

Full scheduling of the CCC operations: POPS

Marc Duhazé¹, Laurent Arnaud² and Gilles Picart³
Centre National d'Etudes Spatiales, Toulouse, France, 31401

For many years, for each phase of a mission (Launch and Early Operations Phase (LEOP), Safe Hold Mode (SHM) recovery ...), all operations of CNES satellites had been driven by a specific excel Sequence Of Events (SOE) produced for this phase. All operations teams had to prepare manually their own plans (TeleCommands (TC) for board team, Ground Control Procedure (GCP) scheduling for flight dynamics and ground teams...) according to this SOE with potential human errors. In order to improve this situation, a piece of software called POPS (Planification des Operations Satellites) has been developed by the operational teams. It allows to produce a Sequence Of Operations (SOO) describing operations to be performed at the Command Control Center (CCC) system level, whatever the mission phase (LEOP, SHM, routine, End Of Life (EOL)...) and to generate coherent operational products such as the SOE or time tagged (TTG) TC plans. To meet this objective, the activities that must be conducted are defined through rules written in an "operational" language. These rules may be assimilated as a software translation of the Flight Operations Plan (FOP) documents. When needed, rules corresponding to the mission phase are instantiated with the current context in order to produce a SOO covering all operational tasks. It is then possible to create the operational products required to operate the mission. The paper will first present the main concept of POPS and its major features. The second part will focus on some operational use cases: PROTEUS, MYRIADE and PLEIADES missions. It will present in a third part, a feed-back including main advantages and operational impacts and then to conclude, some recommendations on the way to deal with this scheduling domain.

I. Introduction

THE mini-micro operations department operates several PROTEUS and MYRIADE satellites in orbit. JASON 1, in 2001, was the first of them to be launched. At this date, all the operations performed in the department was dedicated to this satellite, a brand new platform controlled with a brand new ground segment.

Due to mini-micro activity plan, it was decided to develop a common ground segment, with a CCC based on JASON 1 CCC, and compliant with future operations of any PROTEUS and MYRIADE satellite to come. In 2004, DEMETER was the first MYRIADE satellite to use this CCC, followed by PARASOL and four ESSAIM satellites six months later. Early 2006, CALIPSO was the first PROTEUS family operated from this common ground segment.

It is in this context of eight in-flight satellites, that we had to deal with the next LEOP of COROT spacecraft. In front of the human and cost resources limits reached, we tried to find some ways to rationalize, improve, and secure the operations. The main axis was to imagine some tools over the CCC, to reduce numbers of manual actions synonym of human costs and operational mistake sources. For instance, some tools were developed to improve management of common and specific satellites data, configuration management and deployment of CCC software... One of the main evolution concerns the SOE which reports (on a paper form) all the activities to hold in the CCC needed for a dedicated phase. This SOE was issued manually, with a contribution of all operations teams, with an emphasis on express at any time the operations really done. To help that, we created a tool able **to describe all the CCC activities** depending on conditions (LEOP, routine, EOL, exceptional phases...) **with a system point of view and to produce all operational products** needed, to prepare and lead the operations.

¹ Operations Expert, Mini and Micro Missions Department, marc.duhaze@cnes.fr.

² Ground Operations Expert, Ground Operations Department, laurent.arnaud@cnes.fr

³ Board Operations Expert, Tele-detection Satellites Board Department, gilles.picart@cnes.fr.

II. Main concept

The aims of this software are to provide a system view of CCC activities in a syntax close to the human language, to produce the associated SOE needed to validate the foreseen operations in preparation phase, but also, as far as possible, to guarantee the coherency between “what we say” in the SOE and “what will be really done” during the operations in the CCC.

These requirements lead to a use case concept in three steps: to describe the operations through rules, to estimate these rules on a period taking into account inputs (orbital events, booked passes...) in order to produce the SOO corresponding to this period, and finally to produce all operational products needed to perform CCC activities (ground procedures schedule, time tag TC to upload, SOE) from this SOO.

A. Operations rules

In the first step, the operator has to describe the CCC activities using a syntax. Each activity can include one or more rules. Each rule is composed of a triggering factor with optional pre-conditions and one list of operation cases. Each case of operation includes some tests, and the list of operations themselves including a type and one or more treatments of this type. Figure 1 shows the corresponding syntax.

