INTRODUCTION

The European Space Situational Awareness program is dealing with a number of aspects focused in deploying a fully European system that supports the scenarios for Space Surveillance and Tracking, Space Weather and Near Earth Objects. The concept of support ranges from the definition and implementation of the assets required for the support of the activities to the definition of the operational and data processes and the identification and definition of interfaces. Common to all scenarios and activities are the data objects required for the operation that contain the information that is stored in service and application data centres and is used to interface internally and with external entities.

Standardisation organisations like CCSDS have already performed and analysis on data entities that are partially or fully applicable to the SSA domain, in particular to the Space Surveillance and Tracking (SST), and that can be reused in the implementation of the SST data models and also to facilitate the exchange of data via standardised mechanisms. This paper focuses on the application of navigation standards to describe elements of the SST data model at the conceptual level rather than describing the internal data architecture for data storage.

The motivation for this approach comes from the way in which these standards are created, based on the knowledge of several agencies and organisations with different points of view that contribute robust and well established solutions. The objective is twofold. On the first hand, to define the data model such that the contents of the standard (not quite the format) are mapped into the core data model. This is a data kernel which is characterized by having publically known, interoperable interfaces for common use across the space community. On the second hand, to do so in such a manner that the model can be easily expanded to meet specific needs for each agency, by means of definition of plug-ins or extensions to the core model. Of course this does not prevent other data elements from being included in the model, but the approach guarantees that the internal representation and the usage of the information by all other entities (internal and external to SSA) are done consistently.

The data domains inside the SST that can be identified refer to:

- Trajectories and ephemerides, to be represented by Orbit Parameter Message (OPM) and Orbit Mean-elements Message (OMM) and Orbit Ephemeris Message (OEM)
- Covariance, to be also included in the OPM as the result of an orbit determination process and in the OEM for covariance evolution representation
- Tracking, covered by the Tracking Data Message
- Collision avoidance, not yet supported by a CCSDS standard but the Collision Data Message is being prepared to support this domain
- In orbit tracking sensors that can be supported by the Attitude Data Messages (APM, AEM)
- Sensor planning for survey or tasking that can be supported by the future Pointing Request Message (still in the early stages of standardisation at CCSDS)

This paper describes the potential usage of these standards as an alternative point of view for the description of the SST data model definition, addressing benefits of and drawbacks of the approach with respect to other traditional data modelling approaches.
OVERVIEW OF CCSDS NAVIGATION STANDARDS

There are three CCSDS navigation standards readily available as international recommended standards

  - Orbit Parameter Message (OPM) that implements an osculating state vector at epoch accompanied with orbital elements and impulsive manoeuvre information
  - Orbit Ephemeris Message (OEM) that implements a time sequence of orbital state vectors (ephemeris).
  - Orbit Mean-Elements Message (OMM) that implements a mean element dataset together with orbit model parameters for the mean elements set modelling

Issue 2 of this standard incorporates with respect to Issue 1 the OMM and new capabilities for the other messages (OPM and OEM) including representation of state vector covariance.


- Attitude Data Messages, Blue Book. Issue 1. May 2008 [3]. The Attitude Data Messages (ADM) Recommended Standard specifies two standard message formats for use in transferring spacecraft attitude information. The ADM encompasses the following messages
  - Attitude Parameter Message (APM) that implements an attitude state vector at epoch with different possible representations.
  - Attitude Ephemeris Message (AEM) that implements a time sequence of attitude state vectors (ephemeris).

In addition to these standards there are a number of ongoing initiatives to cover additional navigation related areas that are potentially interesting in the SSA domain, namely:

- Conjunction Data Message (CDM) whose purpose is to provide information about close encounters of objects in orbit around the Earth.
- Pointing Request Message (PRM) whose purpose is to provide details on the pointing of devices to targets (e.g. antenna on-board a satellite to another satellite)

All these standards and other to come are valuable assets for data modelling. They are built on the consensus of many agencies that take into account their own experience in the different ways of using the represented data, incorporating also the inputs of other potential users like satellite operators. When analyzing the modelling of the SSA data, there are many elements that are common to those already represented in the CCSDS navigation messages and therefore it is well worth looking at the details of this already implemented representation to consider them in a possible representation of the SST data model.

