator can monitor the data quality of sensor observational data. The Lumos UI consists of three (3) main pages: Assets, Analysis, and Recommender. The Recommender page is for the Lumos Collection Recommender Services, which is discussed in Section 3.2. The Assets page provides a user a general overview of the satellites and sensors that the Lumos Anomaly Detector is currently monitoring and is shown in the figure below. By clicking on either a sensor or a RSO, the latest filter results are shown on the right-side pane. The Assets page is also where an operator can turn "on" and "off" sensors and RSOs using the yellow switch next to the sensor/RSO. This will toggle whether new sensor observations will be considered by the filter. When a sensor is enabled, any observations the

sensor has of an enabled RSO will make it through the Pre-Processing microservice to the Filter Microservice to be processed through the USKF.

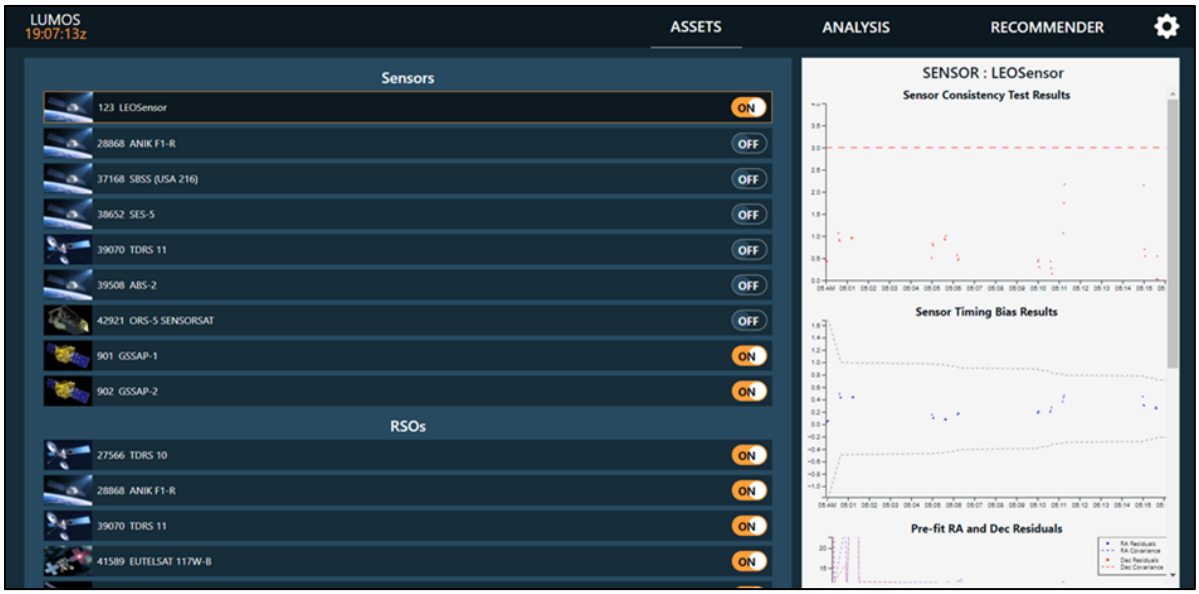

Figure 2: Sensor Anomaly Detection Interface and Selector

The DQS employs a multi-state Unscented Schmidt Kalman Filter (USKF), which leverages a limited number of well-known and well-behaved RSOs tracked by multiple sensors and sensor types in all orbit regimes to produce a near real-time quality assessment without the need for high accuracy reference satellite ephemerides. The metrics produced by the multi-state USKF-based approach also allows one to distinguish true sensor anomalies vs. "apparent" anomalies produced when an RSO maneuvers. This enables assessment of data quality in near real-time. Since RSO observations from multiple sensors are processed by the USKF, the DQS is able to determine if a sensor is experiencing an anomaly by analysis of the USKF states and metrics. The operational concept of this approach is scalable to large numbers of sensors in a surveillance network, including commercial sources of Electro-Optical (EO) and radar data, and can include fusion of multiple data types used to track a common set of RSOs.

