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Joined ESA-DLR Procedure Management Environment

François Trifin[a], Pierre Choukroun[a], Stefan Gärtner[b], Philipp Hamacher[b], Leonard Schlag[b]

[a] *European Space Agency / ESOC, Robert-Bosch-Str. 5, 64293 Darmstadt, Germany*
[b] *Deutsches Zentrum für Luft- und Raumfahrt e. V. /GSOC, Münchener Straße 20, 82234 Weßling, Germany*

Abstract

Operations Procedures Management by mission control centres, including development, verification, validation and maintenance of ground and flight control procedures of spacecraft mission, is a labour-intensive set of tasks requiring highly skilled personnel to manage mission critical elements such as launch and early orbit phase, spacecraft failures, degradation of spacecraft functions, hardware damages, recovery actions and avoidance of mission loss.

Due to the evolution of their mission control systems infrastructure, the European Space Operations Centre (ESA/ESOC) and the German Space Operations Center (DLR/GSOC) require new operations procedure management data systems adapted to the latest technological and conceptual requirements.

Acknowledging the common operational working practices and processes and the extend of the effort required, both control centres combined their engineering teams to develop a joined Procedure Management Environment and took the opportunity to rethink procedure management concepts and how higher efficiency could be achieved.

This paper describes the new operations procedures management system concepts, core principles, technical capabilities and the resulting improvements of the operations activities. How the environment promotes innovation for the benefit of the control centres users and the space industry is also clarified.

The new environment presented is planned to be used by all future space missions operated at ESOC and GSOC as foreseen by the respective control centres strategic migration to their EGS-CC based infrastructure data systems EGOS-CC and GX-CC.

Keywords: Operations Mission Procedure Management Environment

1. Introduction

The present paper presents the procedure management environment integrated to the Operations Preparation Environment for Missions (OPEN-M) software system [4][5][6].

DLR/GSOC and ESA/ESOC are cooperating on their respective projects, GX-CC and EGOS-CC [7], aiming at adopting the new European Ground Systems Common Core (EGS-CC) monitoring and control systems [9] at the control centres, extending the EGS-CC software to the needs and requirements of control centres' operators and supporting the migration of existing missions to the new system. OPEN-M has been developed in the EGOS-CC context over the last years [8] and continue to evolve, lately with the development of procedure management functions.

The European Ground System – Common Core (EGS-CC) is an 'ESA led' initiative to define, develop and maintain a generic product forming the basis of future European space systems monitoring and control applications. DLR and ESA are both also part of the EGS-CC project stakeholders' group.

The EGS-CC based mission control systems will be used to operate a variety of mission families, i.e., Earth Observation, Astronomy, as well as Solar and Planetary missions. The mission control system and its preparation environment (i.e. OPEN-M), used to manage the tailoring data of both the EGS-CC based mission control systems and the space assets, are therefore required to be as 'generic 'as possible to be used as common systems to support this heterogenous mission types. Nevertheless, the harmonisation of the missions needs and the standardisation of their implementation is a key necessity of the centres. This is addressed by the OPEN-M environment design.

At the time of writing this paper, ESOC has already conducted a routine operational pass with the EGOS-CC systems.

2. System concept

The OPEN-M software system aim is to cover the management of the EGOS-CC tailoring data model, including spacecraft "database" and procedure management. This tailoring data model is composed of the EGS-CC tailoring data model with a few additional model extensions specific to mission operations as performed in the control centres. The EGS-CC Tailoring Data Model (TDM, also referred to as Conceptual Data Model (CDM) by the EGS-CC project) is an object-oriented meta-model describing all elements required by the EGS-CC system during its execution. This model covers the description of elements such as packets, parameters, calibrations, routes, procedures, scripts, access points, displays, events, and their relationships.

With the migration of our control centres to EGOS-CC/GX-CC, the OPEN-M system is replacing the previous SCOS-2000 generation of preparation tools used at GSOC and ESOC for the management of data required to operate a Mission Control System. In this context, OPEN-M supersedes the MATIS preparation environment [10], DABYS [11], MOIS [12] and ProToS [2] tools. With respect to the procedure management, the OPEN-M usage, capabilities and functional concepts are primarily a "blend" of the MATIS and ProToS concepts with additional improvements taking advantage of many years of lessons learned through actual operational use on ESA and DLR space missions.

At the control centres, the OPEN-M software is the system realising the operations preparation environment for missions. This environment interfaces with the operational runtime environment where the MCS and MPS are deployed and with the AIV environment where the runtime environment is simulated for the verification and validation activities performed before actual operations.

