IAC-17-B6.1.2

Automated Procedure Based Operations for the European Data Relay System

Jan-Christoph Scharringhausen[a]* and Dr. Thorsten Beck[b]

[a] *EDRS Flight Director, Deutsches Zentrum für Luft- und Raumfahrt e.V. (German Aerospace Center), Münchener Straße 20, 82234 Weßling, Germany, jan-christoph.scharringhausen@dlr.de*
[b] *EDRS Project System Engineer, Deutsches Zentrum für Luft- und Raumfahrt e.V. (German Aerospace Center), Münchener Straße 20, 82234 Weßling, Germany, thorsten.beck@dlr.de*
* Corresponding Author

Abstract

The European Data Relay System (EDRS) provides a high speed data link between ground stations and satellites in low earth orbit. Up to 400 links per day are foreseen to be commanded by the ground-system established at DLR's German Space Operations Center (GSOC). The high command load is beyond the capabilities of a classical operational concept with manual operations. Therefore an automated system has been established at the Devolved Payload Control Center (DPCC), with human interaction only necessary following a contingency either in the ground processing or the space segment. Spacecraft operations are based on Flight Operations Procedures (FOP). These FOPs include all telecommands necessary to command the spacecraft, all telemetry parameters to be verified and additional information such as expected behavior, optional breakpoints and operational criteria. In a classical operational concept, the command release system and the telemetry verification system are often used separately, even if they are integrated into the same system, as it is the case with SCOS-2000. The telecommands are loaded into a stack and are sent by single access, while the telemetry is verified by human observation on a separate display system. For the Devolved Payload Control Center an automatic command and control system to operate the EDRS-A payload in its routine operations phase has been developed. This innovative system commands the payload during nominal operational conditions entirely without human interaction. It uses the same input FOPs as the classical concept but executes the whole procedure at once. This new concept is the first step towards a procedure based operation. Furthermore, this system is used with the EDRS-A payload for manual FOP execution. In this use case the system provides the procedure to the user who executes it step by step. For the routine phase of the upcoming EDRS-C mission this concept will be further developed to provide a complete procedure based interface to the spacecraft controller combining commanding and verifying of entire procedures in one single entity. This new concept will increase the situational awareness while at the same time providing more automation. It will include automated, manual, as well as a semi-automated operation concept focusing on decision breakpoints and automation in between.

Keywords: European Data Relay System (EDRS), Flight Operations Procedure, procedure based operations, spacecraft operations, automated operations

Acronyms/Abbreviations

DPCC	Devolved Payload Control Center
DPU	Data Processing Unit
EDRS	European Data Relay System
FDS	Flight Dynamics System
FOP	Flight Operations Procedure
GSOC	German Space Operations Center
LCT	Laser Communication Terminal
LMS	Link Management System
MCS	Monitoring and Control System
MIB	Mission Information Base
MOC	Mission Operations Center
SCC	Spacecraft Control Centre
SPACON	Spacecraft Controller
TC	Telecommand
TM	Telemetry
TTC	Time-Tagged Telecommand

1. Introduction

The European Data Relay System (EDRS) provides a high speed data link between groundstations and satellites in low earth orbit. On the first geostationary payload, EDRS-A, a laser communication terminal (LCT) as well as a Ka-band inter satellite antenna are available for the service. While a lower speed 600 Mbit/s LCT link is possible in parallel to a Ka-band link, the high speed LCT link with 1800 Mbit/s can only be established while no Ka-band link is ongoing. The system is designed to perform up to 400 links per day, 200 with the optical channel and 200 via Ka-band. The second payload, EDRS-C, will be on a dedicated satellite to be launched into geostationary orbit and will be equipped with a LCT. It is designed for up to 200 optical links as well.

Such a high command load combined with a required on-board autonomy of eight hours and a capability for late requests is beyond the capabilities of manual operational concepts. Only with the assistance of automated systems can we fulfil these high demands reliably and efficiently. For the Devolved Payload Control Center established at DLR's German Space Operations Center, an automatic command and control system to operate the EDRS-A payload in its routine operations phase was developed. This innovative system commands the payload during nominal conditions entirely without human interaction. A Link Management System (LMS) triggers the flight procedures to be executed while an Automator executes these procedures. In the flight procedures the steps are defined relative to a reference time. The Automator sends the telecommands with an execution time up to eight hours in the future to the spacecraft while the telemetry checks are queued and executed at the scheduled time. The Automator also represents a first step towards a procedure based commanding at GSOC.

The next steps will be taken for the Spacecraft Control Center (SCC) for the EDRS-C satellite. Contrary to the DPCC, in which only the payload of EDRS-A is operated, the SCC will be operating the EDRS-C platform as well as the payload. The operating concept will be further developed for the SCC's operations. While EDRS-A provided first steps to automated procedure based operations by the automated execution of procedures and by a modern interface for manual operations, for EDRS-C a new innovative approach for procedure based operation is planned to be used.

