A Technical Comparison of the Public SSA Services in the United States and the European Union

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EXECUTIVE SUMMARY

The number of spacecraft in orbit is growing rapidly, providing critical communications, Earth observation, global navigation, and other services to people on Earth. At the same time, the space sector is seeing new entrants and new technologies being developed. This increased activity benefits the global economy and national security, but it also results in increased congestion in orbit and an increased potential for accidental collisions. Such collisions would end the missions involved and generate debris that could pose a risk to other spacecraft. To ensure the safety and sustainability of this environment, it is essential that global spacecraft operators have reliable access to spaceflight safety services.

The European Union Space Surveillance and Tracking (EU SST) and the United States Traffic Coordination System for Space (TraCSS) programs were created to fulfill this need. Both systems provide space situational awareness (SSA) services free of charge to spacecraft owner/ operators around the world. The goal of both organizations is to support spaceflight safety and sustainability. Both organizations also work closely with the commercial SSA industry, leveraging commercial data and/or capabilities in their government systems and encouraging the commercial SSA sector to provide services that augment government-provided SSA safety services. EU SST and TraCSS recognize that for spacecraft operators to effectively use the government services and for commercial SSA providers to develop their market strategies, they require a clear understanding of the services that will be provided free of charge by the government. This study, carried out by officials from EU SST and TraCSS, aims to provide that clarity. It describes the services provided by each of the programs and analyses similarities and differences among them.

Overall, the study finds that the services provided by EU SST and TraCSS are largely in alignment, particularly with respect to in-orbit collision avoidance services. There are some differences, such as U.S. screening of candidate maneuvers related to routine maneuvering, and anomaly reporting. In some areas where differences exist today, the systems may be more aligned in the future; the EU currently provides a re-entry service, while the U.S. plans to provide such services in a future phase of the program. Similarly, the U.S. will provide SSA data and information as a service, and the EU is considering this function for the future. Both systems expect that government service provision will continue to evolve along with the changing needs of the space industry. Therefore, the paper highlights potential services that are currently under consideration or development, such as launch collision avoidance and improved owner-operator ephemeris.

EU SST and TraCSS are committed to working closely with space actors around the world to support the continued safe and sustainable growth of the space sector. This study is intended to be one step toward continued transparency and engagement, and the intention is to continue to work together as a global community to achieve these goals.

1. INTRODUCTION

The space industry is growing rapidly, with new actors, new capabilities, and an increasing number of spacecraft in orbit. These spacecraft play a critical role in the global economy and national security, and they gather information that generates new knowledge of our planet and the space environment. While this increasing activity creates new opportunities, it also creates challenges, including the potential for accidental collisions that generate debris and threaten other spacecraft. For example, the development of large constellations raises the risk of catastrophic collisions that would generate thousands of debris, such as the 2009 collision between the U.S. Iridium-33 and the Russian Cosmos 2251 satellites. Continued growth of the space sector requires a safe, stable, and sustainable environment.

To support global spaceflight safety and sustainability, both the United States and the European Union have committed to providing Space Situational Awareness (SSA) services to spacecraft operators around the world free of charge. These free, publicly-provided services are critical to addressing increasing congestion in the rapidly growing global space ecosystem. SSA services can encompass a wide variety of activities. Both organizations understand that it is important for spacecraft operators to have a clear understanding of the services offered by each of these programs to support operational safety decisions.

In the European Union, these services are provided by the European Union Space Surveillance and Tracking cooperation (EU SST), which was established in 2014 and has been operational since July 2016. Composed of 15 Member States of the European Union , the EU SST Partnership coordinates the development of space surveillance and tracking capabilities and provides public services in collision avoidance, re-entry and fragmentation analysis, relying on Member States capabilities and on European industry and start-ups. As part of the SSA component of the EU Space Programme, EU SST is the key operational capability for the EU's future approach to Space Traffic Management.

In the United States, spaceflight safety and sustainability services will be provided by the Office of Space Commerce (OSC), an office within the Department of Commerce (DOC) National Oceanic and Atmospheric Administration (NOAA). OSC is developing the Traffic Coordination System for Space (TraCSS), blending government and commercial capabilities. The initial version of the TraCSS system is scheduled to become operational by September 2024, providing services to an initial set of beta users. TraCSS uses an agile development process and will continue to add capabilities and additional users over time through a series of phases. The first phase of the TraCSS system will focus on in-orbit collision avoidance services, while future phases will address launch collision avoidance and re-entry services. At present, spaceflight safety services are provided by the U.S. Department of Defense (DOD) via its space-track.org system. DOD will phase out routine provision of SSA safety services to spacecraft operators after a period of overlap with TraCSS operations, in coordination with DOC.

The SSA services provided by government entities are augmented by services provided by a growing commercial SSA sector. Both EU SST and TraCSS are committed to leveraging and supporting this innovative sector. A clear understanding of the free services offered by governments is important for these commercial entities as they seek to support these government systems while developing their own unique service offerings.

This study, jointly carried out by members of the United States TraCSS program and the EU SST program, defines and compares the full set of services that each program intends to provide free of charge to end users as of August 2024, recognizing that both systems will continue to evolve over time. In the case of TraCSS, which is not yet operational, this comparison represents the services TraCSS intends to provide as it enters operations.[1] The functional definitions of each proposed service are provided and the implementation of these services by each SSA provider are described and compared to identify areas of alignment and non-alignment between the two programs, and to highlight any differences in terminology. The study also considers the rationale behind the provision of these services, highlighting alignment with safety and sustainability goals.