The DQS architecture is highlighted in orange in Figure 3. It takes in observations on a set of "trusted" RSOs from the Data Monitoring Service in near-real-time. Trusted RSOs do not need to be calibration Satellites (CalSats), rather they may be any object that has relatively predictable behavior and is viewable by multiple sensors. This allows the system to provide high-quality assessments and alerts without a reference CalSat in view.

The Stratagem real-time DQS also does not require metrics generated by the provider calibration processes. That data can often experience high latency. On the other hand, the DQS can ingest calibration metrics (observation noise and biases) produced by the sensors and verify those biases. If the sensor data provider incorporates the tracking of CalSats for producing high accuracy ephemerides, the Strategem real-time quality assessment process will also incorporate this precise ephemeris to enhance the Lumos filter performance and expedite convergence.

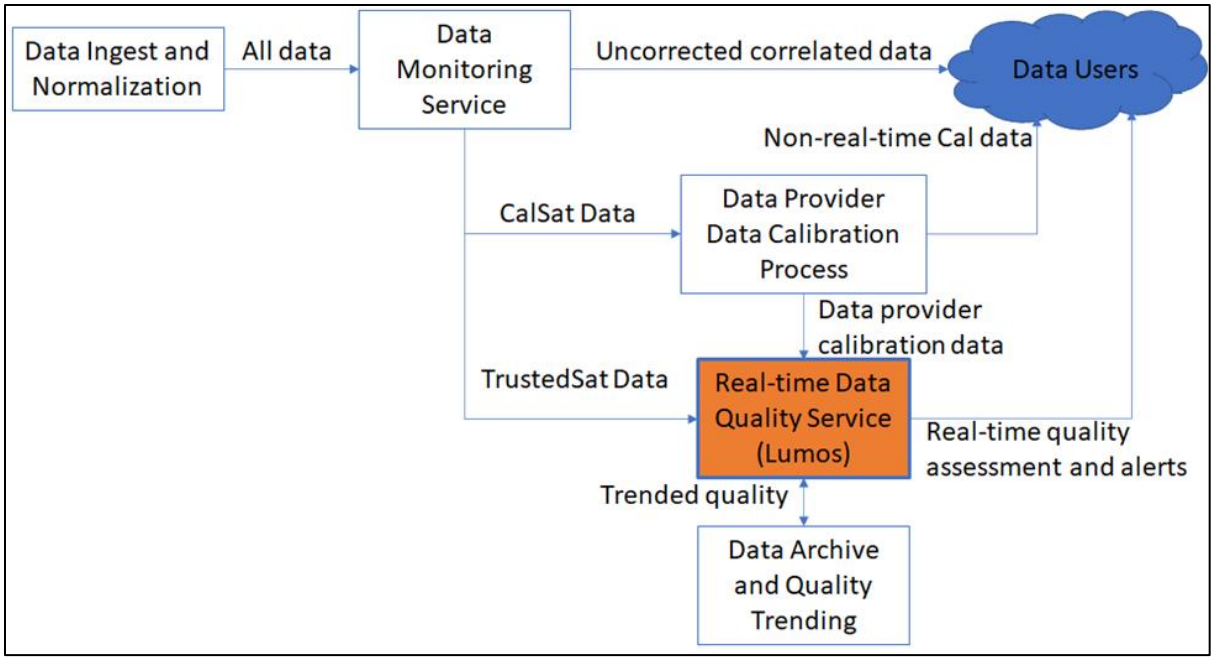

Figure 3: The Data Quality Service Provides Near-Real-Time Assessments Across Multiple Sensor Providers

At the start of the DQS, all ingested data is "normalized" to ensure consistent reference frames are used, units are standardized, and any known and verified biases have been applied prior to data quality processing. These processes utilize IERS based Earth Orientation Parameter (EOP) based data in a set of well-established and validated reference frame transformation functions. The resultant data and state transformations have been further validated in standard calibration processes that utilize the transformations for both observation and reference satellite state transformations.

The Stratagem USKF output produces the metrics needed to determine the quality of the data processed. From within the filter processing, outliers are computed, pre- and post-fit residuals, and the state estimate and covariance are computed. In post processing, the state estimate is compared with the truth state and the filter output is run through an Unscented Rauch-Tung-Striebel (URTS) Smoother which is then used to compute the McReynold's consistency metric. In combination, these measures produce consistent monitoring of data quality.