THE OBJECT CATALOGUE DATA MODEL

The objects catalogue is the main data entity in the SST context; it contains all the information required to characterise the past, current and future evolution of the identified objects around the Earth. The objects catalogue also permits the storage of information required by the observing devices to point to the object to acquire necessary data for improving the knowledge on the object's motion. A number of studies and projects are currently looking into the definition of the data entities that should constitute the model that defines the structure of the SST objects catalogue. These studies are aimed at identifying the different data items to be mapped into the objects catalogue data model starting from SSA requirements in the CRD [6] and experience gained in the representation of navigation, flight dynamics and space surveillance data.

The SST CRD identifies a set of minimum needs for the definition of the objects catalogue, among others

- Object ID
- Publication date
- Orbit determination epoch
- Orbit states
- Orbit uncertainties
- Covariance matrix
In addition, different activities in the SSA preparatory program are requesting data modelling with additional details to those provided in the CRD. For each object, specific characteristics need to be represented

- Object mass
- Drag area and coefficient (when applicable)
- Solar radiation pressure and coefficient
- Manoeuvre information (actual or announced)

There are many other properties to be included in the objects catalogue which are linked to specific properties of each of the catalogued objects. These properties relate to the owner country, the operator, the launch date, the launcher, the element from which the object originally came from in the case of fragments, etc.

At this level this is a shallow view of the final contents of the catalogue. The bullets provided above give a high level representation of the type of information that the catalogue shall contain. One can also derive additional information to detail the identified items, such as units for the different magnitudes, numerical representations, coordinate and time reference frames, formats (e.g. for epoch representation), etc. In some cases these features belong to the data model itself and in other cases they are just means to represent the data; probably in all cases it is necessary to provide the means to ensure that this data or the associated property is represented consistently.

**OTHER DATA ENTITIES**

In addition to the objects catalogue there are other elements in the SST scenario that need to be represented and whose static and evolving properties need to be characterised.

- Tracking devices. They could be located on ground or in space. Both types share properties regarding the observing technique and capabilities (e.g. telescopes, radars, detection sensitivity, field of view, etc.) For those devices that are in orbit there are properties that are shared with those in the objects catalogue like the identification, the satellite physical properties and the ephemerides.
  All tracking devices generate a data item related to the necessity to point the device to a certain target object from the catalogue. In this case the Pointing Request Message (PRM) could be a candidate to model such request, either if it comes from an external source or if it is requested internally in SSA. In the particular case when the request applies to an orbiting device, the need for attitude information makes the ADM suitable to link attitude information for the tracking satellite to the pointing request.

- Conjunction Warnings. One of the key functions of the SSA (and the SST in particular) is the identification of conjunctions between objects in the catalogue. The information of this type of event needs to be accurately described. The Conjunction Data Message (CDM), whose definition is currently in process by the CCSDS navigation working group, intends to implement all the information relevant for the description of a conjunction event. The information in the CDM is constructed from two sources. Readily available data is extracted from common information in the objects catalogue, and the message is completed with data that is generated as part of the conjunction detection process. Orbital information associated to a conjunction event can also be modelled by means of one or more ODM.

- Tracking data. This comes from many different sources but once it has been pre-processed it can be reduced in general to a collection of well defined physical properties: range, range-rate and angles (e.g. azimuth/elevation or right-ascension/declination). These magnitudes can be represented using a Tracking Data Message (TDM) that provides generic representation for the tracking types expected in SST. There are other properties like the observed object magnitude or the RCS that cannot be easily modelled with the TDM.

**A PROPOSED MODEL FOR SST WITH STANDARDS**

A proposed mapping between the SST data objects and a possible representation with existing and intended CCSDS navigation standards is provided in Fig. 1.