[1] Present tense is sometimes used to describe these services for simplicity and flow in this document.

2. INPUTS USED FOR PUBLIC SSA SERVICES

Before turning to a discussion of the services provided by TraCSS and EU SST, it is helpful to have some understanding of the inputs used for the respective systems.

2.1 Sensor Data and Ephemerides Generated from Sensor Data

One of the basic inputs for SSA services is observations taken by sensors, or networks of sensors. Observations can differ in their phenomenology (e.g. radar observations, optical observations, passive RF) and in their geographic location. They may come from a number of different types of organizations, including civil, military, and commercial entities.

The EU SST system uses data from both civil and military sensors operated by its 15 Member States. Today, 97% of measurements shared within EU SST come from military sensors. In addition to data from sensors owned by EU SST member States, the EU SST also purchases commercial sensor data from European Union-owned SSA companies. Sensors located worldwide, from military, civil and commercial origin, contribute data to EU SST. In the near future, EU SST plans to increase its commercial data procurement to reach an equal balance between government and commercial data ingested into the system.

For its initial capability, the U.S. TraCSS system will rely heavily on observations from national security sensors associated with the U.S. Space Surveillance Network, which are collected and processed by the U.S. DOD. The Office of Space Commerce does not receive or analyze these sensor observations directly, but rather receives an unclassified catalog of space objects, including state vectors, from the DOD.

While TraCSS does not presently have the capability to ingest raw sensor data, in the future, TraCSS plans to augment information provided by the DOD with the purchase of ephemerides based on commercial sensor observations. TraCSS could also incorporate ephemerides from sensors operated by international partners.

2.2 Spacecraft Owner/ Operator Provided Information

It is often the spacecraft owner/ operators that have the most accurate information about their own spacecraft and organizations. Therefore, information provided by these entities plays an important role in increasing space safety. Typically, information provided by owner/ operators includes contact information, spacecraft attributes, and owner/ operator ephemerides including maneuver information and associated covariance, if available. Both EU SST and TraCSS collect this information from their registered users.

2.2.1 Operational Contact Information

To facilitate direct coordination and communication among owner/ operators in the event of a conjunction, it is important to have operational contact information – a designated contact that will respond in a timely manner in the event of a conjunction.

The EU SST collects this information from owner/ operators and uses it to communicate directly with owner/ operators in the case of a high interest event (HIE)[2]. The contact information may be shared with other owner/operators in relation to a conjunction with the owner/ operator's permission. EU SST is also examining the possibility of sharing spacecraft operator contact information with the U.S. TraCSS system.

The U.S. will collect this contact information from owner/ operators and make it available to all TraCSS registered users. TraCSS also plans to make owner/ operator information available to other national and regional SSA providers for official purposes.

[2] An HIE is a close approach with a high level of risk potentially requiring a mitigation action from the user.

2.2.2 Satellite Attributes

When registering for SSA services, spacecraft owner/ operators are asked to provide information about their spacecraft such as the size (hard body radius and mass) and maneuverability status. Some information, such as size, is used directly in the conjunction assessment process, while other information can enable quicker coordination among spacecraft owner/ operators in the event of a conjunction. For example, awareness that a counterpart in a potential conjunction is not maneuverable, or has limited maneuverability, may allow for quicker allocation of mitigation responsibility between owner/ operators regarding the event.

Both the EU and U.S. collect this type of information. The U.S. plans to give owner/ operators the option to make the information publicly available or to make it available only to all other TraCSS registered users. EU SST does not redistribute satellite attribute information provided by owner/ operators.

2.2.3 Owner/ Operator Ephemerides, Maneuver Plans, and Covariance

It is often the case that spacecraft owner/ operators have the most accurate information about the location of their spacecraft. They are also uniquely able to provide information about planned maneuvers. This means that owner/ operator ephemerides are an important input into SSA systems, especially with covariance maneuver plans when available.

Both the United States and the EU receive owner/ operator ephemerides for use in conjunction screening. At present, owner/ operators registered in both systems must provide ephemerides to each system independently. Future work could examine options for information exchange among national and regional SSA systems.

When uploading ephemerides and maneuver plans, TraCSS will give owner/ operators the option to make these openly available, consistent with industry best practices. If owner/ operators choose this option, TraCSS will facilitate sharing of this information publicly on a cloud platform. Alternatively, owner/ operators can opt to make ephemerides available only to the U.S. government and all other TraCSS registered users.

EU SST does not currently share owner/ operator ephemerides or maneuver plans publicly or among spacecraft owner/ operators, but this is an important issue that will be considered in the future.

2.3 Auxiliary Information

In addition to sensor data and information provided by spacecraft owner/ operators, there are several additional types of information that are needed as an input to generate state vectors, propagate them to create ephemerides, and carry out conjunction assessments. Some of the most significant types of auxiliary information are described below.

2.3.1 Space Weather Data

Space weather activity can increase the density of the upper atmosphere, leading to increased atmospheric drag that affects the trajectory of spacecraft in orbit. Space weather data and models incorporate this information into predictions of future spacecraft location and conjunction assessment.