This paper starts with an introduction to the European Data Relay System and its operation challenges. Subsequently, an overview of the operational concept of the SCC is provided. Afterwards the operational concept for procedure based operations is outlined by the design principles of the Flight Operation Procedures (FOPs) and by their execution using the automation engine of the SCC.

2. The European Data Relay System

The European Data Relay system is designed primarily to both reduce the delays in transmission of data from low earth orbiting satellites and also to vastly increase the amount of data transmitted over a given period. The system is composed of two geostationary satellites positioned over Europe for in-orbit redundancy. The first (EDRS-A) is realized as a hosted payload on Eutelsat's EB9B satellite and has been launched in January 2016. The second (EDRS-C) will be a dedicated spacecraft based on the SmallGEO platform

developed by OHB. Both satellites are equipped with a LCT to provide high speed optical links of up to 1800 Mbit/s. In addition, the EDRS-A satellite carries a Ka-band inter satellite antenna to establish links to LEO satellites. Both link types are using common RF equipment to relay the received data to the ground via Ka-band. [1]

The central part of the EDRS ground segment shown in figure 1 is the Mission Operations Center (MOC) located at Airbus Defence and Space. It interfaces with all other components and coordinates the overall mission. The MOC receives the link orders which are requests for data transmissions between the LEO satellites and EDRS-A or EDRS-C from the different users. It schedules the mission timeline for both EDRS satellites taken all known constraints into account and sends requests for the scheduled links to the Devolved Payload Control Center, for the EDRS-A payload, and the Spacecraft Control Center for EDRS-C. The MOC also coordinates with four groundstations based at Harwell, Weilheim, and Redu, which receive the user data from both EDRS satellites and deliver the data to the users.
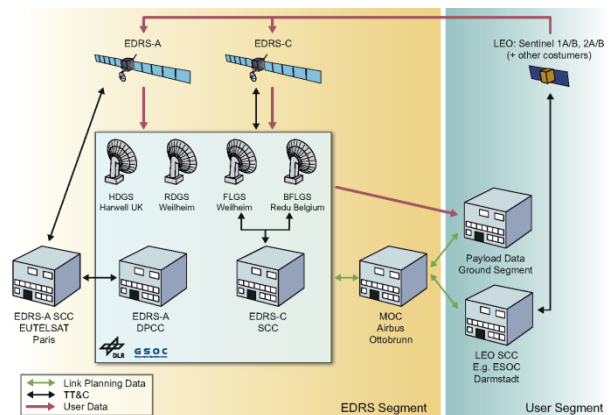

Fig. 1: EDRS system overview

The MOC is connected to the DPCC via a file based interface. The following request types are defined to be delivered by the MOC:

Payload link configuration request
The request type for each link execution either by the LCT or the Ka-band inter satellite antenna. It contains information of the link direction (EDRS to LEO, LEO to EDRS, or bidirectional), link speed, and LCT configuration parameters. It also contains coefficients of the LEO satellite's trajectory in the case of a LCT link, or vector data for the pointing direction of the Ka-band antenna.

Payload routine configuration request

This is a generic request type triggering the automatic execution of a flight operations procedure. The request contains the ID of the FOP, the necessary parameters for the FOP, and an execution time. Only a small number of FOPs are possible to be requested for automated execution.

Payload basic configuration request

This is a generic request for the manual execution of a FOP. Similar to the routine request it contains the ID of the requested FOP, its parameters, and execution time. Contrary to a routine request this FOP is executed manually by the DPCC's or SCC's flight operations team. Only a small quantity of requests of this type is expected. Because of the complexity and required manual intervention of these FOPs no automatic mechanism is established.

Forward tasking data request

The LCT link service provides a mechanism to forward data from the EDRS satellite (in GEO) to the target LEO satellite. These binary data are delivered to the DPCC and SCC via forward tasking data request and uploaded into the data processing unit (DPU) on-board EDRS.

Payload configuration deletion request

All request types above can be deleted by this request type. In the case the DPCC's or SCC's internal processing is ongoing, the process is stopped internally. Otherwise, if the request is already processed into TC sets forwarded to the Eutelsat SCC or commanded to the spacecraft, a FOP to delete the commands from the on-board time-tag TC buffer is generated and executed.

The DPCC and the SCC are located inside the multi-mission environment of the GSOC. The very concept of multi-mission is based on the sharing of existing infrastructure (buildings, network, and software) with other missions. Within this environment a layered architecture of several components providing the EDRS service has been created [2]. A Link Management System is processing the automatic requests received from the MOC [3]. It interacts with a Flight Dynamics System (FDS) and the Automator. The latter is the central component executing the automatized flight operations procedures. All components are reporting their current status to a common monitoring tool [4].

