Advancing Concepts for Global Coordination on SSA

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1. INTRODUCTION

There are multiple independent national and regional space situational awareness systems around the world. These systems use sensors to track objects in space, estimate their present and expected future location, and identify any close approaches between two objects that could potentially result in a collision. Advanced warning of these potential collisions allows spacecraft operators to determine whether it is necessary to carry out a maneuver to avoid a potential collision and coordinate with counterpart operators, if necessary. These services are essential to global spaceflight safety and sustainability. However, each of these systems uses different data sources and different algorithms and processes, and thus, they can be expected to produce at least somewhat different solutions. To minimize the extent to which spacecraft operators receive conflicting information, it is important to facilitate coordination and information sharing among these systems. However, there are many questions about what international coordination could or should entail. What types of information should be shared, and why? What are the highest priorities for information sharing and coordination? What procedures might be needed to enable coordination? This joint study advances our understanding through a case study of cooperation between the European Union Space Surveillance and Tracking Partnership (EU SST) and the United States Traffic Coordination System for Space (TraCSS).

For the purposes of this paper, we use the term "data" to refer to raw or minimally-processed sensor data or measurements, such as that provided in tracking data message (TDM) format. More highly-processed products, such as ephemerides or conjunction data messages are referred to as information.

The European Union Space Surveillance and Tracking cooperation (EU SST) was established in 2014[1] and has been operational since July 2016. Composed of 15 Member States of the European Union[2] as of July 2025, 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 well as on the European Union Agency for the Space Programme (EUSPA) as Front Desk. As of 1st January 2023, EU SST has opened the public collision avoidance service to spacecraft operators around the world beyond users from the European Union to support global spaceflight safety. 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.

The United States is currently developing the Traffic Coordination System for Space (TraCSS) to provide spaceflight safety services to spacecraft owner/ operators around the world free of charge in support of global spaceflight safety. TraCSS became operational in September 2024, providing initial services to a set of beta users. The system is expected to become operational and open to all spacecraft owner/ operators following the production release in January 2026.

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[1] Decision No 541/2014/EU of the European Parliament and of the Council of 16 April 2014 establishing a Framework for Space Surveillance and Tracking Support. https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32014D0541

[2] As per partnership agreement signed on November 2022: Austria, The Czech Republic, Denmark, Finland, France, Germany, Greece, Italy, Latvia, The Netherlands, Poland, Portugal, Romania, Spain and Sweden

During this development and transition phase, free global SSA services continue to be provided by the U.S. Department of Defense (DOD) via its space-track.org system.

When thinking about what information needs to be shared to enable international coordination between SSA systems, we find it useful to distinguish between two important, but distinct, types of information sharing: programmatic and operational. Programmatic information includes information about how an SSA system works. This includes non-sensitive information about the processes, procedures, and standards used by the system, including clear descriptions of these elements as well as information about the underlying rationale for choosing a given approach. Sharing this type of information allows SSA systems to better understand potential sources of, or explanations for, differing outputs – for example, use of different processes for estimating satellite size or different algorithms for determining probability of collision. Sharing programmatic information can allow for improved compatibility and interoperability among systems and a reduction in the potential for conflicting information to be sent to spacecraft operators.

SSA systems also have the option to share operational data and information – information that is used in, or produced by, their systems. When input data is shared, it can allow systems to improve compatibility, alignment, and/or quality of the outputs of the systems. Sharing of information or products generated by the system can allow for improved awareness of how well aligned the systems are in terms of outputs, which can lead to further improvements in compatibility. Operational sharing of system outputs could allow real-time identification of situations in which conflicting results have been produced, enabling real-time coordination that could improve spaceflight safety.

This paper examines specific opportunities and priorities for both programmatic and operational information sharing. Building on prior work[3], it begins by reviewing the services provided by EU SST and TraCSS and highlighting key programmatic information that could be shared about these services.[4] The paper then identifies possibilities for sharing operational data and information, reviewing both challenges and potential benefits of sharing. The paper then focuses on potential scenarios for operational information-sharing, highlighting the scenarios where information sharing would be most beneficial. Finally, the paper addresses the extent to which these findings could be applicable to the broader SSA community.

Table 1: Opportunities for Programmatic and Operational Information Sharing Among SSA Systems

		EU SST Service	TraCSS Service	Potential Programmatic Information Sharing	Potential Operational Information Sharing
Program Overview				• Program Policy and Strategy • Objectives of the system • System architecture • Services provided • Timeline of the program • 6. Future Development Plans	
Services					
1. In-Orbit Collision Avoidance service:					
1. Routine catalog and O/O ephemerides screening and CDM production		Yes	Yes	• Sensor network architecture description • Use of o/o ephemerides and guidance to O/O on ephemeris covariance method • Processes used to evaluate the quality of operational data (input & outputs)	• Owner/ operator Ephemerides • Estimated orbits from sensor data • Hard body radius and other spacecraft attributes

[3] Borowitz, M., Pérez Hernández, C., Hejduk, M., Gillet, A., Moury, M., & Faucher, P. (2024, September). *A technical comparison of the public SSA services in the United States and the European Union*. Retrieved from https://www.space.commerce.gov/joint-paper-compares-ssa-services-provided-by-tracss-eu-sst/

[4] For the purposes of this paper, we focused on information sharing relevant to unclassified information associated with civil and commercial satellites.