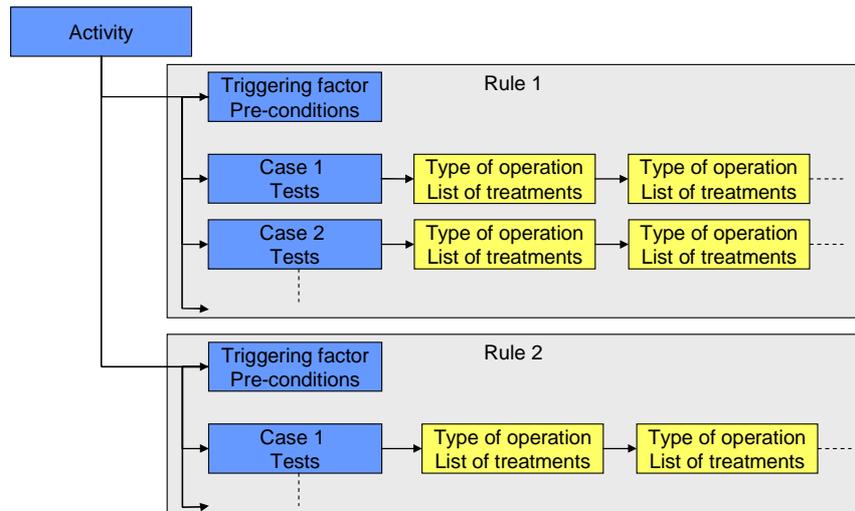


Figure 1. Syntax description of an activity.

For instance, to describe a Coarse Sun Sensor (CSS) board assessment to perform in routine phase, we could key in an activity “*CSS Routine expertise*”, with one rule, triggering on the activating factor “*at 04:00:00*” UT hours with the pre-condition “*during routine phase*”, and then one operation case matching on test “*the 2nd of the month*”, a “*TTG*” type operation with the plan “*CSS_Monitoring_routine*” as treatment. The MMI on Fig. 2 shows this activity in a language close to the CNES operational wording and fully configurable.

Board Team	CSS Routine expertise	Independant rules
# 4 hours monthly expertise		
Triggering on : at 04:00:00		
# Expertise only done in routine phase		
Preconditions : during ROUTINE phase		
# To do the 2nd of each month		
In the following case : the 2nd of the month		
Operation TTG to do +0 sec: CSS expertise		
CSS_Monitoring_routine.pln		

Figure 2. Example of a simple activity.

This encoding allows describing simple or more complex operations as well. During LEOP or exceptional phases, some operations have to be programmed on successive fly-bys, provided that some conditions between fly-bys are complied with. This syntax cops with that.

For example, to change the mission pointing of COROT, coordinated operations have to be performed with the mission center. The first passes of this station setting phase are devoted to exit the instrument of the Attitude and Orbit Control Subsystem (AOCS) platform control loop⁴ and then program the new mission pointing to reach. Overall, this sequence needs three passes, and then the new pointing can be executed on board. This activity can be translated as four linked rules.

⁴ COROT instrument is used in the control loop to reach the attitude control accuracy needed for the mission

- The first rule dedicated to the come back to nominal PROTEUS control mode step 1, triggers on “AOS 10°” of a chosen pass “SKRN01 number 49” for instance. It includes five operations types (*WARNING-SOL*: warning information for ground team, *PGT*: ground control procedures, *WARNING-BORD*: warning information for board team, *FCP*: Flight Control Plan, *PLAN_CM*: commands group delivered by mission center). Each operation is synchronized with a positive or negative delay added to the activating factor timestamp.
- The second and the third rules are just linked to the previous one. The activating factor can be translated as “on AOS 10° of the next pass”. So operations of rule number two will be executed on the booked pass right after “SKRN01-49” and operations of rule three will be executed on the following pass.
- The last rule, will be held on the next ascending node orbital event “OI” following the back-up pass of the third rule.