3. SCC Operations

In principal the operational concept for commanding and monitoring the link service is fully automatic operations. The sheer number of up to 400 links per day is the main driver for such an approach. An additional

driver is the required speed of processing from receiving link requests from the MOC until sending commands to the spacecraft. A late request is possible until 45 minutes (reception at SCC) before its execution. With the involved complexity of each link the processing is beyond the capability of manual commanding concepts.

3.1 The Classical Operations Concept

In the classical concept at GSOC the Spacecraft Controller (SPACON) is the central entity during routine operations. Like a spider in its net all threads converge at him/her.

On the one hand the SPACON interacts with all ground components. These may be the groundstations with which the SPACON has to coordinate e.g. ranging sessions, frequency or handovers. Also some observability of the groundstation for a fast reaction in case of an issue with the spacecraft connection is needed. It might also be support components like the FDS where information must be extracted from to coordinate for example groundstation handovers, station keeping maneuver preparation or eclipse operations.

On the other hand the SPACON operates the spacecraft according to straight forward procedures. The two main components of the ground segment used by the SPACON for carrying out a FOP are the commanding and the telemetry chain.
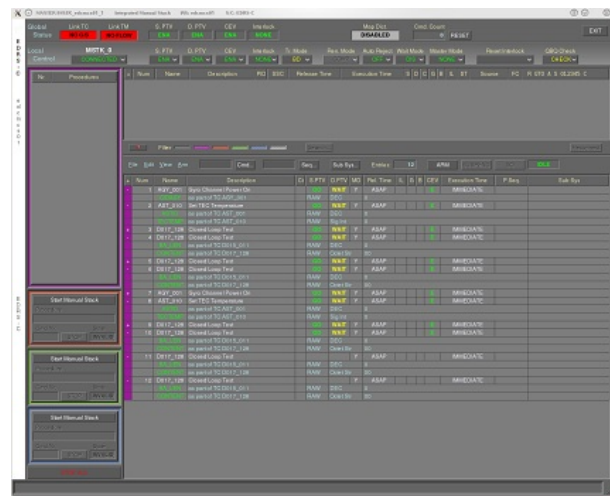

Fig. 2: GECCOS manual stack

On the commanding chain, the tool used is the manual stack of GECCOS, GSOC's core monitoring and control system (MCS), an enhanced derivative of ESA's SCOS-2000. The manual stack is a graphical interface with one telecommand line by line. The SPACON can either load each TC from the Mission Information Base (MIB) or use a pre-defined sequence

from the MIB. If parameters are necessary for the telecommands, the SPACON can either enter these manually to the sequence's TCs or load a Task Parameter File (TPF) which contains all parameters for a specific sequence. Figure 2 shows the manual stack of GECCOS loaded with telecommands.

In order to verify the TCs' execution and to monitor the satellite's status, the SPACON uses the monitoring tool Satmon in addition to GECCOS. This tool provides the satellite's telemetry via alphanumeric display pages and free configurable graphical plots. As a special display type it contains Procedure Pages. These pages list all telemetry checks of a FOP showing their expected values as well as their current value. A check of expected against current value is displayed with a simple red/greed sign. The Procedure Page provides a simple but efficient tool to be followed during the manual FOP execution by the SPACON. In figure 3 a typical view of Satmon shows an Alpha Numeric Display page (top left), a line plot (bottom) as well as a Procedure Page (right).
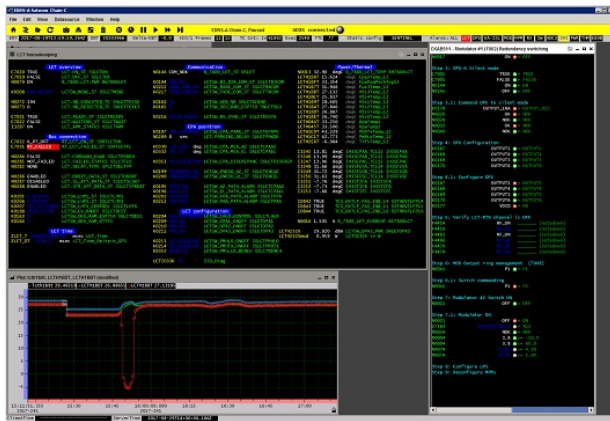

Fig. 3: Satmon display system

3.2 Automated Operations Concept

With the high number of operations for up to 200 links per communication channel, an automated operations system is a necessity. The system is designed to execute all routinely occurring tasks without human interaction. Only in case of anomalies and non-routine tasks, a SPACON must interact. Therefore the operations concept of the SCC integrates both the classical and an automated concept and approaches.