3.2 Lumos Collection Optimization Service:

The TraCSS program and OSC traffic management mission will leverage multiple government, commercial and owner/operator sensor feeds to maintain a current RSO catalog and propagate ephemerides for collision avoidance alerting. Optimizing collection windows and sensor-to-target RSO geometry serves multiple operational purposes. It provides optimal data collections for reduced covariance, reduces the number of sensors tasked (or required), reduces the volume of observations a system needs to process, allows for user input on a time window and future covariance required. In aggregate these benefits form a foundation for basic safety services and improvements to conjunction assessments.

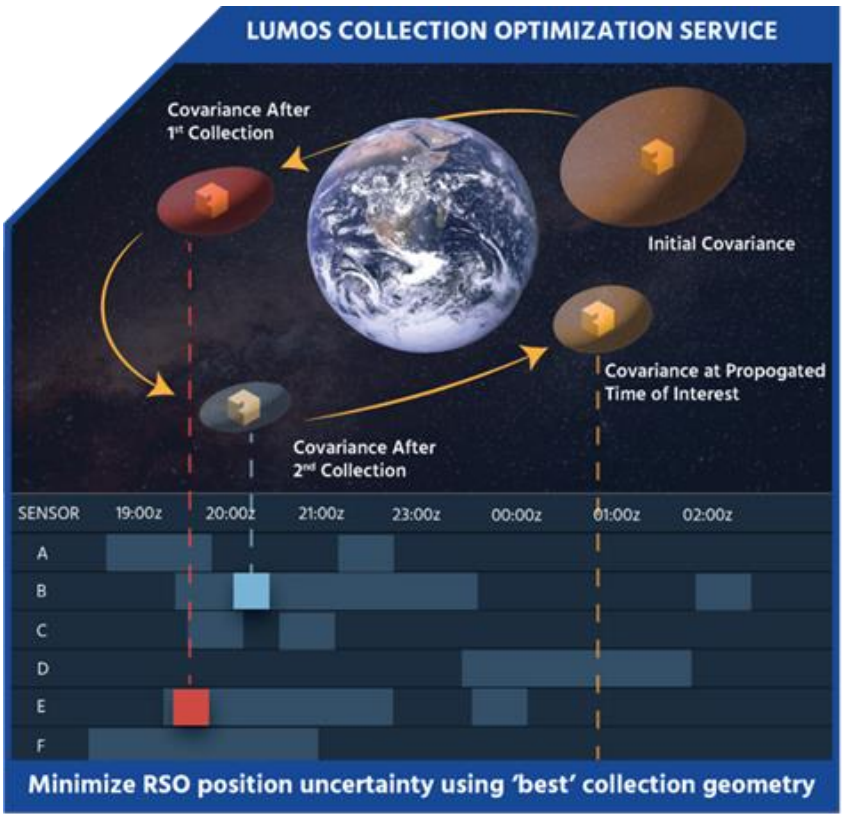

Figure 4: Collection Optimization and Scheduling

It is our experience that it is the best geometry, rather than the volume of observational data that provides the most timely and accurate RSO orbit determination. This service has the added benefit of reducing the volume of observations needed from government and third-party providers that OSC and the TraCSS will likely use. The Lumos Collection Optimization Service is a standalone service within the suite of Lumos tools that can dynamically plan optimal collects for RSO(s) of interest for Electro Optical (EO) space-based and ground-based sensors (Figure 4). It is also undergoing current modifications to optimize radar data as well. Operators can select the level of uncertainty acceptable at specific times of interest for each RSO. The optimization service then dynamically schedules collects across the sensors such that the collects, geometry, sun angles, and time are all optimized for the desired level of uncertainty. In the collection schedule (Figure 4), the resulting collection plan recommended two collects to achieve the desired covariance at the time-of-interest.

The only required data sources are two-line element files (TLEs) to propagate the space-based sensor positions, ground-sensor locations, sensor characteristics, and the initial covariance and state of the RSO(s) of interest. The latter is typically provided as a Vector Covariance Message (VCM). Both the TLE and VCM file formats are well defined file formats within standard SSA processing systems. Additionally, the current sensor schedules can be provided to the optimization service for it to consider additional sensor constraints as well as times where collects are already scheduled.