				• Cadence of CA screening along with update cadence of screening inputs • Screening volume(s) • Process to identify primary CDM • Hard body radius information source and/or calculation approach • Space weather information source and update cadence • Methodology for calculating probability of collision • Standard/ format used for CDM • CDM update frequency • Orbit propagation method and/or drag / force model used for orbit propagation	• Space weather information • Conjunction Data Messages • Operational o/o contact information • Data quality assessment outputs
2. Risk Assessment[5] and Detection and Notification of High Interest Events/Emergency Events		Yes	Yes	• Procedures, criteria, and thresholds for defining high-risk events • Source of information on spacecraft maneuverability (if relevant) • Procedures for alerting spacecraft operators of high-risk events • Additional information and/or tools provided to operators • Response expected from operators (if applicable) • Method for communication with operators • Procedures for after-event evaluation (if relevant)	• High-risk CDMs
3. Additional tracking on the secondary and/or primary objects		Yes	Yes (Future)	• Procedures for pursuing additional tracking • Potential timing of updated observations	
4. Basic CAM Options for selection by O/O[6]		Yes	Yes (Future)	• Procedures for generating and providing collision avoidance maneuver options	
5. Candidate CAM Screening		Yes	Yes	• Process for enabling candidate CAM maneuver screenings	

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

[6] 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.

6. For selected HIE/ Emergency Events, dialogue with O/O		Yes	Yes	• Protocol for dialogue with spacecraft operators (if relevant) • Conditions for engaging in dialogue with spacecraft operators (if relevant) • Limitations on dialogue with spacecraft operators • Common questions from spacecraft owner/ operators	• Shared dialogue with operators
2. Candidate Maneuver Screening		No	Yes	• Process for screening candidate maneuvers (if relevant)	
3. Spacecraft Anomaly Reporting		No	Yes	• Process for anomaly reporting (if relevant) • Process for sharing anomaly information (if relevant)	• Anomaly reports
4. Reentry Monitoring Service		Yes	Yes (Future)	• Description of re-entry monitoring service • Process for developing re-entry predictions	• Re-entry predictions
5. Fragmentation Notification and Analysis Service		Yes	Yes (Notification only)	• Description of fragmentation notification and/or analysis service • Process for sharing fragmentation notifications	• Fragmentation notifications

2. OPPORTUNITIES FOR PROGRAMMATIC INFORMATION SHARING

As noted above, programmatic information consists of information about how an SSA system functions. At a high-level, the primary functions of an SSA system relate directly to the services that the system provides. Therefore, this section reviews the primary services provided by TraCSS and EU SST, as noted in a previous joint study comparing the services of the two systems.[7] In this study, rather than describing the service itself, we focus on the processes and procedures underlying provision of each service, noting the types of detailed programmatic information that could be shared to improve compatibility and interoperability.

2.1 Program Overview

Prior to sharing technical information about how particular system services are implemented, it is useful for SSA systems to share information that provides an overview of the program. This could include the overarching policy or strategy directing the development of the program as well as the objectives of the system and high-level architecture. This study builds on previous work that defined the services provided by TraCSS and EU SST, but it is worth noting that broad discussions of the services provided by each system are a useful and necessary aspect of programmatic information sharing. Finally, it is useful for systems to provide an overview of the timeline of the program as well as any planned future updates.

2.2 In-Orbit Collision Avoidance service

The core service of both EU SST and TraCSS focuses on the provision an in-orbit collision avoidance services. These can be broken into multiple sub-services, including:

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[7] Borowitz, M., Pérez Hernández, C., Hejduk, M., Gillet, A., Moury, M., & Faucher, P. (2024, September). *A technical comparison of the public SSA services in the United States and the European Union*. Retrieved from https://www.space.commerce.gov/joint-paper-compares-ssa-services-provided-by-tracss-eu-sst/

1. Routine catalog and O/O ephemerides screening and CDM production
2. Risk Assessment and Detection and Notification of High Interest Events/Emergency Events
3. Additional tracking on the secondary and/or primary objects
4. Basic CAM Options for selection by O/O
5. Candidate CAM Screening
6. For selected HIE/ Emergency Events, dialogue with O/O

The following section reviews each of these in turn.

2.2.1 Routine Catalog and O/O ephemerides screening and CDM production

As noted above, SSA systems typically use sensor data, combined with space weather and other relevant information, to generate a catalog of space objects that includes information about each space object (e.g. NORAD ID, satellite name, launch date etc.), and particularly its current and predicted future location in space, also known as ephemerides. Information about the current and future location of a spacecraft can also come from the spacecraft owner/ operator(s) themselves. Owner/ operators typically produce these "O/O ephemerides" using onboard GPS or other data sources and they may also incorporate planned maneuvers. Each of these types of ephemerides can be "screened" against the others to determine whether any close approaches, or conjunctions, are expected. If a close approach is detected, a conjunction data message is generated and provided to the spacecraft owner/ operator(s) involved. The CDM includes a probability of collision. It is worth noting that there are multiple accepted algorithms that can be used to calculate this value and sharing information on the methodologies used can be of significant value for coordination.

To improve transparency, compatibility, and interoperability, SSA systems could share information such as:

1. Basic information about the sensor network used for the system. (e.g. The United States publishes information describing the types of sensors that contribute to the Space Surveillance Network and their location around the world. EU SST displays information on the sensor contributing to EU SST on their website)
2. To what extent does the SSA system incorporate owner/ operator ephemerides? Do these ephemerides include covariance? And if so, does the system evaluate covariance realism? What guidance is given to the owner/ operator on how to provide the covariance?
3. What process, if any, does the system use to evaluate data quality?
4. How often is screening done (using a catalog and/or owner/ operator ephemerides)?
5. What screening volume is used and why?
6. Does the system identify a "primary" CDM, and if so, how is this done?
7. How is the hard body radius of a spacecraft determined? (What is the data source/ process?)
8. What space weather data does the system use?
9. What methodology does the system use to calculate probability of collision?
10. Does the system use a recognized standard for the CDM? If so, which standard/ format is used?
11. How often are CDMs updated in the system?
12. What drag/ force model is used for orbit propagation? What orbit propagation method is used?