EU SST uses information on solar irradiance and geomagnetic activity from the U.S. National Oceanic and Atmospheric Administration (NOAA), while the United States currently uses data generated by NOAA and a U.S. contractor supporting DOD.

The U.S. and EU also differ in the specific space weather models that are used. The United States use the Jacchia-Bowman-HASDIM 2009 (JBH09) model, while the EU uses the Drag Temperature Model 2020 (DTM) and Naval Research Laboratory Mass Spectrometer and Incoherent Scatter Radar 2000 (MSIS-2000) models.

2.3.2 Hard Body Radius

Conjunction assessments are also dependent on information regarding the spacecraft size and mass. To be used in conjunction assessment, spacecraft size is generally translated to a single 'hard body radius' (HBR) value, which can differ significantly depending on the approach.

In the EU SST, the HBR used depends on whether the object of interest is a primary object – an operational spacecraft of a registered user, or a secondary object - space debris, an operational spacecraft of a non-registered entity, or an operational spacecraft of another registered user not considered primary in the current screening. For primary objects, EU SST uses hard body radius information provided by owner/ operators regarding their own spacecraft. This information is compared with the information provided in the DISCOS database to ensure consistency. If owner/ operator provided information is not available or for secondary objects, the EU relies on the publicly-available ESA DISCOS database for spacecraft size information. If no information is found in DISCOS, EU SST uses information provided in U.S. CDMs. And last, if none of the available sources contains specific information, default values are set based on the U.S. DOD SATCAT. HBR is sometimes modified for specific conjunctions, if the attitude is known. In the future, EU SST will explore how to make use of the NASA database for obtaining spacecraft size information.

The TraCSS system currently relies on estimates of HBR developed from DoD sensor information (for example radar cross section which can be used to estimate HBR). Another source of information is the NASA hard body radius database. NASA developed this database of size and mass information that uses information derived from the DoD sensors to estimate the size of debris objects and combines the DoD derived values with information from the DISCOS database. The NASA hard body radius database is publicly-available. As noted above, TraCSS is also planning to collect information on spacecraft size and mass directly from satellite owner/ operators. This information would be made available to the U.S. government and registered TraCSS users and may also be made available to the public, depending on owner/ operator permissions.

2.3.3 External Spacecraft Catalogs and/or CDMs

EU SST uses the U.S. Department of Defense (DOD) special perturbation catalog and U.S. Department of Defense (DOD) conjunction data messages (CDMs) as inputs into the system.

TraCSS relies on the U.S. Department of Defense (DOD) special perturbation catalog with covariance information as the foundation for its conjunction assessment process, as it does not operate its own sensors. It does not use the DOD CDMs, or CDMs from any other system.

2.4 Database/ Data Repository

A database or data repository can be used to hold the many different types of data that are utilized in an SSA system. For example, the data collected by different sensors is ingested into a central database, along with appropriate sensor metadata (e.g. sensor ID and location, time of observation).

EU SST maintains a central database of this type. The data collected by each Member State's sensors and sensors' data procured from commercial actors are gathered in the EU SST Database. The EU SST database is used as an internal data sharing platform for EU SST Member States. The exchange of SST data and information within EU SST is governed by an adequate data policy that takes into account security constraints. The EU SST database is the central node for exchanging sensor data, but other important information is also stored and can be retrieved from there – including, for example, sensors parameters, location, and other main features important in the orbital determination process. The EU SST database addresses technical challenges such as overlap of the data, data format, timeliness and compliance with international standards formatting. Besides this important information, the EU SST Database is at the core of SSA data exchanges and it is used, for example, to issue tasking requests and send observations plans to the sensors.

TraCSS will maintain the TraCSS OASIS Data Repository. OASIS will store and manage data from a variety of sources, including the U.S. DOD, commercial SSA providers, and global spacecraft operators. This government data repository will comply with U.S. cybersecurity requirements.

2.5 Catalog of Space Objects and Information

Sensor data is fused and combined with other sources of information to generate a catalog of space objects that includes a designator number (e.g. COSPAR ID[3] and/or NORAD ID), the satellite name, and other information about the spacecraft. The catalog can include spacecraft attributes, such as launch date, launch location, apogee, perigee, period, inclination, hard body radius, as well as information on the spacecraft location (e.g. TLEs, state vectors, and ephemerides) and location uncertainty (covariance).

EU SST generates its own catalog information based on sensor observations. This catalog consists of a set of unclassified objects identified by the NORAD ID and/or the international designator (COSPAR ID). Associated to these objects are the orbits in OEM format according to CCSDS standards and their associated covariances. This catalog of objects is updated regularly as new sensor observations are collected. It is shared in real time within the EU SST Member States, however currently it is not publicly shared. This catalog includes both ephemeris information provided by the EU SST CA users from the primary spacecraft and external ephemerides from public sources (i.e space-track.org). Additionally, Member States can rely on their own computation of catalogs that might contain classified information.

In the United States, the term "catalog" is commonly used to refer to several different products. In the United States, the "authoritative catalog" is maintained by the Department of Defense. This includes a list of satellite names correlated to a designator number (COSPAR ID and/or NORAD ID) and basic orbital information for each spacecraft. The unclassified version of this catalog is provided to the Department of Commerce for use in TraCSS.