Board Team	Subphase 0 : NOM PROTEUS Return	Linked rules
# Return into NOM COROT and NOM PROTEUS STEP 1		
Triggering on : on fly-by event AOS 10 degrees (E33) +10 sec		1
Preconditions : on earth terminal SKRN01 number 49		
In the following case : always		
Operation WARNING_SOL to do -1010 sec : Wait for board team for pass preparation		
Operation PGT to do -1000 sec : Wait for board team		
/COR_PASS_Attendre_go_bord_SQ_PGT.rux		
Operation WARNING_BORD to do +0 sec : Check routine TTG uploaded on-board		
Operation WARNING_BORD to do +5 sec : Raise STR and payload bias		
Operation FCP to do +10 sec : Return into NOM COROT platform mode		
FPM_2_NOM		
Operation PLAN_CM to do +20 sec : Return into VLE APS payload mode		
COR_TC_RT2_TR_TTMODE_VLE_APS*		
Operation FCP to do +40 sec : Return into NOM PROTEUS platform mode STEP 1		
ENAFRIC_4RWS_step1		
# Return into NOM PROTEUS STEP 2 and load of the new pointing		
Triggering on : on fly-by event AOS 10 degrees (E33) +10 sec		2
Preconditions : on earth terminal of TMTC		
# Simple pointing change		
In the following case : always		
Operation WARNING_SOL to do -1010 sec : Wait for board team for pass preparation		
Operation PGT to do -1000 sec : Wait for board team		
/COR_PASS_Attendre_go_bord_SQ_PGT.rux		
Operation FCP to do +10 sec : Return into NOM PROTEUS platform mode STEP 2		
ENAFRIC_4RWS_step2		
Operation INFO_BORD to do +35 sec : New pointing towards LRa05		
Operation FCP to do +40 sec : Pointing upload		
CHANGT_POINTAGE		
# Back-up fly-by		
Triggering on : on fly-by event AOS 10 degrees (E33) +10 sec		3
Preconditions : on earth terminal of TMTC		
In the following case : always		
Operation INFO_BORD to do +5 sec : Back-up fly-by		
# Board new pointing execution		
Triggering on : on orbital event Ascending Node (O1) +0 sec		4
Preconditions : Always		
In the following case : always		
Operation INFO_SAT to do +0 sec : Execution of the new pointing : LRa05		
Pointing LRa05 (NA) reached at \${TIME}		

Figure 3. Example of a complex activity.

B. Rules estimation

The second step consists in the estimation of the rules on a chosen period. It plans all the operations and associated treatments.

The principle is to evaluate each rule according to inputs on the period as orbital events prediction, booked passes ... The software creates then a list of dated operations which can be merge in the current SOO in order to extend or replace it on the chosen period.

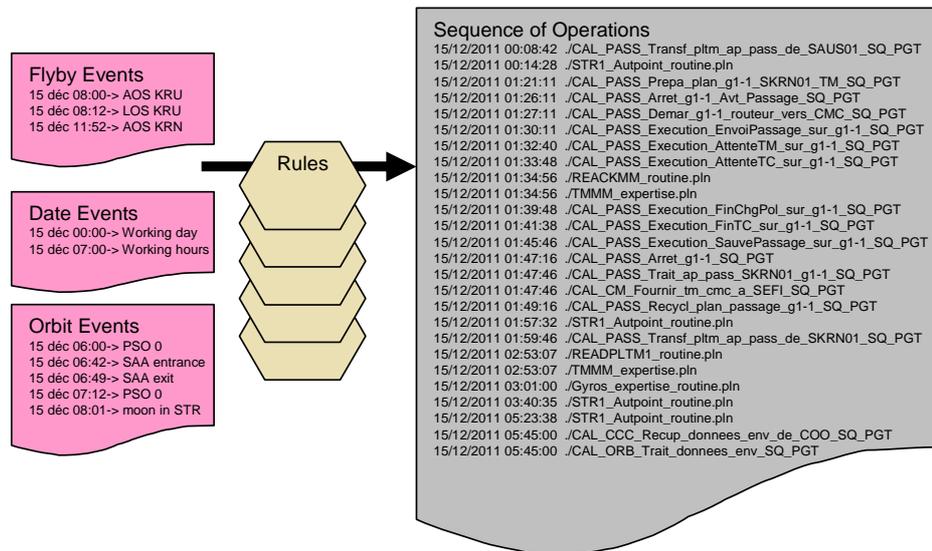


Figure 4. SOO estimation diagram.

C. Operational products generation

The last step allows generating all needed operational products from this SOO. It is possible to select what operational product to generate on which period. Each product generation is based on filters applied to SOO as operations types and activities, and have its own rhythm, for instance generate ground products twice a week, time tag commands to upload once a week, booked pass list synthesis to send to mission center twice a month.