Discussions on these topics between EU SST and TraCSS demonstrated that the two systems each have a sensor network consisting of ground-based optical, radar, and/ or passive RF sensors as well as space-based sensors. Both systems incorporate owner/ operator ephemerides, but have differing approaches to evaluating covariance realism. The systems also differ in their screening volumes, cadence for conducting screenings, hard body radius, space weather information, and algorithms for orbit determination and collision risk computation – these differences will result in differences in the conjunction data messages (CDMs) generated by the systems and present opportunities for future efforts to better align and improve compatibility. Some of these differences are described in more detail in previous study conducted by the two systems.[8] Recent technical discussions between EU SST and TraCSS further illuminated these differences, including explanation of why each system uses the current approach. Even without either system making a change to its processes, this transparency can allow for improved compatibility and coordination among the two systems, as the source of differences in outputs can often be readily traced to these differences in inputs and

[8] Borowitz, M., Pérez Hernández, C., Hejduk, M., Gillet, A., Moury, M., & Faucher, P. (2024, September). *A technical comparison of the public SSA services in the United States and the European Union*. Retrieved from https://www.space.commerce.gov/joint-paper-compares-ssa-services-provided-by-tracss-eu-sst/

procedures. EU SST and TraCSS also identified opportunities for continued discussion on each of these topics to consider the potential for increased alignment and compatibility in the future.

EU SST and TraCSS confirmed that they both generate CDMs in formats that are compliant with standards developed by the Consultative Committee on Space Data Systems (CCSDS). As of August 2025, EU SST is consistent with the current (version 1.0/ blue book) standard and is committed to evolve the system together with CCSDS updates, including the expected future (version 2.0/ pink book) standard. TraCSS has been designed to comply with the expected future (version 2.0/ pink book) standard.

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

After a CDM is generated, further analysis occurs to determine whether the event is of particular concern. This typically involves consideration of the probability of collision associated with the event and the time until closest approach, along with other potential information. This information is compared against set criteria and thresholds to determine whether the event should be considered high risk. Events that are considered high-risk may be subject to special processes for alerting spacecraft operators or other officials. Some SSA providers may also provide additional risk assessment information, tools, or services to spacecraft owner/ operators.

To improve transparency, compatibility, and interoperability, SSA systems could share information such as:

13. What procedures, criteria, and/or thresholds does the system use to identify events of particular concern? What is the definition of these levels (e.g. do they imply that a maneuver is needed on the part of the operator? Or further analysis?)
14. Does the system consider whether objects are operational and maneuverable? If so, what is the source of information on operational status and/or maneuverability?
15. What procedures does the system have in place (if any) to alert spacecraft operators of events that are considered high risk?
16. What additional information, tools, or services (if any) does the system provide to assist spacecraft owner/ operators in risk assessment and planning? Describe these products and how they are created.
17. What response (if any) does the system expect from operators? (Both in terms of action taken on the part of the operator as well as direct acknowledgement or other response to the SSA system.) Is the operator required to simply acknowledge receipt, or do they also provide information about their plans to undertake a maneuver (or not)?
18. How is the response provided? (Email, dedicated messaging system, etc.)
19. What procedures does the system have in place (if any) to gather further data or further analyze high risk events after the TCA has passed?

EU SST and TraCSS both use the probability of collision (Pc), risk geometry, and time to closest approach (TCA) as the key criteria in their risk threshold. However, the two systems use different numerical cut-offs and different terminology for these events. EU SST identifies "high interest events" based on the TCA, the probability of collision, and in some cases the risk geometry. EU SST recommends standard values depending on the orbit regime of the spacecraft, e.g. TCA of three days or less and probability of collision above 5E-4 for LEO spacecraft. In the event of a "high interest event," and if the spacecraft involved is maneuverable, EU SST encourages spacecraft operators to coordinate and undertake a collision avoidance maneuver to lower the risk associated with the event. Similarly, EU SST also defines an "interest event" based on TCA, probability of collision and/or risk geometry, with lower thresholds than for a "high interest event". In the event of a "interest event," EU SST engages further analysis and supervision of the event, and encourages spacecraft operators to maintain vigilance, but does not necessarily recommend action.

During its initial operations, TraCSS will be using the same "emergency criteria" used by the U.S. Space Track system, as laid out in its Spaceflight Safety Handbook for Satellite Operators. For objects in low Earth orbit, emergency events are identified as those with a Pc greater than 1/10,000, an overall miss distance of less than 1 kilometer, and a TCA of less than 3 days. In Geostationary orbit, "emergency events" are those with a miss distance less than 5 km and a TCA of less than 3 days. TraCSS has not articulated expectations for operators associated with these thresholds. TraCSS and EU SST noted that future discussions to consider closer alignment on criteria and definitions for high risk events could be beneficial.

Both EU SST and TraCSS have systems in place to proactively notify operators of high-risk events. In the case of EU SST, these notifications are generated for its registered users. TraCSS makes an attempt to send notifications of emergency events to both registered users and non-registered users. TraCSS also posts all emergency events on its website on an open basis (i.e. under a Creative Commons 1.0 license).

