REDUCING MISSION COSTS THROUGH EFFECTIVE LIFECYCLE MANAGEMENT OF OPERATIONS KNOWLEDGE

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Summary

The objective of this paper is to show how cost reductions in spacecraft manufacturing and operations are being achieved together with an increase in the quality, security and safety of spacecraft operations by the management of operations knowledge. This operations knowledge is managed by a product that harnesses and integrates that which is defined and validated in the various organisations involved throughout the mission development and operations lifecycle. This is achieved without the various organisations having to standardise on control systems or operations languages thereby ensuring that investments made by these organisations are maximised.

These organisations typically consist of:

- A hierarchy of system engineering and AIV teams at the spacecraft prime and its subcontractors who define, build and test databases, develop test sequences and generate and validate user manuals including system operations procedures

- Spacecraft operations centre teams who build the operational database and generate the flight operations procedures based upon the inputs from the manufacturer and the constraints of the ground segment.

Figure 1 represents the current flow of operations knowledge highlighting particular areas where costs are considerable (cost hot spots). Note: for simplicity only the interface between the spacecraft prime and the operator is shown. However the same cost hot spots are found at each of the subcontractors and their subcontractors down to the lowest level subsystems described by data and operated and tested by procedures

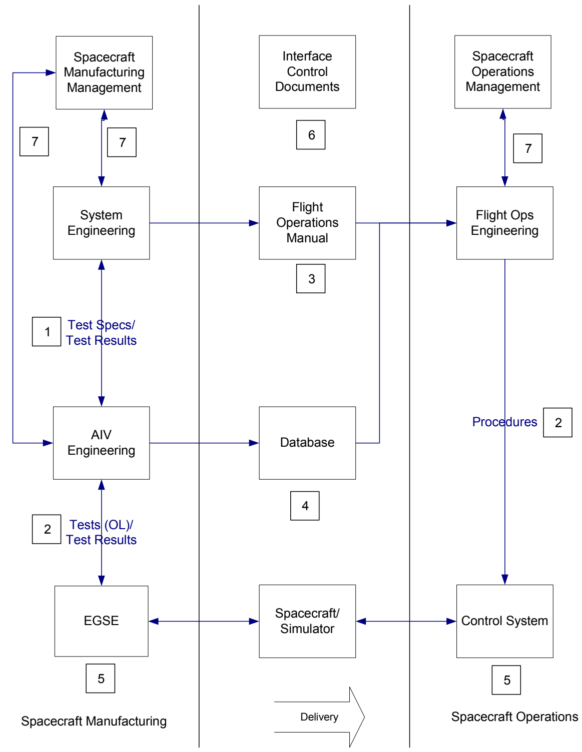

Figure 1: Cost Hot Spots identified within Operations Knowledge Flow

Cost Hot Spot 1: Costly Misunderstandings Between System Engineering And AIV

Many spacecraft manufacturers tend to have:

- System engineering staff who are responsible for designing and validating the functionality of the spacecraft and the associated flight operations procedures

- AIV engineering staff who are responsible for:
    1. Validating the lower level data transfer between the various spacecraft subsystems;

2. Coding and executing the functional tests required by the system engineers

It is the second of the AIV responsibilities that can contribute to large delays in the programme due to misunderstanding between the system engineer and the AIV engineer. In a number of cases we have seen AIV engineers developing functional tests in an operations language (e.g. Cecil, STOL, UCL, Elisa, TCL/TK etc) on behalf of a system engineer, however interpreting the test design incorrectly leading to re-specification and re-execution of the tests – a very lengthy and costly business because invariable these tests require access to the spacecraft.

Cost Hot Spot 2: Unfocussed Effort Expended On Coding And Validation Of Operations And Test Sequences

As indicated above, many spacecraft functional test centres rely on low-level test languages that are coded to provide the test procedures and sequences, based on high-level functional procedures provided by the spacecraft design authority. Keeping the foremost objective in mind that the effort should be focussed towards verifying and validating the spacecraft and that the test manager must be able to count on the integrity of the results achieved, a large degree of confidence is required in the validity of the test procedures and sequences themselves. Errors in coding could potentially go undetected and cause incorrect conclusions to be made about spacecraft functional behaviour (i.e. incorrect operational knowledge), leading to later problems with operations. Engineers therefore have to spend effort on coding according to low-level syntax rules and labour intensive, but relatively ineffectual peer reviews of the resulting test code, which is removing the focus from the validation of the precise functional sequences required by the spacecraft.