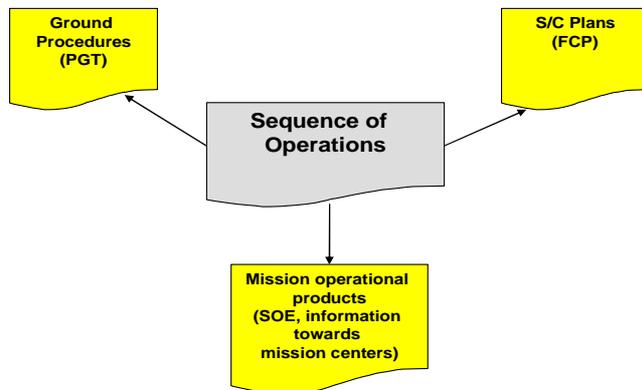


Figure 5. Operational products generation.

To make the software open, extensible, and decoupled from mission specificities, POPS uses scripts as plug-in to interface with the CCC. Plug-ins are used both to transform mission input files into dated events usable in the rules, and to transform the SOO into the mission operational products. With this architecture, POPS does not need to know the different input or output mission formats. This point is fully addressed at plug-in level.

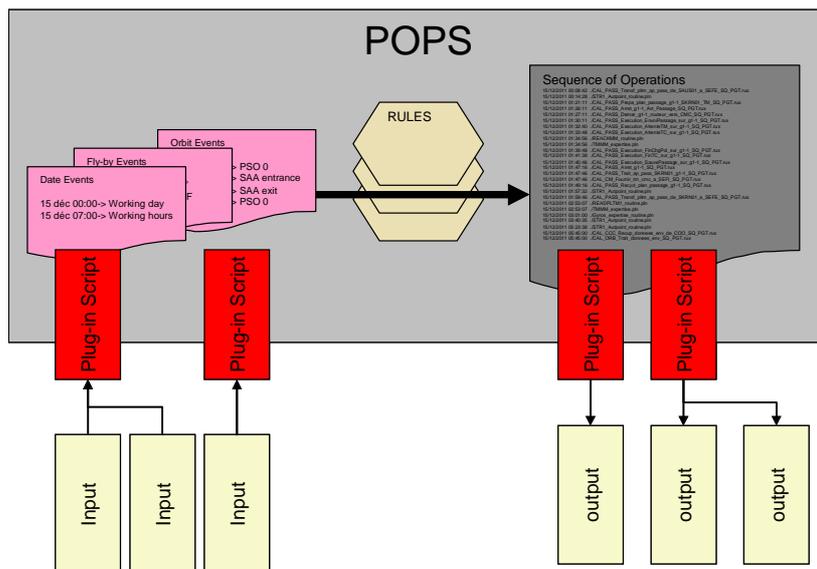


Figure 6. Input output plug-in concept.

POPS concept deals with a real flexible approach because it allows :

- to adapt operations according to mission needs such as:
 - take into account a new kind of input interface through a new plug-in,
 - generate a new kind of operational product through a new plug-in,
 - define specific operations types to cop with organization for instance (specific team involved in the operations),
- to permit operational changes:
 - take into account rules updates,
 - take into account predicted inputs updates, for instance after a booked pass change in near future.

III. POPS major features

All these processes bring a lot of improvements in our operational context of multi-satellites, multi CCC operated by different teams (ground, board, flight dynamics, mission), with some people in charge of one, several or all the missions.

First of all, this tool gives us a standard **system view** of all the activities for a given mission. The MMI presents a condensed view, deployable to go through each activity in details. So in case of anomaly, for instance if the a multi-missions on-call engineer wants to check or understand what has to be done on a specific mission, he can just have a look on POPS activities and go through chosen ones to detail.

