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Integration of Multi-Mission Services into Operations – The Appeal and Reality

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Abstract

EUMETSAT has long adopted and championed the concept of Multi-Mission Elements and Services (MME and MMS) with considerable success. The portfolio of MMS now includes Data Dissemination, Archiving and User Discovery, System Level Monitoring, Service Indication and Reporting, Flight Dynamics Conjunction Analysis, and Infrastructure including Communications, Storage, and Auxiliary Services such as Domain Name Service (DNS).

In addition, the trend at EUMETSAT has also been to train operations and maintenance teams to provide an MMS, such that a single team is able to support multiple spacecraft programmes as a singular service, and the control room design has matured to remove some physical separation between them allowing for a multi-programme environment. Indeed, it can be hard sometimes to determine which services can be considered as mission specific and which part of a broader multi-mission service.

The trend is set to continue with the introduction of infrastructure considered as a "Platform as a Service" (PaaS) delivered to Operations, again with no mission specificity. Multiple programmes may then share the same physical infrastructure and separated only at a virtual layer through containerisation.

While there are obvious advantages to the use of MMS that will be explored in this paper, we consider also the various challenges that such an approach also brings, and how this scales to the extent of implementation. This paper also explores the crucial aspect of how MMS can be integrated into future programmes and the careful planning how this can be achieved to support Integration, Verification & Validation (IVV) activities with an MME platform while not affecting the current programmes that are reliant on the MME.

Keywords: EUMETSAT, Multi-Mission Operations, PaaS

Acronyms/Abbreviations

CFI	Customer Furnished Item
COTS	Commercial off-the-shelf
DLR	Deutsche Zentrum für Luft- und Raumfahrt (German Space Agency)
DVB	Digital Video Broadcast
EARS	EUMETSAT Advanced Retransmission Service
EPS	EUMETSAT Polar System
EPS-SG	EUMETSAT Polar System – Second Generation
ESA	European Space Organisation
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites

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GSRD	Ground Segment Requirements Document
GTS	Global Telecommunication System (of the WMO)
IJPS	Initial Joint Polar System (between EUMETSAT and NOAA)
IV&V	Integration, Verification and Validation
KB	Knowledge Base
KPI	Key Performance Indicator
M&C	Monitoring and Control
MCC	Mission Control Centre
MMDS	Multi Mission Dissemination System
MME	Multi Mission Element
MMS	Multi Mission System
MPT	Mission Performance Tool
MSG	Meteosat Second Generation
MTG	Meteosat Third Generation
NOAA	National Oceanic and Atmospheric Administration
OPE	Operational (Environment)
PaaS	Platform as a Service
RSD	Requirements Specification Document
VAL	Validation (Environment)

1. Introduction

The intention of this paper is to introduce the benefits, considerations, issues and lessons learned related to the introduction of multi-mission systems (MMS) to future programmes, with a focus on the following aspects:

- Requirement Definition
- Service Definition and Declaration
- Interface Control
- Evolution timeframes of MMS compared to the future programme requirements
- Customer furnished items
- Usage of Environments
- IV&V including the scheduling of test campaigns
- Hand over to operations

The concept of General Operations and MMS at EUMETSAT will be introduced as applied to current operational programmes, as a basis to then consider the facets of programme development and how to successfully include multi-mission concepts

2. Introduction to EUMETSAT

EUMETSAT is an intergovernmental organisation based in Darmstadt (Germany), responsible for the exploitation of Europe’s meteorological satellites.

EUMETSAT operates a system of meteorological satellites that observe the atmosphere, ocean and land surfaces – 24 hours a day, 365 days a year. This data is then supplied to the National Meteorological Services of the organisation's Member and Cooperating States in Europe, as well as other users worldwide.

The satellites currently operated in the EUMETSAT HQ are:

- Geostationary satellite MTG-I1 (Meteosat Third Generation – Imaging 1) launched in December 2022 and in commissioning phase until end of 2023. It will provide imaging services supporting nowcasting applications.
- Geostationary satellites Meteosat -10, and -11 over Europe and Africa, Meteosat-9 over the Indian Ocean. This corresponds to the Meteosat Second Generation.
- Metop polar-orbiting satellites (Metop-B and Metop-C) as part of the Initial Joint Polar System (IJPS) shared with the US National Oceanic and Atmospheric Administration (NOAA).
- Jason-CS/Sentinel-6 satellite providing global sea surface height observations for climate monitoring and ocean and seasonal forecasts. Jason-3 is also part of the Jason mission (an international partnership between EUMETSAT, CNES, NOAA, NASA and the European Union via the Copernicus programme), even though it is not operated by EUMETSAT.
- Sentinel-3 satellites (S3A and S3B) collecting observations of global ocean colour, sea surface temperature and sea surface height.

One of the main objectives of EUMETSAT is also to create synergies with other operators of Earth observation satellites. Currently, EUMETSAT cooperates with other agencies including in Europe, China, India, Japan, South Korea and the United States, benefiting from the sharing of data from many other satellites.

The data and products from both EUMETSAT and third party organisations are vital to weather forecasting and make a significant contribution to the monitoring of the environment and climate change. They aid meteorologists in identifying and monitoring the climate change or the development of potentially dangerous weather situations that affect air travel, shipping, road traffic, farming, constructions and many other critical industries.

EUMETSAT's planned missions and launches will continue to grow during the next 20 years. This increasing number of satellites and, consequently, amount of data that needs to be handled generate a big impact on the structure of the organisation. The addition of missions requires not only scaling many of the existing systems, but also redesigning those that become inefficient or simply unable of handling the new load.