The DOD satellite catalog (SATCAT) includes additional information about the spacecraft, including launch date, launch location, apogee, perigee, period, inclination, and an estimate of the hard body radius. In addition to this information and the data provided by the DoD, TraCSS will incorporate additional information into its OASIS data repository. This will include additional attributes of the spacecraft provided by owner/ operators, such as maneuverability, mass, and hard body radius. The OASIS data repository will also include operational point of contact information for each spacecraft, whenever possible. Some of the data resident in the OASIS data repository will be made available to the public; some of the data will be restricted to registered users.

The DoD also maintains a general perturbation dataset, which provides basic information on the trajectory of spacecraft of all object types, provided in the element set or Two-Line element (TLE) set format, commonly referred to as the TLE catalog. In addition, the DoD also maintains a high accuracy catalog, consisting of state vectors generated using a special perturbation model, both with and without covariance information, which provides information on the uncertainty of the data. The general perturbation dataset will be made publicly available on the TraCSS website.

The short descriptions of key input information within Section 2 demonstrate that both the EU SST and TraCSS are built largely on the same types of data and information, although the specific inputs may differ. It also demonstrates that while both programs are government systems, they both intend to incorporate data or information purchased from commercial SSA providers, and they both encourage provision of data by spacecraft operators. In the future, EU SST and TraCSS may consider sharing some of the input information to improve coordination between the two SSA systems.

[3] The International Designator, also known as COSPAR ID, is an international identifier for space objects.

3. PUBLIC SSA SAFETY SERVICES

EU SST and TraCSS are both committed to providing services to spacecraft operators free of charge to support spaceflight safety and space sustainability (Table 1). The following section describes these services in detail and discusses whether each service is provided by one or both systems.

Table 1 EU SST & TraCSS Services Comparison Summary Table (as of August 2024)

		EU SST	TraCSS
1. SSA information as a service			
1. Contact information		No	Yes
2. Satellite attributes		No	Yes
3. O/O ephemerides with planned maneuvers		No	Yes
4. Catalog of space objects		No	Yes
2. In-Orbit Collision Avoidance service:			
1. Routine catalog and O/O ephemerides screening and CDM production		Yes	Yes
2. Risk Assessment[4] and Detection and Notification of High Interest Events/Emergency Events		Yes	Yes
3. Additional tracking on the secondary and/or primary objects		Yes	Yes
4. Basic CAM Options for selection by O/O[5]		Yes	Yes
5. Candidate CAM Screening		Yes	Yes
6. For selected HIE/ Emergency Events, dialogue with O/O		Yes	Yes
3. Candidate Maneuver Screening		No	Yes
4. Spacecraft Anomaly Reporting		No	Yes
5. Reentry Monitoring Service		Yes	Future Phase
6. Fragmentation Notification and Analysis Service:		Yes	Yes (Notification only)
7. Potential Future Services Under Consideration			
1. Launch Collision Avoidance service		TBD	Future Phase
2. Improved O/O Ephemerides		TBD	TBD
3. Space Weather Information and Atmospheric Drag Model		No	TBD
4. Traffic Coordination Platform as a Service		TBD	TBD

[4] Additional risk assessment tools are provided, such as Risk Assessment Evolution Plots, Sensitivity Analysis Plots and Space Weather Sensitivity Plots.

[5] The Collision Avoidance Maneuver options consist of a trade-space plot of possible collision avoidance maneuvers that is based on basic assumptions about the maneuver capabilities of the spacecraft and not tailored to individual spacecraft capabilities, missions, or preferences. The determination and selection of the maneuver is made only by the owner/ operator.

3.1 SSA Information as a Service

Product Provided to Users:

- TraCSS satellite database (US)
- Owner/ operator contact information (US)
- TLE data set (US)
- Owner/ operator ephemerides (US)

The TraCSS program will make available a variety of input information to spacecraft operators. TraCSS registered users will have access to a satellite database with information about spacecraft, such as their NORAD ID, international designator, basic orbital information, and attributes provided by spacecraft owner/ operators. TraCSS registered users will also have access to spacecraft owner/ operator contact information, owner/ operator ephemerides, and TLEs. A subset of this information will also be made publicly available, consistent with the TraCSS data policy and user agreement.

Access to this information allows spacecraft operators to carry out additional analysis and independent examination of the orbital environment, thus promoting spaceflight safety. Publicly-provided information further supports independent research, analysis, and development in the academic, non-profit, and private sector, leading to new knowledge and capabilities as well as supporting innovation and entrepreneurship.

In the future, EU SST plans to make some EU SST catalog information available. It is still under discussion what subset of information, under which format and with what frequency this information will be shared.

3.2 In-Orbit Collision Avoidance Service

Perhaps the most important service offered by government SSA systems is support for collision avoidance. This service includes a number of discrete elements: from routine screenings that generate information to additional notifications and interactions with spacecraft operators to ensure spaceflight safety. This service is provided worldwide free of charge to the registered users of the systems.

3.2.1 Routine catalog and O/O ephemerides screening and CDM production

Product Provided to User:

- *CDMs (including P_c) for their spacecraft (US and EU)*

In order to identify potential conjunctions for a given spacecraft (the primary object), it is necessary to examine the predicted future path of the primary spacecraft in relation to the predicted future path of all other objects in their catalog to determine whether any objects come within a designated physical volume, i.e., screen primary objects against a robust satellite catalog. The screening results in Conjunction Data Messages (CDMs) for objects within the screening volume.