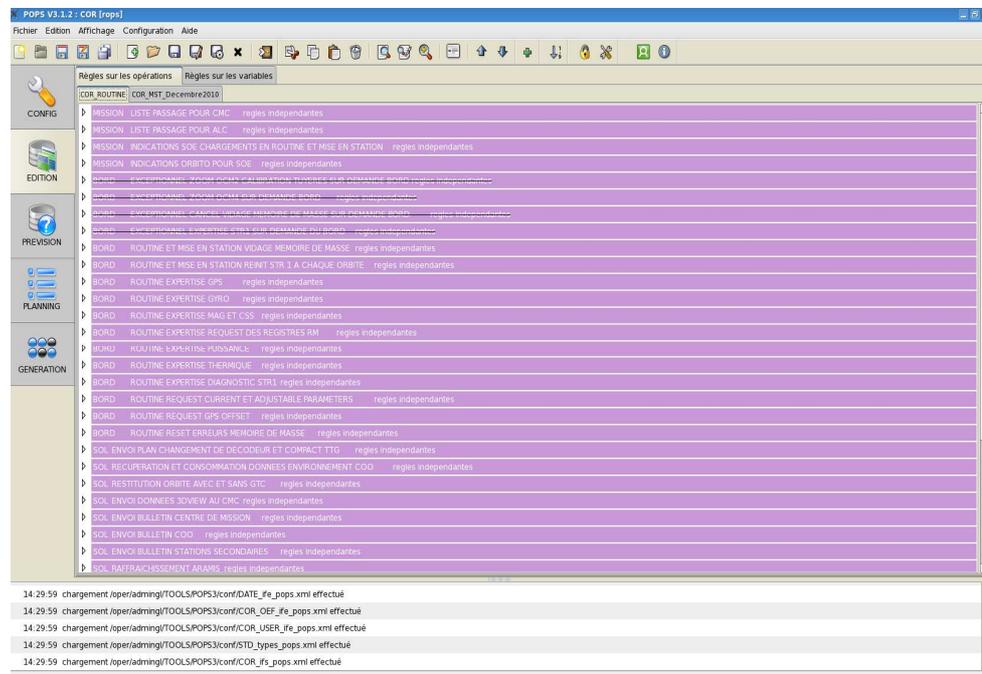


Figure 7. System view of routine activities

The full activities description may be used to issue a part of the FOP. Indeed, an export function converts the rules into a readable format (HTML) which could be merged into any office standard document.

Another main contribution of this software is that **all operational products are coherent**, because they are all produced from the same source (a unique SOO), which is itself generated from coherent rules. **What you see in the SOE is what is really executed on board or ground**. The SOE, as well as the TTG TC plans or the GCP, are elaborated from the same SOO:

- in the SOE, all the SOO treatments are simply written in the paper timeline,
- the ground treatments of the SOO are translated by a dedicated output plug-in in an output interface, directly executed by ground task execution component,
- the TTG treatments are converted by the associated output plug-in form the SOO in a format which can be directly uploaded by ground TM/TC component.

The good writing of **operational rules insure** also for all the mission lifetime, the operations **consistency between business skills of each team**. It is possible to link different team's operations in the same rule: for instance, data ground processing depending on the type of on-board memory downloads.

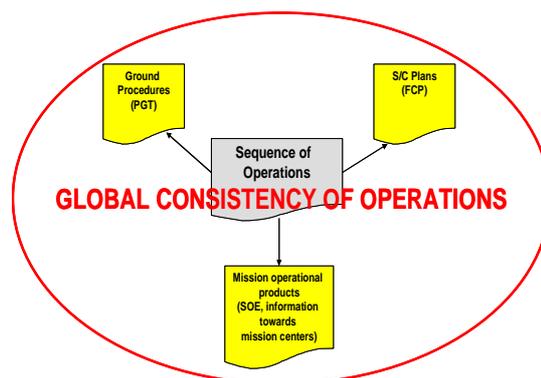


Figure 8. Consistency of all operational products.

Then, **the strength and the flexibility of this software** are really appreciable. It is able to take into account complex activities by linking operations, with or without delays between, describing complex tests combination using “and”/”or” statements, using any input data of the CCC such as orbital events, working days, booked pass.

At last it is also very **easy and fast to update any activity in case of mission evolution**. In the same way, **inherence of activities from another mission** and duplication of activities inside a mission are possible. Activities are saved in a file format and several activities files can be opened in the same workspace. It is possible to define a template activities file dedicated to a specific operation (as the SHM exit of the satellite for instance) and use it when needed by copy paste, in order to apply it to the current context (the first pass to begin the recovery operations for instance). The SOO can be generated from several estimations of different activities files, to perform specific operations besides routine ones.