Both EU SST and TraCSS provide additional risk assessment information and tools to spacecraft operators, including information about the evolution of the probability of collision over time. Officials noted that standardization in the way this information is calculated and presented may be useful for improving the ease with which operators can use and compare the information provided by both systems.

EU SST requests that users report whether they have carried out a collision avoidance maneuver in response to an emergency event, and, if so, whether the collision avoidance maneuver was based on the trade space plot provided by EU SST. TraCSS also intends to request that operators acknowledge receipt of high-risk events. EU SST and TraCSS noted that it may be useful to explore a method for sharing these acknowledgement messages between SSA systems in the future to improve broad awareness that an operator is aware of a high-risk event. Both systems are also exploring options for informing operators when updates on a high-risk event are discontinued because the risk has sufficiently decreased based on updated observational information, maneuvers undertaken, or other factors.

2.2.3 Additional tracking on the secondary and/or primary objects
In select cases, EU SST gathers additional tracking data related to the conjunction event. TraCSS may also collect additional tracking information in certain circumstances.

To improve transparency, compatibility, and interoperability, SSA systems could share information such as:

20. Does the SSA system pursue additional tracking information on high-risk events? Under what conditions is this done and how is the new information provided to operators?
21. Does the SSA system provide information on the next predicted observation opportunity based on sensor location?

2.2.4 Basic CAM options for selection by the O/O
EU SST provides a collision avoidance maneuver trade space plot, and TraCSS intends to evaluate this type of product for users in the future.

To improve transparency, compatibility, and interoperability, SSA systems could share information such as:

22. Does the SSA system provide operators with a collision avoidance maneuver trade space plot or other information about potential collision avoidance maneuvers? If so, how is the plot produced and displayed?

2.2.5 Candidate Collision Avoidance Maneuver Screening
In the event that a spacecraft owner/ operator plans to conduct a collision avoidance maneuver, it is useful to screen that maneuver to ensure it does not generate additional, unintended collision risks. SSA systems can share information about their screening procedures.

To improve transparency, compatibility, and interoperability, SSA systems could share information such as:

23. Does the system provide collision avoidance maneuver screening? How is this done?

Both EU SST and TraCSS screen collision avoidance maneuvers provided by spacecraft operators.

2.2.6 For selected HIE/ Emergency Events, dialogue with O/O
While service provision for spacecraft owner/ operators is generally automated, there may be some cases in which system personnel engage in dialogue with a spacecraft operator.

To improve transparency, compatibility, and interoperability, SSA systems could share information such as:

24. Does the system offer opportunities for dialogue between the SSA provider and operators?
25. Under what conditions does dialogue occur? How frequently do these interactions occur?
26. Are there any limitations or guidelines for the content of these conversations?
27. Are there common questions or requests that the SSA provider receives in these instances?

EU SST and TraCSS both offer opportunities for dialogue with operators in relation to high-risk events. Communication is almost always initiated by EU SST as part of the Collision Avoidance service, but it is often the relatively small or new operators who need further explanation of the information and products provided via the system and discussion of potential actions to be undertaken by the operator. TraCSS, which is currently in pre-operational status, has not yet defined the parameters of dialogue with users.

EU SST and TraCSS officials noted that to improve future coordination, it may be worth considering a process to notify each other, or potentially even include each other, when dialogue with an operator is undertaken. This may be particularly valuable if the conjunction involves spacecraft operators registered in both systems.

2.3 Candidate Maneuver Screening

TraCSS provides on-demand screening of candidate maneuvers by owner operators. This allows spacecraft operators to determine if a maneuver the operator is considering undertaking, including a regular station-keeping maneuver or collision avoidance maneuver, will result in any conjunctions. EU SST does not provide this service – screening is only provided for collision avoidance maneuvers, as noted above.

To improve transparency, compatibility, and interoperability, SSA systems could share information such as:

28. Does the system provide candidate maneuver screening for routine maneuvers?

2.4 Spacecraft Anomaly Reporting

TraCSS requests that operators provide notification when they are experiencing spacecraft anomalies, such as a loss of maneuverability or an inability to communicate with their spacecraft. This improves awareness and may result in the U.S. seeking additional tracking on the object. Updates on spacecraft location will be available in standard satellite catalog information made available to operators on a regular cadence. This information can also be valuable in understanding the ability of a spacecraft to maneuver in the event of a conjunction.

EU SST does not include a spacecraft anomaly reporting function, but officials noted the potential value of this information for accurate catalog maintenance and spaceflight safety. Officials noted that there could be value in sharing this information between TraCSS and EU SST but recognized the potentially sensitive nature of this information, particularly for commercial operators who may not wish to broadly telegraph the fact that their spacecraft is experiencing an anomaly. One future option to consider would be providing operators registered in TraCSS with an option to allow limited sharing of this information with EU SST.

To improve transparency, compatibility, and interoperability, SSA systems could share information such as:

29. Does the system allow spacecraft operators to report spacecraft anomalies? What is done in response to this reporting?
30. Can information about spacecraft anomalies be shared, potentially in a controlled manner, among SSA systems to support spaceflight safety?

2.5 Reentry Monitoring Service

In addition to in-orbit collision avoidance services, many systems provide services related to re-entry. Both EU SST and TraCSS provide some services in this area. At its initial operations, Tracking and Impact Prediction (TIP) messages generated by space-track will be provided openly on the TraCSS website. EU SST provides a re-entry analysis (RE) service for registered users. Since 17 March 2025, the EU SST RE service is open worldwide. The service includes information on all non-controlled re-entry for objects 2,000 kg or more and rocket bodies.