The approach is just a proposal of the many possible. The structure relies on a main object that contains the intrinsic properties like identification, reference mass and areas, ownership, operational status, etc. In addition the core object contains the pointers to the varying data; here is where the definition of data by means of standards is applicable.

- Tracklets from the available devices are modelled using TDM
- Historical orbit determination results are conveniently modelled using OPM. This permits the storage of a sequence of states at epoch that can be propagated to reconstruct any past or future state. This information also includes covariance information generated as part of the orbit determination process. This is also supported by the latest versions of the OPM.
The generation of ephemerides is implemented using OEM. This is useful, for instance, to maintain the predicted orbit from the last available orbit determination and make the prediction available for the collision risk assessment process. Time series of covariance associated to the ephemerides can also be provided in the data structure defined in the OEM.

Ingestion of externally provided orbit data (e.g. from satellite operators) can be stored also as OEM. This isolates through a conversion interface the internal SST representation of this type of data with respect to representations provided by the external entity.

Manoeuvre data can be represented using OPM. Although the manoeuvre itself is represented by the delta-V solely, it is most interesting to provide the manoeuvre information together with the orbital state at an epoch close to the manoeuvre epoch; the OPM is most adequate for this purpose.

Fig. 1. Entity Relationship for SST Objects Catalogue Data Model

The SST processing chain also provides a view on how some of the data objects can be mapped into CCSDS navigation standards.

- Pointing requests. These are generated by the SSA planning system in response to observation requests from the collision risk assessment subsystem (additional tracking required to improve the conjunction knowledge) or from the cataloguing process when the orbit prediction exceeds prescribed accuracy limits (need to perform orbit determination to improve accuracy). In any case the process ends with a request to generate tracking with a certain sensor on the required object. This can be implemented by means of a PRM.

- Conjunction warnings can be modelled with a CDM.

Fig. 2. SST Processing Chain Scheme
The use of standards in the modelling of the data entities involved in the SST also facilitates the implementation of the different subsystems and processing components. Fig. 2 describes some of these entities and the data that is exchanged as part of the SST processing. Most of the exchange elements refer to data entities described above and contain orbital, tracking and pointing request information. If the interfaces are standardised (and this also applies to interfaces external to SST) the implementation and testing reduces risks and facilitates the validation. It also permits that subsystems can be replaced by new ones encapsulated by the standardised interface.

DATA REPRESENTATION AND DATA FORMAT

So far the references to the data model have intentionally excluded any reference to the format in which the data is provided. All references define representation as the process of structuring the data in such way that the representation by means of the CCSDS standard is possible. Actually the way in which the data is formatted is completely irrelevant; what really matters in this process is the identification of the data entities and providing the structure that permits their efficient and easy handling. As mentioned in the introduction, the use of standards in the process of defining the data model benefits from the knowledge on how certain information can be represented in the standard (in data structure terms). Another relevant aspect is how easy it becomes to generate data to be exported when extracting the information from the internal data model; this refers not to the formatting but to the process of generating it with the adequate transformations to make sure it remains:

- **Unambiguous.** Here the benefit of the standard is clear. In the assumption that the standard is well defined, the data contained in it will be unambiguously defined and therefore any identification or conversion should be easily definable in terms of the contents defined by the standard itself. Even in the cases where the standard does not completely close the definition of a certain property it provides the means to tailor the standard to unambiguously define it (e.g. the reference frame in an OPM is an open string that can be forced to take a prescribed collection of values by convention, since the field is mandatory in the OPM the tailoring of the standard in this way makes that any OPM is completely defined with respect to the reference frame).

- **Consistent:** The data model should define the data structures in such a way that the information flow across the data chain doesn’t introduce inconsistencies. This is of utmost importance when data sets are required to remain fully understandable by all actors when the information is cycled through different systems and organizations.