So the major features of this software can be summarized as a **powerful way to describe all the CCC activities** even complex ones, **offering a system view**, being easily updated, allowing to schedule all the operations and **ensuring the consistency from every operational angle**.

IV. Operational use cases

A. PROTEUS and MYRIADE mission families use case

POPS has been used for four years on PROTEUS and MYRIADE missions. At the beginning it was used for ground procedures product only. Now the application field is much larger.

On PROTEUS family (5 missions, 5 satellites) for routine phase operations, we use as inputs:

- predicted orbit events (Orbit position, SSA Entrance, STR blindings, pass characteristics,...),
- predicted manoeuvre characteristics (kind of manoeuvre (2 or 4 thrusters used), number of thrusts, thrusts dates and durations),
- list of booked passes,
- data retrieved from International Earth rotation and Reference system Service (IERS) with UT UT1 shift.

We provide following operational products:

- ground procedures schedule,
- routine TTG TC plans to execute (mass memory downloading),
- assessment TTG TC plans to execute (GPS, STR, GYRO, thermal, power, MAG and CSS destocking or assessment),
- exceptional TTG TC plans to execute (cancel TTG when needed, Telemetry zoom around manoeuvres)
- fly-bys list delivered to mission centres.

```

BEGIN
C
C      16/02/2011 02:59:38 ./REACKMM_routine.pln
C
C =====
C TITLE = READ AND ACK ALL MASS MEMORY
C DESCRIPTION : LTTM/PLTM read/ack in routine
C SAT : PROTEUS
C MODIF : $Log: REACKMM_routine.pln,v Revision 1.0 2007/05/10 07:08:33$
C =====
C
C POPS_DATE_DEBUT = '11/02/16:02:59:38:042'
C
C TC REACKMM (TT_Indicator = 'TIME-TAGGED',TT_Date = '11/02/16:02:59:38:042',DURATION=692)
C
C POPS_DATE_FIN = '11/02/16:03:11:10:042'
C
C
C      16/02/2011 04:57:20 ./READPLTM1_routine.pln
C
C =====
C TITLE = READ PLTM1 ONLY
C DESCRIPTION : TTG PLTM1 reading without ACK
C SAT : PROTEUS
C MODIF : $Log: READPLTM1_routine.pln,v Revision 1.0 2008/06/24 14:12:06$
C =====
C
C POPS_DATE_DEBUT = '11/02/16:04:57:20:028'
C
C TC READPLTM1 (TT_Indicator = 'TIME-TAGGED',TT_Date = '11/02/16:04:57:20:028',DURATION=545)
C
C POPS_DATE_FIN = '11/02/16:05:06:25:028'
C
C
C ...

```

Figure 9. Example of a routine TTG product.

For routine phase operations on MYRIADE family (3 missions, 6 satellites), we use as inputs:

- predicted orbit events (Orbit position, SSA Entrance, STR blindings, pass characteristics,...),
- list of booked passes.

We provide these operational products:

- ground procedures schedule,
- assessment TTG TC plan to execute (SADM maintenance),
- fly-bys list delivered to mission centres.

POPS was also used for specific phases such as the LEOP (already done for the four ELISA satellites and soon for Jason 3), SHM recovery (used on last Jason 1 recovery and for future recoveries on Proteus satellites), and for the station setting phases of COROT mission. A focus will be done on that COROT specific use in chapter C.

In addition to routine products, POPS provides in the specific phases, a detailed SOE to allow a formal validation of the operations by the experts before their execution, but also a mean for all actors to follow the operations in real time, on the same reference, consistent with held operations.