A comparable situation exists as well in many operations centres that rely on a low level operations language as the basis of their automated operations procedures. Since these are designed to be interpreted by software, rather than read by people, using them to perform critical spacecraft operations requires complete confidence in their operational validation. This confidence can be difficult to achieve, since peer reviews are difficult and validation tests may have limitations. Getting the required confidence can result in large additional costs.

Cost Hot Spots 3 and 4: Delivery Of Flight Operations Manual And Database

After the operations procedures have been validated with the spacecraft database at the spacecraft manufacturing site, they are then published in a manual (with perhaps an electronic delivery of the procedures) and delivered to the operator. In parallel, the spacecraft database is delivered to the operator that is then ingested into their control system database. A costly revalidation exercise is then initiated at the operator to validate flight procedures with the ingested database to develop the flight procedures. This process often leads to interpretation problems with cost and schedule impacts on the operator.

Cost Hot Spot 5: Procedures Tend To Be Control System Dependent

Procedures tend to be developed in operations languages which are dependent on the control system, thereby leading to a proliferation of STOL, Elisa, UCL, Cecil, TCL/TK, TOPE etc procedures implemented on a variety of control systems. Thereby forcing an operator to either acquire the same control system as the spacecraft manufacturer to make sure they can use the same OL and thereby the same procedures, or they have to convert from the OL delivered to one that is compatible with their control system. Not a very palatable choice for operators who may have millions of dollars invested in existing control systems and procedures.

Cost Hot Spot 6: Inefficiencies Due To Incompatibility Of Systems

The lack of common systems or standards between the various teams involved in the mission development and operations lifecycle has been the cause of significant effort expenditure in the production of Interface Control Documentation (ICD). These ICD's define and police the interface for data and procedure import and export. However more often that not the various teams on both sides of the interface will have interpreted the ICD differently leading to extra meetings to resolve differences of opinion and delays associated with duplicated effort in procedure generation and re-validation activities.

Cost Hot Spot 7: Black Boxes Become Black Holes

The project management of a spacecraft mission development and operations programme are all too familiar with the headache of the spacecraft test campaign and operational preparation activities which virtually always falls on the critical path of the schedule and invariably soaks up vast amounts of effort and more than often requires extra allocation of resources, double shift work etc. in order to overcome unforeseen problems and meet the schedule. Indeed, space agencies and commercial operators are also used to having to slip launch dates with all the knock-on financial consequences of that decision.

Of all the mission development phases, it is the test campaigns and the operations preparation where management have the least control over ensuring satisfactory progress, with respect to meeting the schedule and ensuring all low level objectives have been achieved. As opposed to design phases, where standardised documentation can be produced and easily reviewed by both internal management and the technical procurement management representatives of the higher level contractors and end customers, an equivalent means to monitor and control the activities in the AIV phase and operations preparation is sorely absent, to the cost of all space missions and their sponsors. Only the engineers working on the test activities or producing the operations procedures can make statements about the progress and even their direct management has little ability to review and verify these statements. Of course, this is not to say that such engineers are not attempting to provide reliable information, or work in a rigorous manner, but it must be recalled that basic scientific and engineering principles relies on effective peer review and effective and independent means of information verification. These principles are employed for other mission phases but cannot effectively be employed in these arguably most critical phases.

AIV and operations activities are therefore like black boxes, with management hoping for smooth progress, but without effective means of control. It is therefore little wonder that they become like black holes concerning expenditure.

Making Sense Of It All: The Mission Operations Information System (MOIS)

Several European spacecraft mission programmes are therefore putting in place a product to tackle these problems and achieve a seamless integration of the database and procedures for the various mission preparation activities and at the same time provide a logical view and effective management of the operations knowledge.

The product is the Mission Operations Information System (MOIS). MOIS addresses the problems encountered in the operational knowledge lifecycle thereby ensuring the correct flow of this operational knowledge from spacecraft design through AIV to flight operations whilst reducing the costs associated with all the interfaces required to build and execute operational knowledge.