- **Efficient:** The data model should define the data structures such that they are readily usable by the entities (SST internal and external) requiring the information. In a potential scenario where, for instance, orbit information is requested for many (potentially all) objects in the catalogue several times it is important that computational intensive operations are minimised.

Traditionally the representation of the CCSDS navigation messages has been performed by encoding the information in flat text files oriented to human understanding. The natural evolution of the standard has resulted in providing the same standards using XML encoding [5]. An example of OPM representation in ASCII text format and the corresponding XML representation of it is provided in Fig. 3.

```
CCSDS_OPM_VERS = 1.0
CREATION_DATE2001-11-06T09:23:57
ORIGINATOR = JAXA

OBJECT_NAME = GODZILLA 5
OBJECT_ID = 1998-057A
CENTER_NAME = EARTH
REF_FRAME = ITRF-97
TIME_SYSTEM = UTC
EPOCH = 1996-12-18T14:28:15.1172
X = 6503.514000
Y = 1239.647000
Z = -717.490000
X_DOT = -0.873160
Y_DOT = 8.740420
Z_DOT = -4.191076
MASS = 3000.000000
SOLAR_RAD_AREA = 18.770000
SOLAR_RAD_COEFF = 1.000000
DRAG_AREA = 18.770000
DRAG_COEFF = 2.500000

<opm id="CCSDS_OPM_VERS" version="1.0">
<header>
<CREATION_DATE>2001-11-06T09:23:57</CREATION_DATE>
<ORIGINATOR>JAXA</ORIGINATOR>
</header>
<body>
<segment>
<meta>
<OBJECT_NAME>GODZILLA 5</OBJECT_NAME>
<CENTER_NAME>EARTH</CENTER_NAME>
<TIME_SYSTEM>UTC</TIME_SYSTEM>
<EPOCH>1996-12-18T14:28:15.1172</EPOCH>
<X>6503.514000</X>
<Y>1239.647000</Y>
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</meta>
</segment>
</body>
</opm>
```

Fig. 3. OPM Example y Text and XML Encoding (from CCSDS 505.0-B-1)
The detail provided in the previous figure is just a representation of one example of the contents of an OPM in the two possible representations. A close look at the available standards clearly indicates that most information in the object catalogue can be mapped into one of the available or intended navigation messages, except the data that describes object inherent properties. The XML representation implies that there is a representation that is structured. This implementation can be extended by aggregation such that the object catalogue data model contains instances of the messages or substructures taken from them that allow the allocation of data elements within the object catalogue data model that are consistent with the navigation message. The objects catalogue data model can then be described by means of an XML schema that shares selected sections with those XML schemas from the standard allowing consistent validation of the catalogue structure directly with the validated schemas from the standard.

CONCLUSIONS

This paper provides an initial insight on the potential use of CCSDS navigation standards in the definition of the SST data structures and in particular in the definition of the SST objects catalogue. Some highlights can be extracted already at this level

- There are several structures in the CCSDS navigation messages that map information that will be contained in one way or another in the SST objects catalogue (object identification, orbital information, covariance, etc. with ODM). Moreover, there is data defined by the SST processes that also maps consistently with messages available or being defined by the CCSDS (e.g. conjunction assessment information with the CDM)
- The use of CCSDS messages as reference information to structure the data allows that knowledge and effort already devoted to the data representation is directly inserted in the definition of the SST data structures.
- The use of standards in the definitions of the SST data model facilitates the unambiguous definition of those sections that map directly into the CCSDS messages. Exporting this data is straightforward and guarantees consistency between the internal representation and the exported data. This is applicable at all levels, that is, between subsystems in the SST context (even SSA wise) and also for the data exchanged with external entities.
- There is an XML representation of the CCSDS navigation messages that permits the representation of the data in a structured manner that can be directly reused in the definition of the SST data model including the use of the associated XML schemas for validation of the relevant sections. The SST data model schema can physically incorporate the CCSDS schemas facilitating the definition of the data model.

REFERENCES