To improve transparency, compatibility, and interoperability, SSA systems could share information such as:

31. Does the system provide a re-entry service? Under what conditions are re-entry predictions calculated and shared? Is information on consistency and/ or accuracy calculated or determined?
32. What is the process for developing re-entry predictions?

2.6 Fragmentation Notification and Analysis Service

SSA systems may also provide users with information about fragmentation or break-up events in orbit – these are situations in which an anomaly on a spacecraft, an accidental collision, or another event results in the creation of new debris or fragments. At initial operations, TraCSS will mirror DoD notifications regarding these events, making them available on the TraCSS website. EU SST provides a fragmentation analysis (FG) service, consisting in an initial notification to users of these events as well as a medium-term (days to weeks) and long-term (2-3 months) estimate of the potential location of these debris objects. This provides information that may be helpful to spacecraft operators in the period between the event and the time at which the objects can be added to the catalog and included in regular conjunction screening processes.

To improve transparency, compatibility, and interoperability, SSA systems could share information such as:

33. Does the system provide a fragmentation notification and/or analysis service?
34. How are fragmentation notifications and analyses generated and shared? How was the analysis validated?

3. OPPORTUNITIES FOR OPERATIONAL INFORMATION SHARING

In addition to sharing programmatic information – information about how the system functions – SSA providers could also consider sharing operational information – the input and output information used or generated by the system. This section provides an overview of key types of input information used and output information generated by SSA systems, based on a case study of TraCSS and EU SST. We discuss the benefits of sharing each type of information in terms of compatibility, interoperability, and spaceflight safety, as well as potential sensitivities that may limit the ability to share data and information.

3.1 Sensor Data

SSA systems generally rely heavily on observations (i.e. raw measurements) collected by sensors on the ground and/or in-orbit. From a technical perspective, fusing data from multiple sensors is generally the most straightforward way to improve the accuracy of SSA services, which directly benefits spaceflight safety. Previous research demonstrated potential gains from sensor data sharing and fusion between EU SST and TraCSS.[9] However, many SSA systems rely on sensors that are owned and operated by defense organizations and/or are considered dual-use. Security concerns often limit the sharing of this type of sensor data. Increasingly, SSA systems are also making use of data collected by commercial SSA sensors, and proprietary or business concerns similarly often limit the sharing of this type of data. Neither the European Union nor the United States regularly share sensor data outside their own system.

3.2 Catalogue of Space Objects

Data collected by sensors is fused into information associated with individual space objects, including their location, direction of travel, and velocity. This can be done using a relatively simple general perturbation model or with a more sophisticated and accurate special perturbation model. Together, this information is referred to as a space object catalogue, and it can be presented in a variety of formats, including two-line elements, state vectors, or ephemerides.

Sharing this type of information can improve mutual awareness and compatibility between systems. For example, it can be used to enable awareness of differences in the perceived location of spacecraft at a given time. While it has historically been considered infeasible to fuse two catalogs, some researchers are examining novel techniques to enable fusion of ephemerides, which could result in higher quality products based on this type of information sharing.

TraCSS makes both a general perturbation (TLE) and special perturbation (ephemerides without covariance) catalog openly available on its website, with updates provided every four hours for TLEs and once a day for the SP ephemerides without covariance. EU SST is currently building a catalog of space objects, that will initially only be shared among the Partnership. EU SST is engaging in a discussion about the possibility and desirability of sharing its catalog. The EU anticipates that at some time in the future EU SST will have a publicly-shared version of the EU SST catalog. This suggests that direct comparison of this information may be possible in the future.

3.3 Operational Contact Information

Operational contact information is critical for ensuring that SSA providers can contact spacecraft operators on a timely basis in the event of a high-risk conjunction for both notification of the event and, if relevant, coordination among operators regarding plans to maneuver. Most SSA systems request spacecraft operators to provide this information, however, it can be challenging to get operational contact information for spacecraft operators not registered with a

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[9] Baral, V., Cano Sánchez, A., Martínez Alcalde, S., & Pérez Hernández, C. (2024). *International sharing of satellite tracking data for improved orbital safety*. In Proceedings of the International Astronautical Congress 2024. See also Hoots, F., Baral, V., Delmas, F., Cano, A., Martínez, S., Pérez, C., Hedjuk, M., Ramsey, P., Auman, K. (2023). *US-EUSST data exchange for improved orbital safety*. Proceedings of the Advanced Maui Optical and Space Surveillance Technologies (AMOS) Conference, September 19-22, 2023

national or regional SSA provider. The United Nations Long Term Sustainability Guidelines call attention to the importance of sharing operational contact information for spaceflight safety.

However, there are some sensitivities to consider. Some operators do not want their contact information shared too broadly (e.g. publicly available) out of concern that the information will be misused. This suggests it would be useful to have a clear way to share operational contact information with relevant entities for the purposes of coordination on operational spaceflight safety issues – for example, sharing that is restricted to spacecraft operators, other national and regional SSA providers, and relevant international bodies, such as the United Nations Office for Outer Space Affairs.

TraCSS has implemented this type of restricted data sharing as part of its data policy and user agreement. EU SST currently shares operational contact information only on a case-by-case basis with the permission of the spacecraft operator. Options for expanded sharing, such as with TraCSS, could be considered.

3.4 Satellite Attributes

Certain information about a spacecraft is particularly important for the provision of SSA services. This can include information that is incorporated into CDMs, such as the size of the spacecraft (hard body radius), or information that is relevant to notification and coordination, such as whether the spacecraft is operational and what type of maneuverability capabilities the spacecraft possesses. This information may be collected directly from spacecraft owner/ operators or from other sources. Sharing this information results in more accurate CDMs, and better compatibility and agreement among SSA providers using the same information. This decreases misalignment between systems and increases spaceflight safety.