Figure 2 represents how MOIS replaces the Cost Hot Spots by allowing management, system engineers, AIV engineers, and operations engineers to share procedures, data, and information whilst at the same utilizing existing infrastructure investments such as EGSE or control systems.

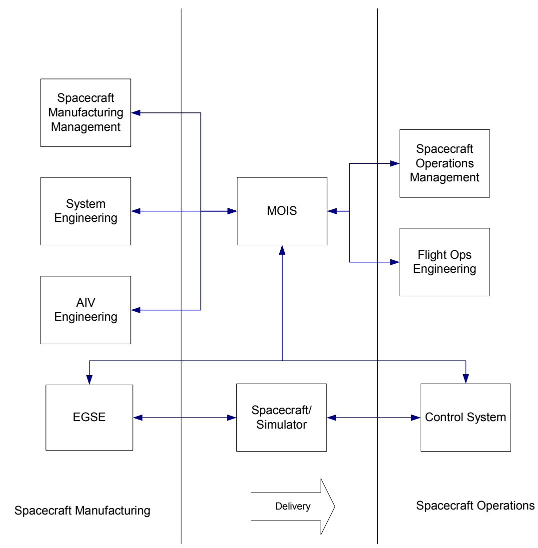

Figure 2: MOIS minimises Cost Hot Spots

MOIS minimises the Costs Hot Spots in the following way:

Solution 1: Removing The Costly Loop Between System Engineering And AIV

MOIS supports different views of the same procedure either at the flowcharting level, tabular level, or OL level. Inherent in the product is the ability for the system engineer to design their functional validation tests through flowcharting techniques and then drill down through integrated excel to database links to develop their procedure in a tabular, easy to understand form. This procedure is directly used by the AIV engineer, as outlined below, therefore removing the possibility of cost due to misinterpretation of information.

There is therefore no further need for a system engineer to rely on an AIV engineer to code up their tests in an OL.

Solution 2: Only Working At The OL Level When Required

The AIV engineers can either execute their test procedures using the same interface as the system engineer (flowcharting and tabular formats), or they can press a button and generate the relevant OL (STOL, UCL, TCL/TK, Elisa, etc).

Also the AIV engineer can take a procedure that the system engineer has developed and add to it for low level testing. AIV engineers inherently like working at the OL level, which they are free to do so.

System engineers and operations engineers therefore no longer require to understand various languages and to follow languages being executed, they can work at the level they require: flowcharting and tabular interfaces which are much more readable and understandable by these engineers. Also procedure validation and execution of procedures at this level leads to greater efficiency since they understand what each procedure step is doing as it is being executed.

Solutions 3 and 4: Minimising Revalidation Activities

With the delivery of procedures and their corresponding data in MOIS (which is control system independent) then there is no need for the operator to revalidate the procedures it receives from the spacecraft manufacturer, or indeed for the spacecraft prime to revalidate the procedures it receives from its subcontractors.

A procedure developed and validated with one control system can be executed on a different control system.

Solution 5: Achieving The Cost Benefits Without Significant Investment

MOIS can be easily integrated into existing organisational infrastructure as well as into a mission programme involving many organisations by virtue of:

- The ability to interface to any mission control or EGSE

- The ability to interface with existing procedures written in operations or test languages.

This means that a programme manager, who is trying to achieve cost savings using MOIS through requiring its usage through the end-to-end system and lifecycle will have an easier job in getting his various mission contractors to agree, since there is no sizeable hurdle of infrastructure replacement to overcome. A seamless integration of validated operations knowledge without having to agree on a single common infrastructure can save significant cost to the mission.

Although we are convinced that the contractors in the mission programme concerned will recognise the internal organisational advantages MOIS brings (as discussed elsewhere in this paper), there could potentially be some reluctance if for example, existing procedures already exist for some of the subsystem under the contractor's responsibility. This however can be handled in one of two ways by making use of the operations language import and export features:

- The contractor could take MOIS as required and import existing procedures into the MOIS tool, thereby achieving the cost saving and effectiveness potential for further work, or

- If the contractor insists in keeping the old procedures in the original format, the interfacing site can import them into MOIS when they are transferred within the course of the mission development. In this way, the system as a whole maintain most of the advantages of operations knowledge synergy described in previous sections.