3.2.1 Link operations

The Link Management System (LMS) is responsible for the planning of all link requests transmitted from the MOC. Usually these requests are available in the SCC latest eight hours prior to their planned execution time

as shown by the autonomy displayed in figure 4. In addition late requests are possible until 45 minutes before execution. At each LMS planning cycle it compares the list of pending (not yet uplinked) link requests with the table mirroring the current state of the on-board time-tagged telecommand (TTC) buffer. As a result of this comparison, the LMS selects which activity (LCT link, forward data, routine) shall be uplinked next. The LMS always takes the next activity in the chain (chronological sorted) and tries to load it into the TTC buffer. In order to assess how many TTC slots are required for an activity, the LMS must know the number of TTC required by each FOP. The LMS scheduling process is triggered either after reception of a payload link configuration request or when the Automator delivers the current state of the TTC buffer to the LMS. This ensures low-latency LMS operation. In the case where there are not enough TTC slots available for a pending complete activity, the LMS postpones the uplink until the next planning cycle. Knowing the feedback from the Automator about the TTC buffer state, the LMS only uses the TTC buffer information that is verified by telemetry. Consequently it is ensured that enough space is really available in the TTC buffer before actually sending commands. As such, the TTC buffer on-board will be constantly kept as full as possible. Through these successive planning cycles, the LMS tries to schedule any request in its request database.
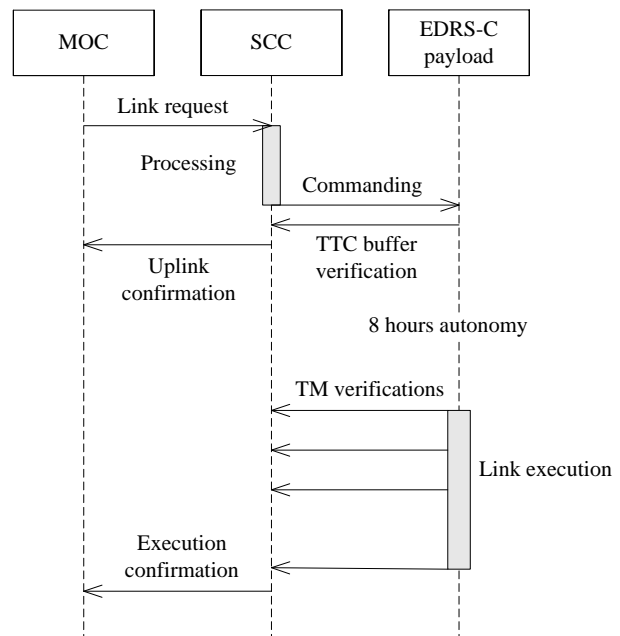

Fig. 4: Optical link sequence

The LCT links are possible in return (from the target LEO satellite via EDRS to the ground), forward (to the LEO satellite), and bidirectional. The actual link

commanding is similar in all three LCT link cases, but for forward and bidirectional links the binary data to be forwarded has to be uploaded to the DPU prior to link execution. This forward tasking data service is done via the normal commanding channel by telecommands containing 62 bytes of data. The filling of the DPU forward data buffer of five megabytes is planned by the LMS with a lower priority as the link commanding in order to not block the link execution. The LMS for DPCC and SCC is explained in more detail in [3].

3.2.2 Situational Awareness

In the classical manual operations concept, the SPACON is the one triggering all operational processes. A fully automated system with its built-in complexity is more difficult to monitor. Therefore, in order to have a detailed overview of what is going on there needs to be a centralized monitoring component which provides a comprehensive overview of all performed activities and which will enhance situation awareness both in nominal and anomaly situations. Furthermore, as part of GSOC's multi-mission concept, the SPACON is shared between multiple missions. Gathering the situational awareness after a not normal situation occurred is one of the big challenges emerging from an automated system.

A centralized reporting component is implemented into the automated system. The software NEMO (NEtwork MOnitoring) was developed to monitor the server systems at GSOC and was expanded to monitor all components of the DPCC and the SCC.

Figure 5 shows the standard view of NEMO for the DPCC. More information on situational awareness in DPCC and SCC can be found in [4].
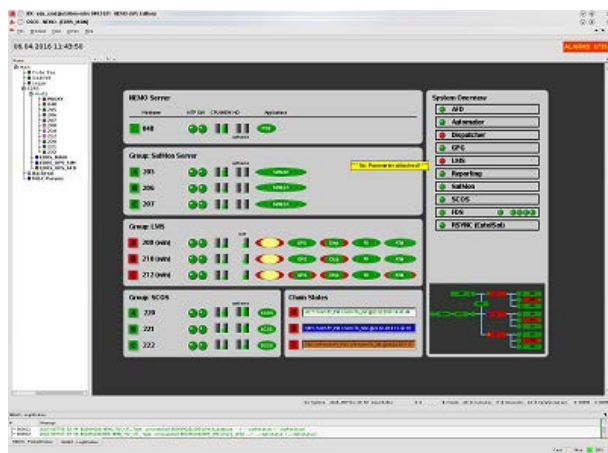