Extensive data consistency is key for a preparation environment to minimise the time between an inconsistency creation and resolution. For this reason, the system aims at consistency checking all aspects of the data as much as possible and as fast as possible, well before the data leaves the preparation environment.

To optimise the interactions between environments and the data lifecycle, DevOps practices are integrated into the system architecture by supporting and emphasising continuous integration, delivery and deployment. This can drastically improve the verification and validation user effort by removing frequent and no longer necessary human tasks. The aim is to evolve overtime the OPEN preparation environment as a DevOps platform for space operations. Those aspects are the subject of another SpaceOps 2023 paper [3] and are further elaborated there.

Along with a software migration from SCOS-2000 to EGOS-CC/GX-CC, the system concepts and design must accommodate the migration of existing mission data from SCOS-2000 formats to EGS-CC formats and the working practices of the user community at the same time. SCOS-2000 MIB databases and procedures must be converted, imported and make sense for the new system without having to rely on additional human inputs. The new formats must also be able to accommodate the content of those old formats (e.g. lack of data precision in imported legacy data). The new system is therefore an improved evolution of the previous generation of systems and is designed to not create any usability rupture for the final users, the operators. The system must be familiar, yet more efficient in all aspects.

3. System users

As the system is dedicated to the creation and modification of the data required for the preparation, verification, validation and execution of the spacecraft monitoring and control operations on EGS-CC based systems, any engineer requiring those capabilities can benefit from the use of the OPEN-M software. The operation control centres users are primarily spacecraft operations engineers, mission controllers, spacecraft analysts and MCS support engineers.

4. Activity procedure

4.1. Execution concepts

The most important manual and automated execution concepts related to planned and unplanned mission operations are now briefly explained.

An activity is defined as a space system monitoring and control function, and can take the form of a telecommand, a monitoring and control procedure or even a system function. An activity procedure can either be executed by the EGS-CC based MCS through its automation component or used to generate a set of activity lists. An activity list is, in simple terms, an ordered list of monitoring and control activities with very limited decision logic which are executed either manually through the MCS activity stack (a commanding source which manages activities execution and dispatches them for further processing) or scheduled by the mission planning system.

Planned mission operations are executed as follows. The mission planning system generates a time-tagged list of operations to be executed covering a given time period (e.g., one period). These are referred to as 'increments'. The planned operations which are expected to be executed without operators' involvement are delivered in two separate increments, one covering the operations to be executed automatically on ground (via the ground schedule) and one covering the operations (commands) to be executed automatically on-board (via the on-board schedule). Each planned operation is associated to an absolute time, or orbital position, when it is expected to be executed (either on-board or on-ground).

The ground schedule increment is expected to contain all operations to be executed on ground in order to enable the interactions with the space segment (e.g. execution of pass operations, upload of the on-board schedule increment, management of the download of mission data) and manage the associated ground processing; In a similar manner, the on-board schedule increment is expected to contain all operations to be executed on on-board the spacecraft; Each increment is delivered as a self-standing file which can be autonomously processed in order to load it into its target schedule (either on-board or on-ground).

The automated execution of operations on ground requiring advanced decision logic is achieved by means of operator-defined automation procedures whose execution is triggered by planned (time-tagged) operations execution requests.

A planned or unplanned operation which is expected to be executed with operators' involvement (e.g. due to complexity or uncertainty) require a human operator to manually read and follow the instructions specified in the nominal or contingency procedure being executed. To minimise human errors, this operation is computer assisted by loading the pre-set commands contained in the activity lists of the related procedure on the MCS activity stack.

The reaction to unexpected events requiring immediate reaction can be supported by triggering 'recovery operations' based on specified events. The recovery action is either pre-specified as an automated activity or handled by a human operator. The action list comes into play for this second case. The action list is a mapping between mission event types occurring during the operation of the mission (e.g., Out-Of-Limits) and the operators expected initial reaction. This may for example instruct the spacecraft controller on duty to execute contingency procedures or to contact the on-call engineer for further guidance.

4.2. Definition concepts

Based on the above operation execution concepts, the purpose of a procedure is therefore to support the execution use cases with the following definition capabilities. A procedure must be able to:

- Specify activity lists used in mission planning increments for automated operation execution
- Specify nominal and contingency procedures manually executable with computer assistance through activity lists
- Specify procedures fully automatable and capable of handling advanced decision logic for nominal and contingency operations

OPEN-M manages a procedure model addressing all above user cases at once. The procedure model is based on the ECSS standard ECSS-E-ST-70-32C and such that the procedures can:

- generate EGS-CC activity lists
- define human operator readable nominal and contingency procedures
- be natively fully executed by an EGS-CC based system without human intervention

A constraint to the procedure model design is the need to migrate existing missions by converting and importing legacy SCOS-2000 based flight control procedures without human effort. As those procedures were created for human interpretation, the import is achieved by capturing informal natural language operator statements or instructions at key locations within the formal procedure model in a coherent manner. The consequence is the relaxation of the procedure level of formalism for those types of procedures. In effect, using informal instructions deny the procedure automated execution without human intervention.