In cases when owner/ operator ephemerides are provided, these are screened against each other and against the rest of the objects. This process also generates CDMs. Thus multiple CDMs for the same conjunction event (for example, catalog vs. catalog; catalog vs ephemeris; ephemeris vs. catalog; ephemeris vs ephemeris, etc), are produced. To assist satellite owner/operators in deciphering the results, a "primary" CDM can be identified. Although it is challenging to definitively conclude which CDM is most accurate, the "primary" CDM can be determined using basic decision rules based on the typical fidelity of the data sources used. One such method, used by EU SST, is described below.

Both the EU and U.S. systems incorporate data quality monitoring into these processes to ensure consistency and accuracy of the results. This data quality process might lead to acquiring additional tracking data or information when necessary. [Process described in section 3.2.3]

The EU screens user-registered spacecraft against the EU SST catalog as well as the U.S. high accuracy catalog without covariance, twice a day. The cadence is based on the fact that typically, owner/ operators provide ephemerides once a day. More frequent screenings are carried out when additional information is received (e.g. if a user sends updated ephemerides). All vs. all screening is done once a day.

For primary objects, EU SST uses ephemerides provided by the O/O of the spacecraft. If ephemerides cannot be provided by the users, EU SST uses information from the SP catalog or directly from U.S. CDMs (whichever is the most up-to-date). For the secondaries, EU SST uses either autonomous information from its catalog, or U.S. CDM information (whichever is more reliable for each conjunction).

With the goal of detecting risky conjunctions, EU SST also re-analyzes CDM information coming from the U.S. that involves the spacecraft of EU SST registered users. This analysis includes: 1) Update the information of the primary ephemerides including covariance, 2) incorporate updated HBR for primary objects, and 3) recompute probability of collision (Pc) miss distance, and radial distance. This process generates additional CDMs as an output. EU SST uses Pc methodologies that are specific to each type of conjunction (i.e low relative speed encounters).

EU SST determines which CDM is considered “primary” for provision to the user based on an understanding of the typical reliability of various data sources, although this process may be updated in the future [1]. The reliability analysis is executed at each screening time, so the data sources used to generate the CDM provided to the user may change at each screening time.

In both the EU and the U.S., the screening includes data integrity monitoring of ephemerides ingested into the screening tool as well as the CDMs output. Both organizations provide CDMs that comply with CCSDS standards, using all mandatory fields. Both organizations also regularly include the probability of collision, which is not a mandatory field.

In addition to calculating the Pc, EU SST generates a “scaled probability of collision,” which involves carrying out a sensitivity analysis to consider the “uncertainties of the uncertainties” (namely, uncertainty of the covariances themselves) associated with the CDM information.

For the U.S., active satellites will be screened on a 4-hour cadence. All vs. all screening (which also assesses debris on debris conjunctions) will be done once per day. In early phases of TraCSS, screening will be based on the unclassified DoD high accuracy catalog with covariance and O/O submitted ephemerides. In the future, the catalog may include data from commercial and/or foreign entities. The U.S. intends to indicate a ‘primary’ CDM, but the process for doing so has not yet been finalized. The U.S. is also seeking to improve the Pc calculation with improved methodologies for the specific conjunctions to ensure a reliable Pc is always provided in the CDM.

3.2.2 Risk Assessment and Detection and Notification of High Interest Events/ Emergency Events

Products Provided to User:

- *HIE Flag on CDMs (EU)*
- *Notifications to spacecraft owner/ operators involved (EU and US)*
- *Notifications posted to TraCSS website (U.S.)*
- *Risk Evolution Plot (EU and US)*
- *Space Weather Sensitivity Plot (US)*
- *Conjunction consequence information (U.S.)*

After the CDMs are generated for a given conjunction, additional risk assessment is conducted, and it is determined whether they meet criteria for further action. These criteria typically include time to closest approach, probability of collision, and geometry (miss distance and radial distance). In addition to providing individual CDMs, additional information and visualizations may be generated to aid in risk assessment.

The EU separates the CDMs into three groups, 1) High Interest Event (HIE): close approaches with a high level of risk potentially requiring a course of action from the user, 2) Interest Event (IE): close approaches that require further analysis, and 3) Information (INFO): close approaches with a low level of risk but within the screening volume. If only one, or a subset, of the CDMs produced in relation to a given event meet the criteria for HIE, then these are further analyzed to determine whether additional tracking and/or a maneuver is necessary, based on the time and information available. If the primary CDM is designated as a high interest event, then the CDM will be flagged for the user, and an email alert will be sent to the user.

Similarly, the U.S. will set criteria for a threshold that defines an "Emergency Event." When an event is determined to meet this threshold, the spacecraft owner/ operators will be notified, and a notification of the event will be posted publicly on the TraCSS website.

The basic concept between the definition of an HIE and an Emergency Event is similar – the identification of a conjunction event above a given threshold for risk. However, the implementation of these concepts, including the determination of the threshold and/or the process for identifying these events may differ. For both systems, identification of an HIE/ Emergency Event also leads to additional actions, as described below.

In terms of information and visualizations for the user, both the U.S. and the EU provide risk evolution plots that show how the miss distance and probability of collision have changed over time with each subsequent screening. This helps owner/ operators understand how the risk is evolving as the time of closest approach draws nearer. In addition, EU SST provides a version of this plot focused on the evolution of the scaled Pc.

