Testbed to Evaluate New Approaches for STM

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Abstract

Under Space Policy Directive Three (SPD-3), the Department of Commerce (DOC) is taking on leadership of STM. With increasing activities in commercial space in a contested and congested domain, this mandate requires DOC to innovate approaches to space traffic management and its supporting technology to maintain and improve upon DoD's long history of successful, safe, and reliable on-orbit operations. We believe that this is most effectively done using a testbed approach, one that is vertically-integrated and transdisciplinary to ensure that new contributions are recognized, peer-reviewed, and make their way into operations in a transparent fashion from research to operations.

1. Introduction

Today's DoD Space Situational Awareness (SSA)-inspired operational construct and infrastructure lacks a coherent framework for infusing next-generation SSA and Space Traffic Management (STM) technology germinating in today's university research laboratories. In particular, new technologies and capabilities are needed that will enable flexible, enterprise approaches and decision support tools for the evolving needs of commercial space operators and traditional government stakeholders. Universities Space Research Association (USRA), partnered with The MITRE Corporation, an operator of multiple Federally Funded Research and Development Centers (FFRDCs) for the US Government, is assisting the Department of Commerce (DOC) with its STM imperative. A vertically integrated, transdisciplinary approach that ensures that contributions from the broad university research community, coupled with the systems integration and engineering expertise of a trusted FFRDC, are being applied in support of this all-important DOC STM mission.

The impetus for such a collaboration between government, academia, and FFRDCs is the implementation of an open architecture (OA) and data repository, as described in SPD3, that permits ingestion, access, interoperability and exploitation of space data enterprise-wide. Such a system must be capable of supporting operational needs of SSA/STM as well as offering a Research to Operations (R2O) platform that can be utilized to investigate and develop every aspect of the enterprise from the sensor architecture to the operational environment. Further, it must offer an economically viable ecosystem that fosters and incentivizes commercial development in the harsh and congested environment of space. The power of this approach is that it will allow the impacts of crucial developments from every domain to be assessed at the enterprise level by domain experts, furthering our national interests for safe and secure operations in space through innovative research, state of the art technology development and infusion, and economic development.

SPD-3 sets the stage for the creation of an OA data repository, pulling from various SSA/STM nodes, into a data-dependent enterprise architecture. The repository must reduce data integration cost and complexity while retaining ease of data discovery and analytics. Further, it must contain data structures that allow it to be data type- and format-agnostic so any data can be exploited. It must at a minimum:

- Provide data security
- Ensure owner-controlled access to their data
- Persist and expose data in a manner that allows for it to be optimally exploited
- Retain maximum data interoperability that is platform-agnostic
- Provide a means of transparently evaluating the performance of various STM (and other) algorithms' performance
- Be intuitive, easy to use, and allow widespread user discovery/interaction/ingestion of new and existing data sources
- Incentivize data owner participation
- Support three fundamental data distribution methods: Publish/Subscribe (Pub/Sub), Request/Response (Req/Res), and bulk delivery
- Provide ease of access for university researchers and a testbed environment to support a process of continuous improvements

Today, the exemplar of such an enterprise data repository is the US Air Force Space and Missile System Center's Unified Data Library (UDL), providing a relevant model for an enterprise solution. The UDL in its current iteration provides a data agnostic, secure and accessible platform that allows consumers and providers a place to explore, collaborate and utilize data for development of space capabilities. That model could be shared by DOC and DOD, as implied in SPD-3, accelerating a path to STM/SSA enterprise research and development by capitalizing on existing efforts, leveraging the intellectual power of the national university-based S&T community. Utilizing this architectural construct and a data repository, critical research could be conducted on existing and future data streams to provide previously unimagined capability. Ultimately, DOC may choose to use non-DOD approaches, but the UDL is a near-term capability that can be used to develop future STM system characteristics. USRA and MITRE are uniquely experienced to support the development of the STM OA for the DOC, and to advance scholarly, unbiased research and development that is independently evaluated and tested in enterprise relevant environments.