Fig. 5: NEMO component monitoring

4. Flight Operations Procedures

The European Cooperation for Space Standardization (ECSS) defines an operations procedure: "An operations procedure is an elementary component of the mission operations plan that defines the actions to achieve a specific operational objective. The complete set of operational procedures covers all planned operations for the space and ground segments. An operations procedure is a "building block" used in the construction of the actual operations to be performed in a given mission phase. An operations procedure may be called up by a mission timeline, an automatically executing schedule, another procedure or it can be initiated manually." [5]

At GSOC the operations procedures are divided into flight and ground procedures. A Flight Operations Procedure (FOP) is a predefined and validated set of instructions to operate the spacecraft. It contains all instructions necessary for safe and reliable execution of a specific task. This includes the exact timing and sequence of commands to be sent to the spacecraft and of checks performed on the satellites telemetry. These are complemented by comments providing further details for the person executing the FOP. More advanced FOPs include some logical decisions, such as if-then-else branches or while loops.

In the classical telecommand based manual operations concept these FOPs are read and executed by a human. In certain circumstances, this might lead to human errors during execution, which need to be prevented by the design of the FOP. Complex logical operations are error prone, especially in stressful situations. The execution by a procedure based system where the logical operation is followed by the system reduces the possibility of errors in those cases. On the other side is the human knowledge based on the study of handbooks and experience an addition to the information included in the FOP. The operator can react on any not normal situation by some means based on the knowledge. The operator knows how to react if any telecommand execution or telemetry check fails, at least where to look for an appropriate reaction. This knowledge is still available in a procedure based system, but it is not immediately available during fully automated execution. For this operational mode much more conditional paths must be implemented into the FOP. It needs to have a case to be executed on certain contingency cases identified by explicit checks. To define and implement all necessary contingency cases is an additional effort which may significantly increase the FOP development time.

In figure 6 a typical FOP is shown. The start and the end of the FOP are marked by the red rows. The light blue row includes the procedure's variables. Step 2 and 3 show the visualization of a repeat-until-loop while the steps 4, 5 and 6 represent an if-then-else decision. Telecommands can be identified by their yellow color while telemetry checks are white.

Fig. 6: Flight Operations Procedure

For an automated operations concept the FOP must be readable for humans and the automation engine. A lot of information that is known to the human operators must be brought into the FOP for the procedure based execution system. For example one point to be considered is the timeout of telemetry checks. Conventional FOPs do not include such a timeout. The operator knows the delay of a telemetry value to change after a commands execution. This delay depends on the time the TC needs to be fully executed, e.g. the switch on time of a component on-board, but also on the telemetry downlink time. At different mission scenarios the interval of the same TM might be as short as once per second, but also a downlink every couple of minutes is possible. This is known to the human operator, but not to the machine. A time window must be defined for every TM check to advice the automation engine how long to wait until the verification shall be completed. Also a lot of information can be given in the comments of a FOP. It is possible for example to give the information that only one of the following two TM checks must be successful. Or a comment can define that a following TM check must not be exactly the defined value but it must be visible that the current value is approximating to the expected one. These comments cannot be processed by the automation

engine and must be transformed into logical statements such as if-then-else decisions.

4.1 FOP execution step approach

A major decision for the FOP design is the execution step approach:

Statement by statement

The execution of a FOP can be statement by statement. In this approach the executor takes every single statement of a FOP, such as telecommands and telemetry checks, executes the statement and waits for its success before the next statement is executed. This approach is the easiest to follow and therefore the easiest and safest design of the FOP. However it lacks a certain dynamic. With no statements being processed in parallel the execution is time consuming.

Step by step

The statements of a FOP are hierarchically organized in steps. The step by step approach uses this hierarchy in the execution of the FOP and executes all statements of a step in parallel. The telecommands of the step are transmitted to the spacecraft one after the other with a defined delay in between, while the telemetry checks are verified all in parallel with their defined timeout period. This approach gives a certain flow to the execution of the FOP. The execution is still easy to follow but the FOP design is more complex. All preconditions for the telecommands execution of an entire step must be fulfilled before the step. This has to be taken into account during the design.

All at once

While the statement by statement and step by step approach are both equally possible with advantages and disadvantages, the all at once approach should be avoided. In this approach all statements of the entire FOP are executed in parallel. The step hierarchy is only for the human eye in order to understand the procedure. It might be used for short procedures only if a failure in the execution does not cause any harm on the spacecraft under every circumstance. However also for these procedures one of the other approaches is superior.