The U.S. also plans to provide information that helps spacecraft operators to understand how sensitive the prediction is to the space weather mismodeling (i.e. the sensitivity of the P_C to atmospheric density forecast error). In addition, information from a NASA-developed tool will provide operators with an estimate of the number of trackable fragments that would be generated if a collision were to take place because of a given close approach. Estimating the amount of debris that will be created can help operators identify situations that may warrant additional consideration and potential action, even if they are below typical probability of collision thresholds of concern.

3.2.3 Additional tracking on the secondary and/or primary objects

Products Provided to User:

- *Notification to user that additional tracking is being requested and time updated CDM is expected to be available (U.S.)*
- *Updated CDM taking into account new data, if relevant (US and EU)*

It is sometimes possible to conduct additional tracking of an object involved in a conjunction event to improve that object's predicted state at the time of closest approach. This improved information can produce a higher-fidelity CDM (i.e. greater certainty with regard to the probability of collision and miss distance associated with the event.)

In the EU, additional tracking is requested for both primary and secondary objects. For a primary object, additional tracking would be requested if the owner/ operator ephemerides are of insufficient quality or not available. For a secondary object, additional tracking requests are considered for every HIE when the secondary is a non-active spacecraft. If the secondary is an object that the EU sensor network is capable of tracking, a tasking request is sent to the EU sensor network composed of military, civil and commercial sensors, and prioritized.

EU SST makes use of a coordinated scheduler to optimize the data collection of the EU sensor network, based on availability and sensors' performances and capabilities, as well as detection opportunities. Despite this, in some cases, it may not be possible to collect enough data to compute a higher quality ephemeris. For this reason, users are not always informed when EU SST makes a tracking request. However, for every HIE, if the collected data as sufficiently improved the object's orbit and the conjunction assessment result, users are sent an updated CDM with up-to-date data to inform them of the new risk level of the event.

In the U.S., additional information may be procured when a CDM is generated in which the ephemeris of one or both objects is deficient. In these cases, TraCSS will purchase updated ephemerides from the commercial SSA sector, and this new ephemeris will be used to generate a new CDM. If an updated ephemeris is being sought, TraCSS informs the user involved in the conjunction that additional information is being procured. This allows the owner/ operator to update their decision-making plan regarding the conjunction event.

3.2.4 Basic Collision Avoidance Maneuver Options for selection by O/O

Products Provided to User:

- *Collision Avoidance Maneuver Trade-Space Plot (EU and US)*

When a conjunction of concern has been identified, spacecraft operators may choose to develop a collision avoidance strategy, which may involve a maneuver that will reduce the probability of collision to an acceptable level. Collision avoidance maneuver (CAM) options may differ based on the capabilities of the spacecraft, preferences of the spacecraft operator, the time of the maneuver, and the length of time of the burn to undertake the maneuver.

However, it is possible to generate a maneuver plot showing a trade-space of possible collision avoidance maneuvers that is based on basic assumptions about the maneuver capabilities of the spacecraft and not tailored to individual spacecraft capabilities, missions, or preferences. These maneuver plots simply show the relationship between the time of the maneuver (relative to the time of closest approach) and the amount of effort required to perform a maneuver in space, namely delta-v burn, necessary to lower the risk of collision to a given level.

This information helps to inform the spacecraft operator that there are options to mitigate the risk of collision, without optimizing this choice or directing towards a particular action. This allows the user to make an informed decision to ensure operational spaceflight safety. Both EU SST and TraCSS provide this information to spacecraft operators for conjunction events of concern (i.e. HIE or Emergency Events).

3.2.5 Candidate Collision Avoidance Maneuver Screening

Product Provided to User:
- *CDMs (including Pc) related to the candidate collision avoidance maneuver (US and EU)*

When a spacecraft operator is planning to carry out a collision avoidance maneuver, they can submit a spacecraft ephemeris that includes the planned maneuver, and it will be screened to identify any potential conjunction that would occur if the maneuver was carried out. This allows spacecraft operators to ensure that their planned maneuver will not generate an additional conjunction situation in the process of clearing the original conjunction.

The EU SST and U.S. TraCCS system both provide this service. In the EU, this is done on a near-real time basis, with the screening occurring within 30 minutes of submission of the candidate maneuver plan ephemeris. In the United States, the candidate maneuver plan ephemeris would be screened as part of the regular screening cadence.

3.2.6 For selected HIE/ Emergency Events, dialogue with O/O

Product Provided to User:
- Response requested from spacecraft operators (EU and US)
- Selected Dialogue with Spacecraft Operators (EU and US)

For conjunction events of particular concern, it is valuable to confirm whether the spacecraft operator(s) involved have received the notifications and information provided about the event and to understand how the spacecraft operator(s) plan to respond. (Noting that a response may include either a planned collision avoidance maneuver or a decision not to maneuver.) During this process, some spacecraft operators may benefit from one-on-one interactions with the SSA provider. For example, less experienced operators may need additional assistance to understand the notifications or other information provided for a particular conjunction event.