The Lumos Collection Optimization Service has two selectable optimization algorithms, Monte Carlo Markov Chain and Genetic Algorithm, to find the optimal collection plan. Both optimizers are implemented using the core library of Ray, a Python library that allows for the easy scaling of the algorithms across multiple threads. The UI displays the entire in-view collection opportunities over time in the transparent orange bands, and the optimized collection opportunities in bright orange (Figure 5). Each user input for RSO of interest, collection window and collection requirements is complete with user instructions and amplifications for ease of use. The UI also provides the ability to export the tasking displayed in the UI to a CSV and can easily be updated to output other formats more convenient for providing collection requests to sensors.

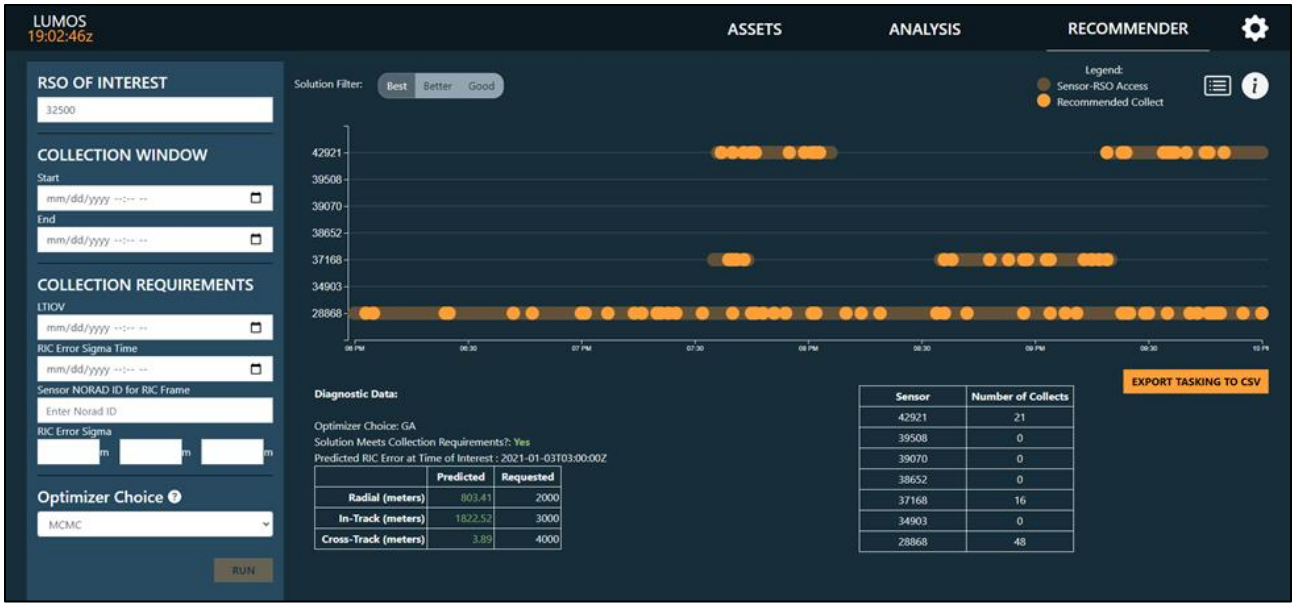

Figure 5: Collection Optimization UI

3.3 Modular Architecture Design and Security

Deploying to an operational framework is inherent in our software design and would be compatible with the TraCSS program. The Lumos suite of capabilities use a microservices architecture for all its components. All the components are containerized and can run in either a Docker compose setting or in Kubernetes It uses Postgres for the database and RabbitMQ for the messaging framework (Figure 6). The UI components are loosely couple and communicate using either ReSTful services or messaging.