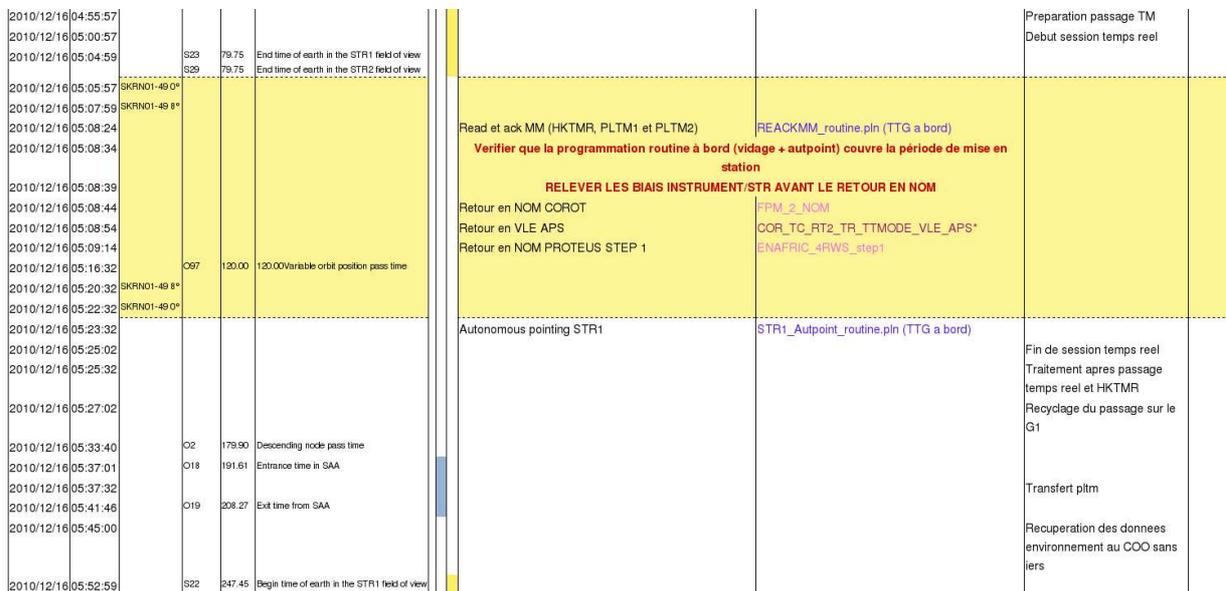


Figure 10. Example of a Sequence Of Events (SOE).

B. PLEIADES mission use case

At the beginning of the project, PLEIADES, latest Earth observation satellite from the CNES, foresaw using a dedicated software to produce an operations chronology quite similar to a SOE. This software proposed to define operations through fixed lists of tests and operations. It provided the operations chronology in a locked format.

The board team wanted to improve this software to give it more flexibility. In front of the modifications cost, it was decided to try POPS software. In only two weeks, plug-in to deal with new inputs format were developed and LEOP rules key in. A first SOE was issued for the second LEOP dress rehearsal a few months before launch, and fully compliant with experts and operational requirements. It was then decided to definitively use POPS for the LEOP operations instead of the initial tool.

C. Zoom on COROT (PROTEUS family) use case

COROT mission has always led development and use of POPS software. It was the first which has integrated some rules for its specific station setting phase. To improve the management the rules are split into different sets: routine, SHM recovery, and station setting.

Routine set is used permanently to handle nominal operations (passes management, daily flight dynamics precessing, deliveries to mission center, earth terminals management, assessment and routine TTG management,...).

SHM recovery and station setting sets are used as templates, duplicated as needed to prepare future operations. Some tests have to be updated, to take into account current context (mainly calendar constraints and available passes). Specific operations can be then produced and added to routine ones.

This process has been applied twelve times for station settings phase performed about every three months. Before POPS availability, ten station setting phases were held with adaptations on routine operations, and a SOE produced by dedicated software based on Excel. This old way had several drawbacks. Sometimes performed operations were not on line with operations described in the SOE, all updates of the operations during preparation or execution phase were heavy and pretty long. The amount of time preparation was about two or three days. Thanks to POPS software, using recurrent validated rules, it is reduced to half a day.

V. Operational feedback

D. Main advantages

POPS software was developed in an iterative way, led by the operational people, on a four years period (about 2 man-year effort). Three main versions were released (in 2006, 2008, and 2010) with each time a larger scope and including feedback of the previous version. This method provided us a tool fully in-line with our operational requirements refined as time goes by.

As mentioned above in highlights chapter, we really appreciate powerful and flexibility of this software, which help us to easily take into account almost all new mission needs without needed any CCC software modification. It also helps us everyday to integrate late requests while always keeping full consistency of the whole operations.