Solution 6: Minimising The Need To Develop Interface Control Documents

There is no need to define ICD's for procedure and database interfaces since the spacecraft manufacturer, and it's subcontractors, can use MOIS on their existing infrastructure and deliver the procedures and database to the operator (or to the prime if they are subcontractors) who can then run the same procedure on their control system.

The removal of ICD's leads to the added advantage of removing misinterpretation thereby minimising re-validation activities that in turn reduces the overall mission development and operations lifecycle and thereby reduces costs.

Solution 7: Regaining Control Of The AIV And Operations Preparation Phases

A major initial design driver for the MOIS product was to empower the managers of the operations knowledge preparation and validation process, such that effective verification of the attainment of activity objectives can be assessed, resulting in a far more robust and predictable mission development schedule. Problems can be identified at an early stage when corrective action can be performed within the limits of the contingency effort planned by the managers, the implications of testing with different hardware and software configurations can be more easily assessed and the need for retesting following configuration updates more readily established.

With these new tools, project managers will be better able to avoid unpleasant surprises coming from these black-box mission development phases and be confident that they are in-touch with what is really happening in the clean room or in the mission control room. Furthermore, project managers will be able to gain visibility more clearly to the low-level issues which are problematic from mission to mission and therefore better prepare for them on subsequent missions and more accurately predict the effort and schedule necessary to perform these activities. Even without taking into account the efficiencies brought by MOIS to the engineers, this will help reduce the final mission costs in its own right.

Management and peer reviews of test campaign progress, operations preparation progress, as well as formal ground segment readiness reviews and flight acceptance reviews will now have the means to accurately assess whether:

- The spacecraft functions at subsystem and system level have all been successfully tested with the correct hardware and software configurations in representative environments

- The spacecraft operations procedures are complete and consistent with the spacecraft manufacturer's operations manual information and spacecraft functional test results

- The spacecraft operations procedures are validated using the correct spacecraft and simulator configurations, with the correct ground segment configurations.

A programme management decision to adopt MOIS both in AIV and operations in order to overcome the inefficiencies and reduce the significance of the cost hot spots described in this paper will benefit in the following manner:

- Validated databases and procedures at each site (e.g. subsystem responsible) can be transferred to the interfacing contractors for integration in their procedures, along with full configuration control information about how validation was achieved (environment, versions etc.)

- The process can continue throughout spacecraft testing up to system level, where a full integration of the spacecraft is made, along with all the corresponding procedures and database items.

- A transfer to the Operations Centre can be made such that all the validation effort previously spent in production of the flight operation manual and test procedures can be built upon, enabling the focus of revalidation effort to be better and more efficiently directed for operations preparation purposes.

- Since all sites will have the same view of procedures and access to the same configuration control information, inter-organisation communications will be highly efficient and reviews can take place of other organisations' outputs without the problem of having to compare internal equivalent procedures in different formats.

Organisations Experience on using MOIS

This section summarises a selection of organisations which have rolled out MOIS together with how they are using it and which Cost Hot Spots they minimise by their use of MOIS:

1. European Space Agency Operations Centre (ESOC)

Standard for all missions (Earth observation, space science, and LEOP services) for flight procedure development, validation and execution.

Started using MOIS on Cluster2 and has used MOIS for every mission since

Cost Hot Spots 2, 5 and 7 are minimised

2. European Space Agency's Technology Centre, ESTEC

Analyse spacecraft prime deliveries (procedures and databases)

Started using MOIS on MetOp and is now being adopted for other Earth Observation missions.

Cost Hot Spot 6 is minimised

3. European Meteorological Satellite Organisation, EUMETSAT

Used on their latest mission (EPS, the European arm of the International Joint Polar System it shares with NOAA) for flight procedure development, validation and execution.

Is able to share service module procedures with its LEOP service provider, ESOC, even though they operate using different control systems

Cost Hot Spots 2, 5 and 7 are minimised

4. French Space Agency, CNES

Used on their latest mission (ATV – Automated Transfer Vehicle for the International Space Station) for flight procedure development, validation and execution.