The TraCSS user agreement requires users to provide satellite attributes openly (under a CC0 license). Information is also collected from DoD, NASA, or other sources. These satellite attributes, including hard body radius, maneuverability, and other attributes will be made available on the TraCSS website without a need for registration. EU SST requests this information to the registered users prior to the start of the collision avoidance service. If the information provided by the users is misaligned with other open sources (DISCOS Database, Celestrack, etc) EU SST encourages the users to authorize them to share this information the be properly found across references. However, EU SST does not currently share satellite attributes publicly but sees potential value for spaceflight safety in sharing this information.

3.5 O/O Ephemerides with Covariance and Maneuver Plan

Spacecraft owner/ operators often produce their own ephemerides – information about the current and planned future location of their spacecraft – using onboard GNSS or other data sources. Owner/ operators are also able to incorporate maneuver plans into these ephemerides – information that cannot be gathered from any other source. This makes high-quality owner/ operator ephemerides with covariance and maneuver plans particularly valuable for SSA systems.

Sharing this information, so that SSA providers have access to O/O ephemerides and maneuver plans from as many operators as possible, results in more accurate CDMs and better agreement between SSA providers using the same information, again improving spaceflight safety. Having access to the maneuvers plans allow the other spacecraft o/o and SSA systems to disregard potential risks, and to minimize the maneuver recommendations optimizing the coordination. In addition, understanding the method each owner/ operator used to calculate and propagate the covariance will provide useful information to other owner/ operators, which may be used to better understand the potential conjunction.

The TraCSS user agreement requires users to provide satellite O/O ephemerides and maneuver plans openly (under a Creative Commons 1.0 license). The information will be made available on the TraCSS website without a need for registration, as well as through major cloud providers. This would allow other SSA providers, including EU SST to access and incorporate any O/O ephemerides provided to TraCSS. EU SST requires users to provide satellite o/o ephemerides and maneuver plans regularly (minimum once a day in LEO and once a week in GEO/MEO). EU SST is accepting several formats, however it is encouraging users to make use of CCSDS standard information in order to increase interoperability. However, EU SST does not currently share publicly owner/ operator ephemerides with maneuver plans, except on a case-by-case basis in response to specific events. EU SST is considering working with owner/ operators to increase the ability to share this information.

3.6 Space Weather Data

Space weather information is incorporated into atmospheric drag models that have a significant impact on the predictions of future spacecraft location and thus on the probability of collision between two space objects. Sharing this information would enable systems to use a common source of information, improving compatibility and alignment among systems.

EU SST currently uses NOAA space weather data, but may use a European data source in the future. TraCSS relies on information from the Department of Defense that is not shared. TraCSS is investigating the creation of an open-source space weather model for future use that would enable broader sharing of this information.

3.7 Conjunction Data Messages (CDMs) including Probability of Collision (Pc)

One of the primary outputs of SSA systems is the conjunction data message (CDM). This product provides information about the two objects that are predicted to have a conjunction, including the estimated miss distance, probability of collision, and time to closest approach. The message also includes additional information about the spacecraft involved.

Sharing CDMs can allow SSA systems to understand the extent to which the systems are producing conflicting results. This could lead to focused efforts to understand the source of these differences and improve system alignment. If CDMs are shared and analyzed on an operational basis, it could allow conflicting results to be flagged and addressed by SSA systems, and these situations could be managed in partnership with the spacecraft operators involved, directly supporting spaceflight safety.

However, CDMs are sometimes considered sensitive and neither EU SST nor TraCSS shares all CDMs openly. Therefore, as with sensor data and ephemerides, it may be useful to consider whether there are particular conditions under which CDMs could be shared. The following section discusses potential scenarios for information sharing.

1.8 Data Quality Assessment Output

When the system operator conducts data quality assessment, for example examining the consistency of ephemerides provided by an owner/ operator over time, the results of this assessment could be shared with other SSA systems.

4. SCENARIOS FOR PRIORITY OPERATIONAL INFORMATION SHARING

This section considers potential scenarios under which enhanced information sharing could be prioritized and enabled. This would enable SSA providers to share information that might otherwise be restricted – such as CDMs, ephemerides, or sensor data – in order to meet specific spaceflight safety goals. We focus here on in-orbit collision avoidance, and specifically events that have resulted in the generation of a conjunction data message (CDM), but similar logic could be applied to re-entry notifications and fragmentation notifications and analysis..

4.1 Criteria for Consideration

Our team identified three criteria and two additional considerations that could be taken into account to define potential scenarios of interest. The first criterion is consideration of whether the conjunction event is considered high-risk – i.e. does it exceed the threshold to be considered a High Interest Event (by EU SST) or Emergency Event (by TraCSS). Note that at present, EU SST and TraCSS use different thresholds to determine whether a conjunction falls into these categories. However, even if both systems adopt matching risk thresholds, differences in input data and analyses undertaken by each system can still result in different determinations of risk. This means there are three potential outcomes: 1) both systems agree that the event is high-risk (it is designated a HIE by EU SST and an emergency event by TraCSS), 2) both systems agree that the event is not high-risk (not an HIE or emergency event), or 3) one system designates the conjunction is high risk while the other determines the event is not high risk. The third outcome would generate the highest priority for information sharing between the systems, because this is a situation in which an operator is getting conflicting guidance from the two systems regarding the necessity of taking action. There could also be motivation to share information in the first outcome, because if both systems believe the event is high-risk, it may be valuable to confirm that the systems agree on the predicted timing and other conditions of the event.