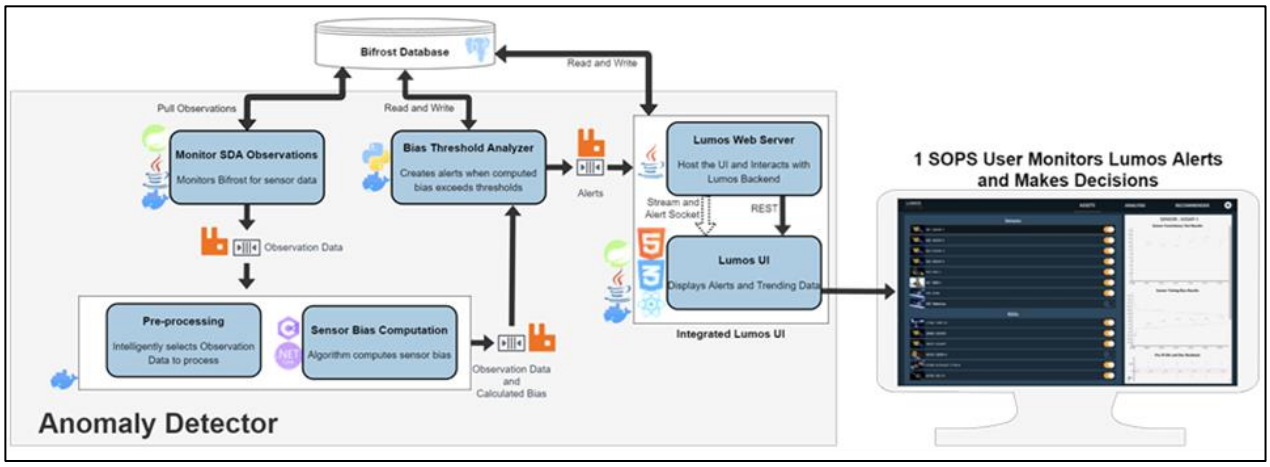

Figure 6: Containerization for Ease of Deployment

Code quality and security are at the heart of Stratagem's development practices. All code intended for operations, whether a service or a library to be used by services, follows the same stringent practices and checks as it moves through automated Gitlab pipelines. All code changes are seen by at least two developers, an author and reviewer. Unit test coverage must exceed 80%, but usually is kept around 90%. Dependency checkers, such as the Open Web Application Security Project's (OWASP) Dependency Check Tool, run on every build. Finally, the code is analyzed by Sonarqube, with the expectation that it will pass all checks with "A" ratings.

Additionally, Stratagem demonstrated the ease of integrating Lumos in other SSA solutions during a demonstration program. In this program, Stratagem leveraged the extensibility of the Microservice Architecture of Lumos to quickly change the data sources to another customer's architecture. This further buys down risk of integrating Lumos in other customer systems

4. Impacts of Proposed Basic SSA Safety Services on Commercial SSA Providers

As a winning component of the USSF first "Fight Tonight" initiative, our Lumos suite of capabilities will enhance the ability of 1SOPS to monitor the quality of data from their space-based sensors used in downstream SSA data processing and optimize sensor collections. The Department of Commerce and the Office of Space Commerce can benefit from this same technology by integrating it into basic SSA safety services and applying it to a wide range of data sources. Sensor providers may individually optimize collection opportunities for their network and individually monitor data quality, but Lumos uniquely ensures DoC can apply these capabilities across multiple platforms, data types and vendors.

Another significant advantage for the government of the Lumos Collection Optimization service is the automated sensor collection schedule designed to achieve pre-planned accuracy requirements for RSO's of interest. This optimization process ensures the only the best data is available for propagated conjunctions from available sensors and reduces the volume of collections needed.

5. Tenets of Participation and Receipt of Basic SSA Safety Services

As part of our integration and follow-on sustainment services, we offer added enhancements to mission essential SSA capability as more numerous, advanced and complex commercial satellite networks and data sources are deployed.

The source code for the Lumos Collection Optimization Service and DQS are available to DoC under SBIR government purpose rights (less IRAD funded improvements for radar data ingestion and other functional improvements). Stratagem supports two pricing models. The first is a development, integration and sustainment model where we would provide a cost for deploying, configuring and maintaining either or both of the services into the TraCSS program during the contract period of performance. We would include any contract specific development and reoccurring maintenance tail. The second model we support is where we would specify a price to OSC for each quality assessment or optimization performed. Depending on the RFP, Stratagem might recommend different strategies. End-users of the improved data would not be charged a fee for use, as it would be a product imbedded in the basic traffic safety services provided.