When an HIE is predicted, if the spacecraft is capable of maneuvering, EU SST will send an email to the spacecraft operator a few days in advance to alert them of the risk and suggest that they take some mitigation action, as noted above. Spacecraft operators can respond to acknowledge receipt of the HIE notification and provide their plans to mitigate the risk. This could include a planned collision avoidance maneuver, adjustment to a previously planned station-keeping maneuver, or taking no action while the other spacecraft involved undertakes a maneuver (if this has been discussed and agreed). In some cases, EU SST also offers to engage in dialogue to discuss the possibilities for mitigating the risk. This dialogue can occur via phone, email, or messaging with the user. EU SST also follows up with the spacecraft operator after the maneuver to confirm that a maneuver took place and whether it was one of the set of proposed maneuvers provided by EU SST.

Similarly, in the case of Emergency Events, TraCSS will request that spacecraft operators involved to provide TraCSS with their planned response. In some cases, TraCSS may also initiate dialogue with owner/ operators. This engagement may occur via phone, email, or other mode, at the discretion of TraCSS.

3.3 Candidate Maneuver Screening

Product Provided to User:

- *CDMs (including Pc) related to the candidate maneuver (US)*

Spacecraft operators routinely maneuver their spacecraft for a variety of reasons, such as station-keeping to maintain their orbit. In advance of these actions, spacecraft operators may choose to screen candidate maneuvers to ensure they will not result in the creation of new conjunction events. TraCSS provides candidate maneuver screenings on a regular cadence, for a limited number of candidate maneuvers. EU SST does not currently provide this service.

3.4 Spacecraft Anomaly Reporting

Product Provided to Users:

- *Anomaly reporting (U.S.)*

Spacecraft may experience anomalies or non-nominal conditions on orbit. Reporting these situations to SSA providers can improve spaceflight safety by alerting the providers of potential issues on orbit, allowing them to take steps to ensure they can maintain custody of the object (i.e. ensure that sensors continue to be able to locate and track the object). Positional information generated from observational sensors can be valuable to spacecraft operators if they need to re-establish communication with their spacecraft or as they otherwise investigate the anomaly.

TraCSS will encourage spacecraft operators to report such events. Spacecraft position information (e.g. TLEs) will continue to be shared via the TraCSS website on the regular cadence. EU SST does not facilitate anomaly reporting.

3.5 Reentry Monitoring Service

Product Provided to Users:

- *30 day reentry list (EU)*
- *Reentry report (EU)*

TraCSS is not providing re-entry monitoring services in its Phase 1 release, so the details of these services are not yet defined.

EU SST delivers a Re-Entry Analysis Service consisting of providing a risk assessment of uncontrolled re-entry of man-made space objects into the Earth's atmosphere and generating related information. The objects that are monitored are rocket bodies, objects of interest and objects with a mass greater than 2000Kg – or, if no mass information is available, with a radar cross section larger than $1m^{2.}$ Information regarding re-entries is added to a 30 day re-entry list; between 4 and 3 days before a re-entry event, more information on the specific re-entry is provided in a re entry report. At the time of publication of the present paper, this service is provided free of charge for EU registered users.

3.6 Fragmentation Notification and Analysis Service

Product Provided to Users:

- *Break-up Notification (US)*
- *Fragmentation Analysis Information Product Notifications (EU)*

When a break-up or fragmentation event occurs, the EU sends a notification to all registered users called a "short-term" notification. The EU Fragmentation Service Analysis is then used to propagate forward the effects of such a break-up or in-orbit collision after it has occurred to predict where the debris will be in the future in the mid- and long-term, and additional notifications are sent out with this information. (Eventually, these debris objects will be added to the catalog and propagated, but this process typically takes several weeks or longer.) At the publication of this paper, this service is provided free of charge for EU registered users.

The DoD generates break-up notifications when an object in space generates significant additional pieces of debris. TraCSS will mirror these DoD notifications.

3.7 Potential Future Services Under Consideration

There are some areas in which the U.S. and EU are aware of ongoing challenges in which public services could improve spaceflight safety, but which are not sufficiently understood or developed for those services to be offered in the near-term. This section highlights four areas where government SSA providers are investigating issues that could lead to additional services in the future.

3.7.1 Launch Collision Avoidance Service

Launch collision avoidance services allow entities planning a launch to identify and examine any potential conjunctions associated with the proposed launch trajectory.

TraCSS has not determined what services will be provided for launch collision and the immediate transition from launch to orbit. TraCSS will be coordinating with the Department of Transportation and DoD to define the services for this phase.

EU SST is still determining whether it will provide pre-launch conjunction assessment. However, in Europe there are existing national capabilities to provide this service. France is providing launch collision avoidance service for the launches from French Guyana, as part of the compliance with national regulations.

3.7.2 Improved Owner/ Operator Ephemerides

TraCSS and EU SST recognize the value of high-quality owner-operator ephemerides with covariance and maneuver plans for spaceflight safety, but also acknowledge that reliable generation of this information is a challenge for some operators. TraCSS is examining a wide range of potential methods for assisting operators in this effort.

3.7.3 Space Weather Atmospheric Drag Model

TraCSS recognizes that space-weather induced perturbations to atmospheric density have a significant impact on conjunction risk. TraCSS is working with researchers at NOAA to develop a new space weather atmospheric drag model that can be used within TraCSS and by owner/ operators to improve the accuracy of orbit determination and ephemerides generation.

3.7.4 Space Traffic Coordination Platform as a Service

EU SST and TraCSS both provide some services that allow or encourage spacecraft owner/ operators to provide information about their planned response to a conjunction event, particularly when the risk is high. In cases that involve two active spacecraft, space safety requires a coordinated response between the two operators.