4.2 FOP scheduling

The timing is an important characteristic of a FOP. Its design and definition importance is even increased for FOPs that should be executed procedure based. While a human operator in the classical concept takes some responsibility of the timing based on his training and experience, all timings must be defined in the FOP for an automated execution. On the first level the time when the FOP is executed must be defined. The

execution start is either triggered by another part of the control center, the LMS, or by human interaction. In case of a direct procedure, meaning a FOP without statements to be executed time tagged, no further reference times must be available. For procedures to be executed time tagged, the LMS or the human operator defines one or more reference times. These times are used for the execution of a sequence of telecommands and telemetry checks. These are either scheduled at the reference time or with a delta time to this reference. The telecommands are sent immediately to the on-board telecommand schedule and will be executed at the given time. The telemetry checks are queued inside the automation engine and are executed at the correct time later on.

5. Flight Operations Execution

The FOPs' executing component is the Automation Engine, also referred to as the Automator, of the SCC. It provides two main functionalities to the operator: On the one hand it instantiates the FOPs and initiates their execution. On the other hand it is keeping track of the FOPs' execution. The Automator connects to the MCS GECCOS via its external interfaces. Through this interface, the Automator can inject telecommands, and fetch or subscribe to telemetry packets and parameters. The telecommands are sent to the spacecraft via the groundstation which gives feedback about the success of the release to the MCS. The spacecraft acknowledges the successful reception and execution of the telecommand in the telemetry via the PUS service. With the information of the service telemetry packets, the MCS flags the telecommand's success or failure. This information is available in the MCS's TC history which is fetched by the Automator regularly. The telemetry checks defined in the FOP are executed by the Automator by requesting the parameter from the MCS and evaluating it every second during its timeout period.

The FOPs are deposited in a version controlled repository available to the Automator. All FOPs must be instantiated before their execution. This can be done automatically or manually. For automated execution the Automator receives a FOP request from the LMS, identifying the FOP to be executed and including all necessary instantiation values. When the Automator receives such a request, it loads the FOP, instantiates it and start its execution fully automatically. No interaction by a SPACON is needed. In case of a manual execution of a FOP the Automator provides a graphical user interface shown in figure 7. The SPACON can use this view to load the FOP and instantiate it by either loading a Task Parameter File or by entering the instantiation values manually. On the left side of the instantiation view an overview of the

FOP is displayed to the user. The right side provides the variables of the FOP and all editable parameters of the TCs, TM checks and calls to other procedures. The values entered are verified against the parameter definitions provided in the Mission Information Base. After the FOP is instantiated by the SPACON, it is possible to save the instantiation values for later reuse or documentation, and the FOP is transferred into the execution view.

After the FOP has been transferred to the execution view, the Automator provides three execution modes:

Manual Mode
The execution in manual mode is close to the classical operations concept. The SPACON executes the procedure in the Automator GUI either step by step or statement by statement. The benefit to the classical concept is the procedure based approach. In one single component the release tool for the telecommands and the telemetry verifying tool are combined. The flow through the FOP is much better visualized as it is if the tools are separated.

Automatic Mode
The automatic mode is used to process the FOP requests from the LMS. The execution is using the step by step approach. The Automator is capable of executing numerous FOPs in parallel in this mode. This is necessary due to the on-board autonomy required for the EDRS service. The execution of a LCT link FOP is started eight hours in advance of the actual link start time by uploading all TTC into the on-board schedule. This is the first step of the link FOP. The steps afterwards are verifying the successful execution of the TCs and of the link. These telemetry verifications are queued in the Automator and executed at the correct time during the link. Accordingly the step by step execution of each FOP has duration of eight hours.

Semi-Automatic Mode
In semi-automatic mode the SPACON triggers the execution of the FOP and follows its execution, but in contrary to the manual mode the SPACON does not need to advance the execution. The semi-automatic execution follows the step by step approach. An interaction by the SPACON is only needed at the beginning of the FOP by starting its execution. Afterwards the Automator executes the entire FOP step by step until the end. This can be interrupted by control statements in the FOP used as a breakpoint where an operator must decide if the FOPs execution shall go on. This mode provides benefits to the GSOC multi-mission concept, because it is possible for only one or two SPACONs to operate a fleet of satellites in parallel. The automation engine is executing the FOPs for the

SPACON who only has to pay attention to the execution at the beginning or at non nominal situations.

For manual or semi-automatic mode the Automator provides the execution view shown in figure 8. It displays the procedures variables on the top right side. These have been set during the instantiation of the FOP but can be recapped here. Below, the controls for the FOP execution can be found. On the left side the main procedure view displays the steps to be followed by the user. The currently executed statement can be identified by its blue border as shown on the yellow telecommand. The successful execution of a telemetry check statement is indicated by a green check mark while for the telecommand statements three check marks indicate the successful reception, execution start and execution finish on-board. In semi-automatic mode one statement after the other is executed in this view which can easily be followed by the SPACON.