The software brings more reliability in the system:

- Using validated rules avoid careless mistakes in repetitive tasks,
- Operational constraints are always respected when there are coded in the tests of the rules (required delay between operations, for instance),
- Completeness of needed treatments is guarantee, even in case of a lot of operations to perform (numerous events or activities),
- Automatic insertion of complex computed data in the operational product, depending on the foreseen context (duration of mass memory downloading to upload depending on fly-by characteristics for instance), reduces manual errors possibilities.

Furthermore, it proved with Pleiades that it can be easily and quickly adapted to new situations (such as new mission context including new inputs format with new foreseen events).

Finally, we can say that it covers our first requirement which was to manage more missions with the same manpower in particular by lightening routine operations workload. In 2006, mini-mission operations required 24 man-year to operate five in-flight missions and to prepare a new mission, to compare nowadays to 23,5 man-year for height in-flight missions and on mission in preparation. Even if all this production gain cannot be fully attributed to POPS, a significant part shall be.

E. Operational impacts

Using this software imply a significant evolution of the operational tasks performed by the different teams. They spend today much more time on technical activities (as anomaly following and investigations for board team) and less time on nominal routine operations. The business cores moved upstream to deeper operation preparations, and downstream to anomaly studies, and technical assessments. Therefore the teams are less physically present in the control centers.

Routine tasks are reduced to provide the operational products for next period, making as needed minor rules updates, and a general monitoring during working days and hours.

With the increasing use of the software by all the teams, it has been necessary to improve rules edition organization. Coordination during activities definition phase must be tightened. Responsibility of each team must be well defined on each common activity.

VI. Conclusion

As a conclusion, this software brings us what we need in this multi-mission context, with a significant reduction of available manpower to conduct the operations.

The consistency of the all operational products, allows reducing coordination errors. Furthermore, the use of rules which are managed and validated as other operational data, improves the whole reliability of the system.

This software was developed during operational exploitation phase of mini-micro missions. It did not exist in the first releases of the control centre components. Now, POPS is integrated as a main concept added to ours CCC. It was developed by the users for the users. In front of the success encountered, it has been industrialized.

Finally, our recommendation to deal with this kind of scheduling concept is to integrate the needs at the beginning of a CCC development. The SOO could be seen not only as a way to produce consistency operational products to be able to match with existing component, but also as a list of operations used by a system sequencer. This sequencer would handle calling of operations executers components depending of the operations type. We can then imagine, some reports of the operations execution from these components to the system sequencer. It could allow a monitoring in real time of operations execution at system level, with the fine operations execution details at components level. That is the way we extend the POPS concept, in the operational requirements of the next generation of CCC product line which will be used to operate all the future CNES missions.

Appendix A

Acronym List

AOCS	Attitude and Orbit Control Subsystem
CCC	Control Command Center
CNES	Centre National d'Etudes Spatiales (French Space Agency)
CSS	Coarse Sun Sensor
EOL	End Of Life
FOP	Flight Operations Plan
GCP	Ground Control Procedure
GCP	Ground Control Procedure
GPS	Global Positioning System
GYRO	GYROscope
LEOP	Launch and Early Operations Phase
MAG	Magnetometer
MMI	Man-machine interface
POPS	Planification des OPérations Satellites (Satellites operations planner)
SHM	Safe Hold Mode
SOE	Sequence Of Events
SOE	Sequence Of Events
SOO	Sequence Of Operations
STR	Star TRacker
TC	TeleCommand
TM	Telemetry
TTG	TimeTaGged

Appendix B

Glossary

CALIPSO	PROTEUS satellite dedicated to the study of the clouds and aerosols radiative impacts to predict climate evolution.
COROT	PROTEUS satellite dedicated to stellar seismology and search for extrasolar planets.
DEMETER	MYRIADE satellite dedicated to the study of the natural or anthropic ionospheric disturbances.
ESSAIM	Four MYRIADE satellites dedicated to a defense mission
JASON 1	PROTEUS satellite dedicated to measurement of ocean surface topography, surface wind speed and wave height..
MYRIADE	Reconfigurable platform for observation, telecommunications and scientific uses. Designed for 100/150 kg satellites on low orbits.
PARASOL	MYRIADE satellite dedicated to the characterization of the clouds and aerosols microphysical and radiative properties
PLEIADES	Very high resolution panchromatic and multispectral earth observation satellite
PROTEUS	Reconfigurable platform for observation, telecommunications and scientific uses. Designed for 500/700 kg satellites on low orbits.