However, by supporting both manual and automated use cases, the procedure model allows the operator to progressively formalise existing procedures' content and achieve full automation when needed. The degree of procedure formalism and automatability is therefore progressively adjustable by the operators. The operators can use the same software and same procedure model for all their use cases. It is nevertheless noted that the number of tooling assistances provided by the software system increase proportionally to the level of formalism used by the operator (e.g., an informal statement ambiguous for the computer cannot be consistency checked nor autocompleted).

The coherent yet scalable model allows to specify procedures of various types while ensuring adequacy of the procedures, from the most basic procedures, such as a simple list of sequential instructions, to most complex execution use cases requiring all necessary operation decision logics and instructions.

A domain specific model is used as procedure format, allowing dedicated domain specific constructs and fine control on the tooling support. Multiple representations of the procedure are therefore also more easily achievable (e.g. textual, tabular, flowchart or others) compared to general purpose languages.

Finally, elements of the system under monitoring and control are addressed within the procedures in terms of EGS-CC monitoring and control elements as specified by the EGS-CC Tailoring Model Monitoring and Control Model (EGS-CC TDM MCM). The operator is therefore describing the operation against the mission's MCM.

5. System architecture

5.1. Beyond a procedure environment

While the OPEN-M system provides an environment for the management of control procedures, the system is primarily an environment dedicated to the management of EGS-CC-based tailoring data for missions. As the EGS-CC tailoring data natively includes flight control procedures as one element of its data model, the system naturally covers the management of procedures. Therefore, functionalities such as version control, consistency checking and collaboration functions are common to all data types.

Beyond procedures, OPEN-M supports the users in defining and managing all EGS-CC tailoring data such as monitoring and control activities, telemetry and telecommand packets, parameters, calibrations, checks, user defined displays and others.

5.2. Common framework with Ground Station procedures environment

All functions common to both the management of ground station procedures and mission control procedures share the same software implementation through the common use of the OPEN Framework. However, while OPEN-S, the ground station preparation environment, provides a dedicated implementation for the ground station procedures, OPEN-M equivalently provides dedicated software for the mission control procedures.

5.3. OPEN-M environment and user workflow

The OPEN-M environment is composed of a set of applications and processes working together to form a coherent system. The system is realised as a mix of web and desktop applications distributed on the client and server sides.

Central to the environment is the user data lifecycle based on continuous integration and delivery principles [3] supporting an iterative cyclic workflow enabling automation of workflow tasks by design. Tasks categorised as change planning and tracking, data creation and import, data modification, verification, validation, release, deployment, and evaluation compose the workflow and are managed by dedicated components.

5.4. OPEN-M rich client application

The user interface allowing tailoring data creation, import and modification is provided by the OPEN-M Rich Client application component, which is based on the OPEN Framework [6], itself based on the Eclipse Rich Client Platform (RCP). This desktop application enables tailoring data creation and modification through various specialised editors. Those editors are contributed through the Eclipse plugin mechanism to the application.

Editors are specialised based on tailoring data types and user editing usability.

- Form editors: one editor for each data types with user configurable layout; The set of editors supports all elements of the EGS-CC tailoring data model
- Table editors: a set of inter-dependent spreadsheet-like editors dedicated to data types such as Parameters, Activity Lists, Packets, ...
- Activity procedure textual editor (detailed below)
- Activity procedure tabular editor (detailed below)
- User defined display editor

- Synthetic expression editor
- Application script editor: allowing scripting the functions of the OPEN-M application for advanced data processing and user automation of the application functions
- Tailoring data consistency check editor

5.5. Standalone or multiuser collaborative deployment

Users can use the OPEN-M Rich Client application either stand-alone (with optional network connectivity) or in a collaborative mode as a client application exchanging information with a set of server processes for collaborative work with an integrated version control management.

This architecture allows many spacecraft engineers to collaboratively work simultaneously on the tailoring data.

5.6. Portal-M web application

The user interface supporting tailoring data visualisation and change management (covering change tracking, verification, validation, release, deployment) is provided by the Portal-M web component. This web application provides complementary functionalities to the Rich Client application and coordinate with the AIV and execution environments for the validation and deployment of the data.

Pushing forward towards the automatization of the verification and validation and deployment tasks, with the same spirit as a software DevOps environment, changes can be tracked through their various states and automatically released and deployed to the appropriate target environment, either for validation with the simulator or actual execution using the operational mission control system.