The Automator is realized in server-client architecture. A central server component is remotely controlled by a GUI client. In addition to the controlling client it is also possible to use multiple monitoring clients to follow the execution. This approach can be used in a multi-role control room situation, like the control of the launch phase of a satellite, where one member of the flight operations team is in charge and executing the FOP while other members of the team are following the execution.

In the near future it is planned to implement an additional view on the FOP as a flow diagram. This kind of representation reduces the detail to the step level only, but provides a better overview over the FOP. Flow diagrams are already in use for a fast understanding of the FOP's content but so far limited to a static diagram. The foreseen implementation into the Automator execution viewpoint will enable a fast overview on the current execution status for members of the operations team only following the operations. It is the idea to use a standardized behavior modeling language such as flow diagrams of the systems modeling language SysML [6] for this representation.

6. Conclusion

The procedure based operation concept advances the automation as well as the multi-mission concept at the German Space Operations Center. The first steps have been taken in the DPCC for the operations of the EDRS-A payload and have proven the feasibility of this approach. The planned extensions to the DPCC's capabilities for the upcoming EDRS-C mission shown in this paper are designed and will be implemented before launch. This cutting edge concept will not only provide more situational awareness of the operations but also enable new concepts in automated spacecraft operations. One new concept for GSOC currently under investigation is the automatization of station keeping maneuvers for geostationary satellites.

References

[1] Wallrapp, F., Ballweg, R., and Gataullin, Y.: The European Data Relay System (EDRS): Operational Challenges, IAC-11.B6.2.4, 62nd International Astronautical Congress, Cape Town, South Africa, 03-07 October 2011

[2] Beck, T., Schmidhuber, M. and Scharringhausen, J.: Automation of Complex Operational Scenarios - Providing 24/7 Inter-Satellite Links with EDRS, AIAA 2016-2417, SpaceOps 2016 Conferences, Daejeon, Korea, 16-20 May 2016

[3] Göttfert, T., Grishechkin, B., Wörle, M., and Lenzen, C.: The Link Management System for the European Data Relay System, AIAA 2016-2645, SpaceOps 2016 Conferences, Daejeon, Korea, 16-20 May 2016

[4] Scharringhausen, J., Kolbeck, A., and Beck, T.: A Robot on the Operator's Chair - The Fine Line Between Automated Routine Operations and Situational Awareness, AIAA 2016-2508, SpaceOps 2016 Conferences, Daejeon, Korea, 16-20 May 2016

[5] ECSS Secretariat, ESA-ESTEC, Requirements & Standards Division: Space engineering: Ground systems and operations, ECSS-E-ST-70C, Noordwijk, The Netherlands, 31st July 2008