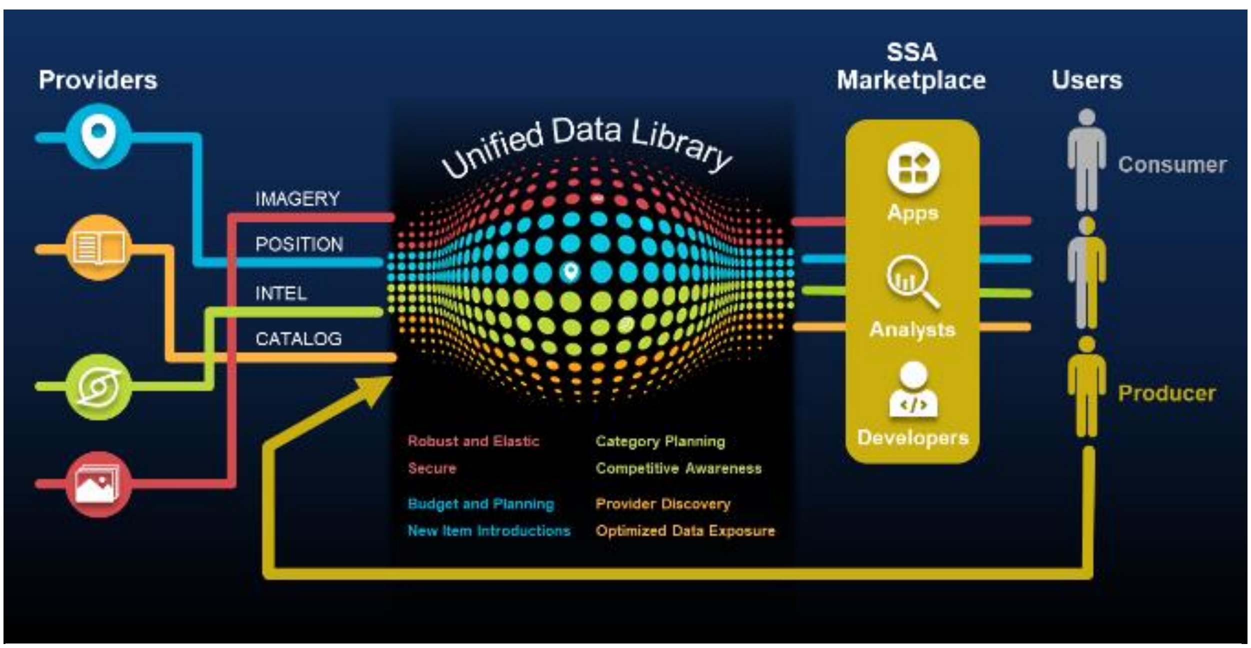

***Fig. 1**. Unified Data Library and data management platform details.*

A simplified representation of UDL is illustrated in figure 1.

This partnership, on behalf of, and in collaboration with the government will infuse DOC strategy, planning, and operations with leading-edge university aerospace technology R&D in astrodynamics, advanced sensors, and intelligent systems to improve DOC mission delivery. What's needed is a cohesive, managed approach to discover, study, test and transition new methodologies to clearly and substantively improve the accuracy and precision associated with orbital ephemerides and covariance realism of these space objects. This improvement will be enabled by new, innovative algorithms, more intelligent data processing, novel tracking filters, and techniques for maneuver detection and characterization in near real time — all necessary ingredients to better inform STM decision makers, operators, to facilitate rapid, highly accurate conjunction assessments, minimizing false alarms in the increasingly congested near-Earth environment. These important aspects of the STM problem are ones particularly well-suited to scholarly research, innovative technology and mathematical approaches and the highly competitive, peer-reviewed university research paradigm. We propose to fully exploit this intellectual richness for the betterment of the DOC STM mission.

2. Process

The Office of Space Commerce, USRA and MITRE have funded a three-month summer pilot of this development model standing up a combined industry-academia collaboration to achieve publishable results.

MITRE provided systems engineering and STM expertise and testbed to prototype and demonstrate these R&D capabilities in simulated and, eventually, real operations. In the future, this open testbed could be made available to the broader academic community and beyond to perform research and encourage collaboration and innovation in areas identified in SPD-3. Key functions include performing systems engineering and integration, addressing characteristics of a future data repository, including: 1) data integrity measures to ensure data accuracy and availability; 2) data standards to ensure sufficient quality from diverse sources; 3) inclusion of satellite owner/operator ephemerides to inform orbital location and planned maneuvers; and 4) standardized formats to enable development of applications to leverage the data. In the future, as DOC identifies its future state conjunction assessment platform, this test environment could then be used to determine how R&D approaches can appreciably improve assessments to make them timelier and more accurate for DOC communications.