At present, EU SST maintains a communication and coordination platform, where only registered EU SST users to the system can exchange information over a potential conjunction. It is not currently accessible to spacecraft operators not registered in EU SST. The role of EU SST is to provide accurate information but not to interfere in the decisions of the two actors involved. This platform is set up to help coordination, and to promote and encourage transparency and accountability in the framework of detected risks.

Several space industry entities and organizations are also examining best practices and technical solutions for this type of coordination. EU SST and TraCSS are both aware that major national and regional SSA providers may have an important role to play in helping to facilitate this coordination in the future, although at present, a specific solution is not well defined.

4. DISCUSSION AND CONCLUSIONS

Both the United States and the European Union have committed to providing SSA services free of charge to spacecraft operators around the world to support spaceflight safety and sustainability. This study aimed to provide clarity to spacecraft operators, commercial SSA providers and others in the space sector with respect to the services offered by EU SST and/or TraCSS, highlighting the similarities and differences in the offerings of each system. This exercise allows spacecraft operators to understand how these services can best be incorporated into operational safety decisions and enables commercial SSA providers to develop and differentiate their services from those provided by governments. The information may also be of benefit to other government SSA programs as they consider their own provision of services.

This joint study demonstrated that there is significant alignment in the way that EU SST and TraCSS have defined and will be implementing their public SSA services. In particular, the components of the respective collision avoidance services are very similar. Differences are seen in the U.S. provision of SSA data and information as a service, candidate maneuver screenings for routine maneuvers, and anomaly reporting – which are not provided by the EU. In both cases, future evolutions of the systems could lead to broader alignment. For example, EU SST is considering releasing a subset of the EU catalog at a future stage. Similarly, EU is currently providing re-entry services, and TraCSS plans to add such services at a later phase of development. Both have limited launch collision avoidance services at present, but plan to examine these in the near future. Each of these issues could be a good topic for future joint studies.

Further, both organizations recognize that the development and provision of SSA services for spaceflight safety and space sustainability require ongoing evaluation and evolution to match the evolving needs and capabilities of the space industry. In particular, TraCSS and EU SST recognize specific challenges related to the reliable provision of high-quality owner/ operator ephemerides with planned maneuvers, as well as improved incorporation of space weather information. In addition, both organizations also see an important role for the commercial SSA ecosystem that is developing innovative solutions at a fast pace. To foster the consolidation of this ecosystem, both systems intend to increasingly rely on and leverage commercial capabilities.

This study also demonstrated that while these two programs were developed and are operated independently, it was productive to come together to systematically compare the two systems. It is worth noting that this process was not quick or simple. The joint study required significant time and effort from policy and technical experts from both programs to address issues related to terminology, process, rationale, and implementation details. However, ultimately resulted in significantly improved understanding among the two systems. Knowledge and information sharing also supported more informed development and decision-making within each system and greater transparency and understanding for external actors, as well.

While this study focused on existing system inputs and services, there are other joint studies between OSC and EU SST that are exploring how data exchanges and data fusion can contribute to better collision avoidance solutions and improve covariance realism. These other studies find that technical cooperation can have a significant improvement of the quality of the SSA products and services that support spaceflight safety. [2][3]

In addition to these studies, there are many other issues that could be addressed in future research between TraCSS and EUSST. For example, discussion of architectures, processes, and algorithms could provide further insight into the similarities and differences between these systems. Alternatively, a systematic analysis could be performed to determine how TraCSS and EUSST could exchange information in support of the SSA services identified here. TraCSS and EUSST could also further investigate the similarities and differences between their implementation of High Interest Events and Emergency Events. Additional discussion by both EU SST and TraCSS of the potential future services under consideration listed here could also be beneficial.

Future studies could also incorporate additional national or regional providers, expanding information sharing and coordination. Studies could focus on how coordination takes place among national and regional SSA providers, including operational information exchanges that support global spaceflight safety and sustainability. In addition to comparing the types of services provided, future studies could examine how national and regional SSA providers could compare and better align the information output by their systems, helping to provide more consistent guidance to spacecraft operators.

Ultimately, this study aimed to provide important insight into two of the largest public space situational awareness programs in the world, bring greater clarity to the broader space community regarding the future of space safety services and facilitate international discussion. Spaceflight safety and sustainability are critical to the continued growth of the space sector, and continued engagement and coordination among the global space community is essential for achieving that goal.

5. LIST OF ACRONYMS

CA	Collision avoidance
CAM	collision avoidance maneuver
CDM	Conjunction data message
DOC	Department of Commerce
DOD	Department of Defense
ESA	European Space Agency
EU	European Union
EU SST	European Union Space Surveillance and Tracking
HBR	hard body radius
HIE	High Interest Event
IE	Interest Event
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
O/O	Owner/ operators
OSC	Office of Space Commerce
Pc	Probability of collision
SATCAT	Satellite Catalog
SSA	Space Situational Awareness
TLE	Two-line element set
TraCSS	Traffic Coordination System for Space
U.S.	United States

6. REFERENCES

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[3]Felix Hoots, Valentin Baral, Alejandro Cano, Santiago Martinez, Matt Hejduk. "International Sharing of Satellite Tracking Data for Improved Orbital Safety." *AAS/AIAA Astrodynamics Specialist Conference*. (2024).