The second criterion for consideration is whether either of the objects involved in the event is registered within EU SST and/or TraCSS. There are four potential outcomes for this criteria: 1) both objects may be registered in both systems, 2) one object is registered in EU SST and the other object is registered in TraCSS, 3) one object is registered in both EU SST and TraCSS and the other object isn't registered in either system, or 4) neither object is registered in either system. With respect to this criterion, outcome 2) would have the highest priority for information sharing, because spacecraft operators involved in the same event could potentially get contradictory information without being aware this is occurring. However, any situation in which both systems have a user involved in the event (outcome 1, 2, and 3) would benefit from information sharing and coordination among SSA providers to improve awareness and alignment to provide consistent information to the spacecraft operator, rather than potentially providing conflicting information to the spacecraft operator.

The third criterion for consideration is whether the objects involved in the spacecraft are maneuverable. This criterion has three potential outcomes: 1) both objects are maneuverable, 2) one of the objects in maneuverable, 3) neither object is maneuverable. The highest priority for information sharing would occur when both objects are maneuverable (situation 1). Situation 3), in which neither object is maneuverable, would be low priority for information sharing, since no action could be taken by either operator. However, it is worth noting that identifying and understanding discrepancies in outcomes in these cases could still be beneficial for improving overall alignment and compatibility between the systems.

Finally, sharing must also consider what type of operational (near real-time) data or information should be shared, which may be subject to policy or regulatory constraints. The fourth item considers whether data – raw or minimally processed sensor data – will be shared. This is a binary variable – either sensor data will be exchanged or not. The fifth item focuses on operational (near real-time) information sharing, including 1) ephemerides generated based on sensor data, 2) owner/ operator ephemerides with maneuver plans, or 3) conjunction data messages (CDMs). Benefits, sensitivities and status quo associated with sharing each of these information types were discussed above.

Table 2: Criteria to Consider for Information Sharing

Conditions that may require information sharing:

1. Is the event a HIE and/or "Emergency Event"
    a. HIE and Emergency Event
    b. HIE only, not Emergency Event
    c. Not HIE, only Emergency Event
    d. Not HIE or Emergency Event
2. Is either of the objects involved (primary or secondary) registered to EU SST and/or TraCSS
    a. Both items registered in both systems
    b. One item registered in both system, other object in neither
    c. One or both item registered in one system, not the other
    d. Both item registered in neither system
3. Is either of the objects maneuverable?
    a. Both objects are maneuverable
    b. One item is maneuverable
    c. Neither item is maneuverable

Additional constraints/ options to consider:

4. Will sensor data be exchanged?
    a. Sensor data exchanged
    b. No sensor data exchanged
5. Type of information shared:
    a. Ephemerides (generated from sensors data)
    b. O/o ephemerides with maneuver plans
    c. CDMs

4.2 Scenarios for Information Sharing

Combining the five criteria described above creates over 100 different scenarios. However, rather than evaluate each of these scenarios, we will focus here on four options, including the scenarios representing the broadest sharing and the most limited sharing as well as two middle-ground scenarios. We will discuss the benefits and drawbacks of each.

Scenario 1 Full Sharing: The broadest sharing would involve sharing all types of data and information for all conjunction events, regardless of whether the event is considered high-risk, involves registered users of either system, or whether either spacecraft is maneuverable. This level of sharing would generate the most information for analysis, but it would also be most challenging to accomplish due to existing restrictions on information sharing. Security or proprietary considerations would likely make this level of sharing impossible at present, even between close partners.

Scenario 2 Sharing for All Registered Users: A slightly more limited option could include sharing of CDMs and relevant ephemerides for all conjunctions in which at least one of the objects is registered in at least one of the systems. At present, many owner/ operators registered in space-track and EU SST have opted to have their U.S.-produced CDMs shared with EU SST via space-track, so this level of sharing would likely be feasible by TraCSS. EU SST does not currently have a reciprocal sharing option, so this would need to be investigated.

Scenario 3 Sharing for High-Risk Events: A more focused approach could involve sharing CDMs and relevant ephemerides for all high-risk conjunction events – i.e. when either or both system identifies an event as a high-risk conjunction (i.e. HIE or emergency event) – that involve a spacecraft registered in at least one of the systems. This would limit sharing to a more focused set of events where the benefits of coordination are clear – avoiding confusion or conflicting information related to a potential collision in orbit. In the case of TraCSS, CDMs for emergency events are openly available, so this level of sharing already aligns with current information sharing plans.

Scenario 4 Limited Sharing for High-Risk Events: One of the most limited information-sharing scenario would involve sharing only CDMs in cases in which one or both systems identifies a high-risk event, both EU SST and TraCSS have a registered user involved in the conjunction, and at least one of the objects is maneuverable. This would keep the number of events of interest and associated information sharing low, potentially making it easier to share information. However, it would also limit the ability to identify patterns or trends in the data, which may make improvements in compatibility and alignment more difficult to achieve.

Overall, we believe that Scenario 3 Sharing for High-Risk Events offers the best balance between recognizing existing information sharing restrictions and reaping the space safety benefits from increased sharing and coordination.