The component integrates the Flight Operation Plan (FOP) and action list management. The Flight Operation Plan is the organised set of nominal and contingency procedures foreseen to perform the mission.

5.7. Server-side components

Both the Rich Client and Portal-M frontend components interface, through REST APIs, to a set of backend processes composed of Spring Boot based processes and a Gitlab application. The Gitlab processes are used as a DevOps platform for the management of the tailoring data [3]. A relational database management system is used to store centralised information, such as action list and change requests. Mission tailoring data files are version controlled through a set of git repositories and centrally coordinated within the gitlab environment.

5.8. Multi mission deployment

The frontend applications and backend server processes and related data storage are deployable within a Kubernetes (K8s) instance, therefore allowing scalability, load-balancing, redundancy and standardised management of rollouts and rollbacks. Such deployment is therefore foreseen to be used soon for all ESOC missions, which represent about 200 users. While the Rich Client application is deployable directly within the user desktop environment, a K8s remote deployment accessible through remote display provides the flexibility of a modern cloud approach.

5.9. Activity procedure editors

As part of the OPEN-M Rich Client application, the environment provides mechanisms allowing “plugin” editors to edit a procedure with their own representation. Currently, a textual and a tabular representation editor are implemented. A visualisation flowchart is complementing the user experience and provide a view on the high-level flow of procedure steps.

Along with the functions shared by all tailoring data editors of the application, the system provides cross-editors logic dedicated to the procedure management (e.g., procedure dedicated consistency checks). Most application components are common to all procedure editors (MCM tree, workspace view, history, logs, ...).

From the usability point of view, the user perceives this as an integrated system, as one single procedure editor, providing multiple representations. The user can quickly switch between editors while the procedure is being modified. Elements of the Monitoring and Control Model can be drag and dropped within the procedure editor.

Additional plugin procedure editors can be contributed by developers via the standard RCP mechanisms to the application and allows for the integration of third-party editors.

5.10. Activity procedure textual editor

The textual representation of the procedure uses a domain specific language to represent the procedures and is implemented using the Eclipse Xtext framework [13]. This offers semantic colouring, auto-completion, fast consistency checks, automatic formatting, assisted refactoring, and other support features typically expected by modern general purpose language editors.

This is the default editor and is provided along the OPEN-M application software.

5.11. Activity procedure tabular editor

With a procedure representation inherited from ProToS, the procedure tabular editor offers a familiar user experience. The representation benefits from years of operational usage across a set of GSOC missions. It offers an alternative object-based view of the procedures content as well as easy to use editing functionalities while hiding some of the procedure languages complexity in the background.

This tabular editor component has license terms and conditions different from the OPEN software.

6. User efficiency

While it is too early to compare factual user efficiency metrics, the system improvements point toward a significant rise of productivity compared to the previous generation of systems.

- Higher levels of procedure formalisation can be achieved and therefore more software assistance is provided to automate the user tasks for editing, verifying, and validating procedures
- The functions of various legacy tools are more coherently integrated into a harmonised user environment; Manual and automated procedure formats are now unified
- Multiple procedure representations allow for more adequate usability and user experience. A textual representation of the procedure allows for more speedy procedure content changes
- Improved management of the data lifecycle following a DevOps approach

7. Community collaboration

The OPEN software source code, documentation and development environment are made available through the Space CODEV platform [1][14] within the territory of the ESA Member States and under a permissive software license allowing commercialisation of the software. Space CODEV is a collaboration platform of the European Space community born from an ESA initiative. The collaborative software development platform is based on the Gitlab platform and provides means to contribute to the software used by a community of partners including ESA.

The design of the OPEN-M rich client software natively supports extensions under different licensing conditions and implemented by different parties working collaboratively together. Extensions can be implemented as Eclipse plugins or other mechanisms. The GSOC OPEN-M procedure tabular editor implemented by DLR is an example of a proprietary extension.

8. Takeaway

This paper provides an insight into the procedure management environment which will be used to handle the challenging operational requirements at GSOC and ESOC on a collection of missions ranging from low orbit earth observation to deep space missions.

The procedure execution concepts and rational for the overall system and procedure design have been introduced. While most of the automated operations are planned and automatically executed through planned increments, control procedures can be operationally executed in various manners and through different channels. The new system covers all those in an integrated and coherent user environment.

The software is made available within a community of partners and the GSOC procedure editor is an example of extensions developed on top of the OPEN system to be benefit of the community.

The new environment presented is planned to be used by all future space missions operated at ESOC and GSOC as foreseen by the respective control centres strategic migration to their EGS-CC based infrastructure data systems EGOS-CC and GX-CC.

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