[6] Object Management Group, Inc.: OMG Systems Modeling Language, Version 1.5, OMG document formal/2017-05-01, May 2017
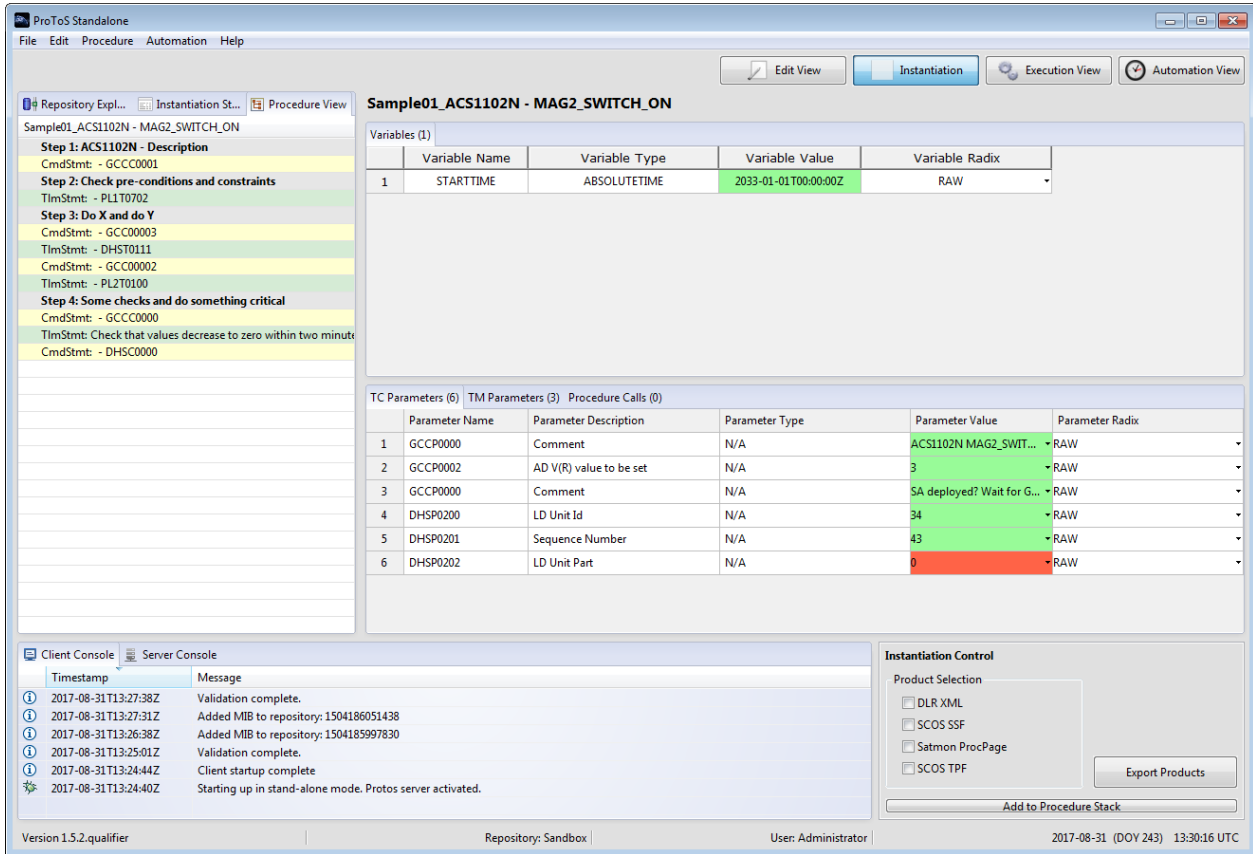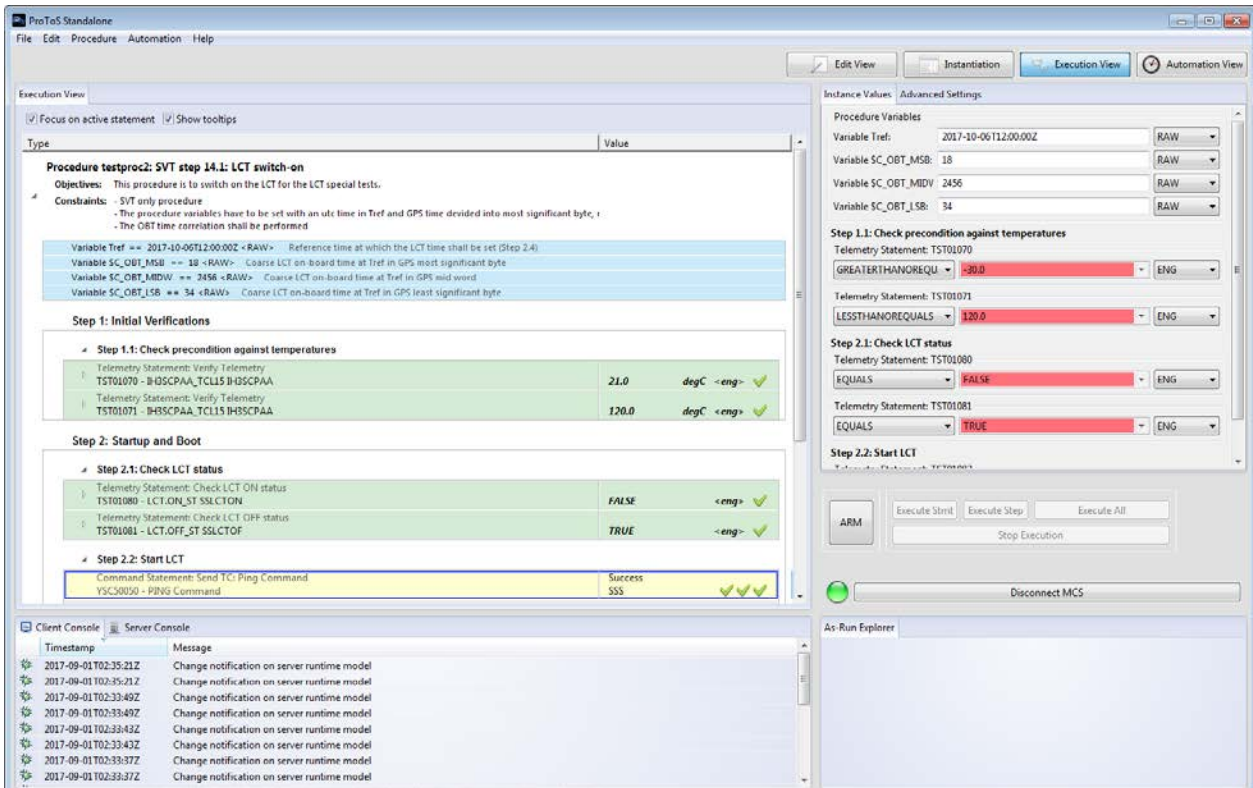
Fig. 7: Automator instantiation view

Fig. 8: Automator execution view