Table 3: Scenarios for SSA Information Sharing

Scenario	**Information Shared**	**Criteria for Sharing**	**Pros**	**Cons**
1. Full Sharing	Sensor data Ephemerides CDMs	None (Sharing for All Events)	• Addresses all possible events	Not compatible with current national security and proprietary information sharing limitations
2. Sharing for All Registered Users	Ephemerides CDMs	One or both objects are registered in EU SST and/or TraCSS	• Enables broad sharing for all events of potential interest to users of the two systems • Similar with current status quo for EU SST access to U.S.-generated CDMs (currently shared via space-track.org) • enables sharing of a relatively broad set of CDMs, which enables extensive comparison to better understand differences/ reasons for differences between TraCSS and EU SST CDMs	Requires significant updates to current information sharing procedures
3. Sharing for High-Risk Events	Ephemerides CDMs	Event is designated as high-risk (HIE	• Prioritizes high-risk events of most interest to spacecraft operators	

		or Emergency event) One or both objects are registered in EU SST and/or TraCSS	• Consistent with existing TraCSS information sharing policy • EU SST currently shares additional information in the event of high-interest events	
4. Limited Sharing for High-Risk Events	CDMs	Event is designated as high-risk (HIE or Emergency event) EU SST and TraCSS both have a registered user involved At least one object is maneuverable	• Prioritizes only the events that are most operationally relevant to TraCSS and EU SST users • Limited sharing may require fewer resources for early stages of coordination	Limited information sharing may slow ability to understand broader patterns and underlying causes of differences between systems

5. CONCLSIONS AND NEXT STEPS

Space situational awareness systems tracking objects orbiting the Earth and detecting potential collisions are essential to ensuring global spaceflight safety and sustainability. With the development of such systems around the world, coordination among them is crucial to minimize the instances in which operators receive non-contradictory information enabling timely decision-making in case of a risky close approach with another space object.

Focusing on EU SST and TraCSS as a case study, the present paper established a useful typology of information that may be shared between the two systems, distinguishing the sharing of programmatic information from that of operational information. It also introduced a list of both programmatic and operational information for each of the services provided by TraCSS and EU SST. An analysis of opportunities for both types of information sharing has shed light on key questions and criteria to consider, on different scenarios for information sharing, on potential issues to overcome, as well as on advantages and potential drawbacks related to the sharing of information. Programmatic information could be shared periodically between systems through technical meetings and discussions, for example in annual or bi-annual meetings. Near real-time operational information exchange would require significant levels of technical coordination and integration. EU SST and TraCSS plan to explore specific operational procedures for operational coordination in future work. Through the illumination of these two types of information sharing, this paper therefore constitutes a helpful and systematic basis for reflection for any future SSA system and global coordination framework at large.

As far as EU SST and TraCSS are concerned, the paper concludes that sharing of programmatic information is beneficial to help better understand the source of differences in outputs of event analysis through comparing both systems' inputs, methods and criteria. Sharing operational information may enable both systems to better assess the risk posed by a close approach and enable more efficient response to mitigate that risk. Overall, information sharing may foster increased alignment and compatibility of both systems in the future and contributes to ensuring space safety and sustainability.

Certain potential barriers to information sharing were also identified. Current national security and proprietary considerations may limit a full sharing of information for all close approached between two space objects. The sharing of sensor data is particularly sensitive. That being said, the sharing of ephemerides and CDMs may be sufficient to contribute to spaceflight safety, even if restricted to high interest events/emergency events.

Coordination between EU SST and TraCSS is an important first step, but to support global spaceflight safety, it is important to expand coordination to other SSA providers around the world. The overall goals and processes described here with respect to cooperation between EU SST and TraCSS also apply to other SSA systems. Improved transparency, compatibility, and interoperability among independent systems would help to ensure spacecraft operators receive more consistent guidance on spaceflight safety issues and events. It would also facilitate improved coordination among spacecraft operators.

To achieve this improved coordination, SSA providers could share the same types of programmatic information described in Section 2 above. Different systems may be able or willing to share information in different ways or to different extents, but any level of information sharing should provide some benefit, and understanding perspectives on data and information sharing preference and policies is beneficial in itself. It is also possible that other SSA systems will conceive of their services in different ways, so there may be topics not covered in this paper that other systems would find useful to discuss. This paper and the topics described in section 2 could be considered a starting point to build on in these broader discussions. As EU SST and TraCSS found in an earlier joint study, simply standardizing language and terminology around SSA services, information, and activities can be a significant undertaking that produces useful outcomes in the form of improved mutual understanding for the SSA providers as well as the broader community.

SSA systems around the world could also discuss the types of operational data and information sharing discussed in Section 3. Once again, the information provided here could be considered a starting point for discussion, with other SSA providers providing further insight into their perspectives on the value and feasibility of sharing different types of information.

Moving beyond sharing of information to operational coordination, such as that described in the scenarios and procedures laid out in Section 4, will be more complex. These scenarios identified could also be re-examined to incorporate additional perspectives about the highest priority needs for operational information sharing and near-real time coordination. A significant future challenge – both in terms of bilateral coordination between EU SST and TraCSS as well as for broader coordination – will be to identify concrete technical methods and operational procedures for sharing operational information. Nevertheless, the programmatic and operational information-sharing discussions described here would be an important foundation to enable these more technically-focused discussions necessary to enable operational coordination.

Coordination among national and regional SSA providers is critical, as many of these systems are a central, authoritative source of information for spacecraft operators. However, it would also be valuable to incorporate commercial SSA providers, as these entities also provide key services to spacecraft operators. Commercial operators may have some limitations in their ability to share programmatic or operational information, due to a desire to protect proprietary processes or information that provide market advantage. However, it is likely that some level of information sharing would be possible and beneficial. Enabling the providers to participate in this discussion at a level that works for them would be valuable.