Decided to adopt MOIS in order to minimise flight procedure development activities because they could re-use vehicle control procedures from the spacecraft prime, EADS-LV, even though they both use different control systems.

Cost Hot Spots 2, 5 and 7 are minimised

5. German Space Agency, GSOC

Standard for all German scientific missions for flight procedure development, validation and execution.

GSOC were updating their infrastructure and MOIS supported their new standard control system and other potential control systems they may have to use to offer LEOP services.

Cost Hot Spots 2, 5 and 7 are minimised

6. Astrium Germany

Standard for all spacecraft manufacturing, AIV and system engineering activities driving a number of different EGSEs.

Started to use MOIS on the Rosetta mission to develop large delta-V procedures to recover the schedule that was slipping in part because the AIT team was supplied by another company that often led to misinterpretations leading to delays. Since Rosetta Astrium are now using MOIS on all other missions.

Cost Hot Spots 1,2, 3,4 5 and 7 are minimised.

7. EADS-LV

AIV and system engineering activities for their latest mission to manufacturer and test 8 ATVs.

EADS were about to develop a number of systems and employ a number of contractors to develop OL's for test campaigns and excel macros for vehicle control procedures and on-board control procedures. Adoption of MOIS led to same procedure generating different outputs (UCL for AIV engineers, OBCP and VCP for system engineers) that led to a reduction in the number of contractors required to develop test campaigns thereby saving costs.

Cost Hot Spots 1,2, 3,4 5 and 7 are minimised.

Example Control Systems which MOIS drives

In addition to being able to generate telecommands and process telemetry at the procedure level in real time, MOIS has the following interfaces:

- MOIS generates TC sequences and TOPE TCL/TK language for the SCOS1B and SCOS2000 control systems

- MOIS generates UCL language for the CGS control system

- MOIS generates Elisa language for the OpenCentre control system

- MOIS generates STOL language for the EPOCH2000 control system

Languages are added as and when required, in addition Rhea is currently developing and under contract to parse existing OL's back into MOIS with the first two languages TCL/TK and UCL. Other language parsing will be added as and when required.

Cost Savings Summary

Throughout this paper, we have highlighted how the concepts contained in MOIS and the integrated and seamless approach to operations knowledge management throughout the mission lifecycle and across the end-to-end system will both directly reduce effort and reduce risks will lead to additional cost savings.

Quantifying this depends of course on getting access to the detailed planned cost breakdowns of recent missions and looking in detail at programme and project manager's resource and time planning for future missions. Due to mission diversity and lack of direct access to such cost and planning breakdowns, we are not in a position to provide cost saving figures. However, it is clear from recent sales that those programme and project managers have performed their own calculations and decided that significant cost savings are indeed to be expected.

Two recent papers have been written on this subject:

1. A report concerning the successful experience of retrofitting MOIS in the late stages of spacecraft development into the Rosetta spacecraft mission was made for the SpaceOps in 2002 (*Strandberg, Ferri, Monham, 2002*). Astrium were able to use their heritage EGSE system that supports its own test sequence coding language (Elisa) since MOIS is able to generate the code. As an illustration of the cost savings achieved from that mission, Astrium GmbH reported that it had been possible to produce the test code for a large delta-V manoeuvre (approximately 3000 code lines) and run it without any manual changes. The time for conversion of the test code from the MOIS level was negligible as it was performed at the time you press an icon within the MOIS tool.
2. ATV is the first mission to have chosen MOIS right across the mission as the initial baseline, where the spacecraft prime, EADS-LV, and the Operator, CNES will use the product for all AIV test procedures development, On-board control procedure development, vehicle procedure development, and flight procedure development. EADS-LV have recently presented the advantages of using MOIS throughout the complete mission development and operations lifecycle at DASIA 2003 (*Operational Concepts For The ATV Project And Applications With MOIS Tool by J. Camel, S. Vial)*.

Conclusions

One of the major considerations for any mission is the cost of preparing and operating it. The concept of identifying where the cost hot spots are and developing a product which reduces these costs whilst at the same time utilizing current infrastructure investments will significantly bring down the costs for future missions. This product, MOIS, has been rolled out to the majority of European primes and operators and significant cost savings have been identified by these organisations leading to the adoption of MOIS as a standard for mission preparation and operation in a number of these organisations.