USRA served as a bridge into the university community, mitigating barriers created by cultural differences, security concerns, and a lack of shared knowledge. USRA works to translate requirements to maximize the value of important early-stage research being done at universities. USRA has developed and honed its ability to network with universities and convene panels, workshops, and conferences to communicate challenges and create focused agile teams to tackle science and technology development challenges.

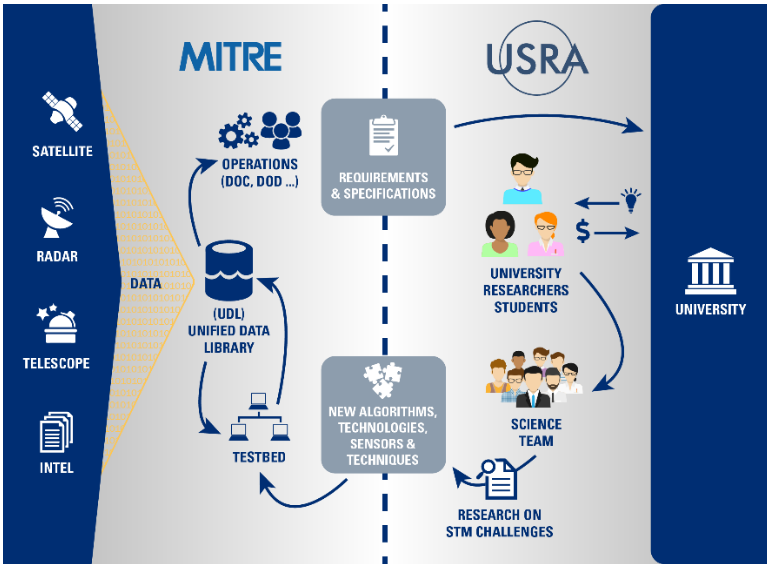

Fig. 2. USRA, MITRE research and development process

3. Results

The pilot focused on reducing the time required to do object launch window calculations and evaluating collision risk over a limited volume in space, with high accuracy. A competitive process identified STM researchers from Purdue University and University of Arizona (UA). Working with MITRE systems engineers, university scientists developed and tested several new approaches. We will report on the process, challenge areas, next steps and research results at AMOS. These new methodologies are briefly outlined below.

UA has developed a brute-force collision prediction algorithm that is parallelizable and can be run on high-powered computing clusters. This leverages a recently developed and validated code that integrates regularized formulations of the equations of motions more robustly than the current state-of-the-art orbit propagators (Amato et al., 2019, CeMDA, 131:21). This is then used to establish a baseline for evaluating various techniques (e.g., Hoots, 1984, CeMDA, 33:143; Gronchi, 2005, CeMDA, 93:295) for the prediction of satellite-satellite close encounters and the estimation of collision probability. UA has furthermore adapted a new approach (JeongAhn and Malhotra, 2017, AJ, 153:235) for calculating collision probability in the highly-perturbed, near-Earth environment.

Purdue has also developed a method that defines a baseline probability surface (as shown in previous work, e.g., for sensor tasking of object populations) as a background. This already structures space and gives the potential insertion trajectory knowledge on dense resp. sparse regions and is one component of the overall risk value. On top of that, actual catalog objects, e.g., from TLEs, are added, and the uncertainties are either hypothesized or used directly, if such knowledge exists. Based on the surface values and actual TLE objects, collision orbits are preselected and handed over for more precise computation.

The advanced simulation capabilities for orbit propagation and collision prediction will validate and augment Purdue's tools. The crossing, high-risk orbits, showing a significant probability of collision from Purdue's probability-surface approach, will then be selected to be numerically propagated using our tools to get the most accurate results. The PC is then recomputed for those orbits as a means of assessing risk.

These new approaches are currently being tested on the TLE catalog, the result of which will be discussed at AMOS. They will eventually be incorporated into the STM OA, allowing for further development and evaluation of the algorithm performance.