The EUMETSAT Mission Control Centre (MCC) is based at its headquarters in Darmstadt (Germany) and is divided into two control rooms, one for the geostationary (GEO) missions and the other for the Low Earth Orbit (LEO) missions. Shift teams of satellite and ground segment controllers work 24 hours a day, supported by teams of on-call operators and maintenance engineers.

The MCC is the part of the overall ground segment responsible for the safe operation of all satellites. It provides monitoring and control functions for the spacecraft and antennas, but also monitoring of science data (L0, L1, etc.) and supporting infrastructure. It also provides reporting functions in order to notify the user community in case of expected or unexpected events, display the status of each mission in a real-near time manner, or generate KPI reports.

Figure 1: EUMETSAT MSG MCC

3. EUMETSAT and Operations Multi-Mission Concepts

The concept of "Multi-mission systems and operations" (MMS) has been developed in EUMETSAT over many years as a response to the ever increasing size and complexity of mission operations. The concept of MMS can be applied at multiple levels including facility, software, hardware, infrastructure and teams. Gradually the MMS concept is being matured into the industry standard concept of "as a Service"; a recent project proposes to replace the hardware supporting most missions when becoming obsolete with a generic "Platform as a Service" (PaaS), which will provide all the hardware, infrastructure, storage, network, orchestration and high availability support up to a virtual server level on which the ground segment functions shall be hosted.

EUMETSAT currently defines the following systems as being multi mission:

- Data Access (Archiving and Discovery, otherwise known as "pull data services" plus Reprocessing of legacy data with the latest algorithms)
- Dissemination (real time push of data to end users via DVB-S and Internet)
- Infrastructure (hardware, network, storage, building)
- Security Monitoring and Incident Response
- System Monitoring, Reporting and Service Indication to end users (Event based, data flow, periodic, ground segment and spacecraft telemetry propagation)
- Monitoring and control infrastructure, based on SCOS, tailored for the various missions,
- Offline Analysis Tools for Spacecraft and Ground Segment data and products
- Flight Dynamics, including Conjunction Analysis

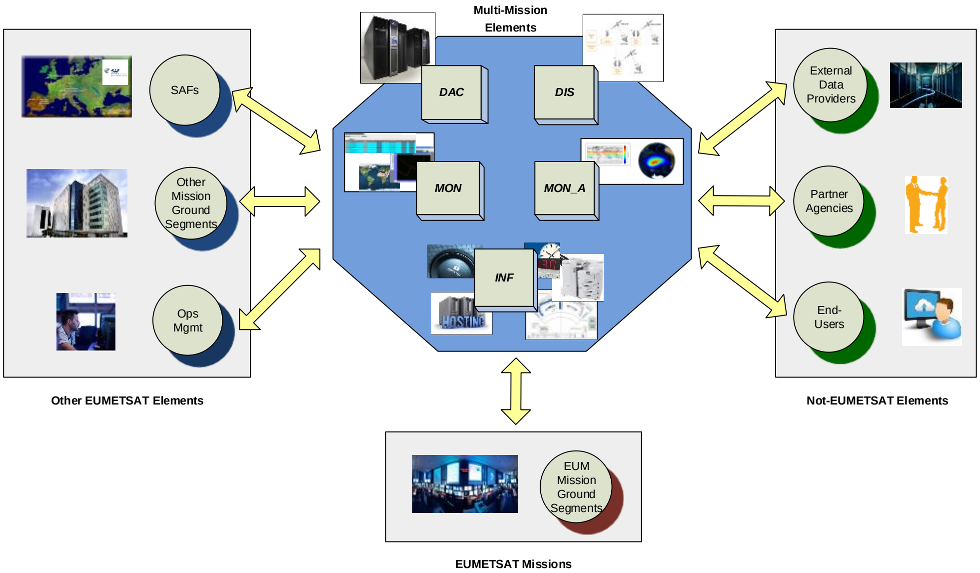

Figure 2: Multi-Mission System Examples

Additionally, teams responsible for traditionally mission specific functions e.g. mission planning, have found it desirable to cross train team members for at least two different missions in order to keep flexibility in the team and knowledge retention.

It is apparent from the above that the MMS concept is one that is extensively employed at EUMETSAT and considered in almost all aspects of ground segment and spacecraft operations. It is logical therefore that this concept is also considered at an early stage of programme development. The considerations based on the experience of using these MMS for current and future programmes are explored further in the following sections.

4. Benefits, Limitation, Considerations and Lessons Learned for MMS in Current Programmes

When considering the use of MMS, it is important to trade off the benefits against limitations. The notable benefits of using MMS in the context of current programmes include:

- Decreased cost and overhead of development and evolution, since the kernel infrastructure is already in place and at a level of maturity across the operational programmes;
- Decreased cost and overhead of hardware and software maintenance support through the reuse of platforms and software for multiple missions
- Decreased cost and overhead of operations on-call support by using combined teams

However, these can be outweighed by disadvantages including:

- Increased complexity of the overall MMS including any required changes – in particular time taken to verify and validate releases may be increased exponentially by the potential impact to multiple different missions, or user requirements may conflict.
- Scheduling conflicts for maintenance and upgrades – especially during time of system freezes due to launches, special operations and holiday periods, it may be almost impossible to find a suitable maintenance slot for a system supporting multiple missions
- Complexity of the roll out, depending on the various programme needs and timelines, which could lead to multiple versions of an MMS requiring support in parallel.

Experience has led to some important considerations and lessons learned in the management of MMS:

- A robust monitoring and problem escalation concept:
    - identifying a central point of contact between different control teams in order to liase with an engineering team in event of a problem investigation (i.e. avoid multiple people calling an engineer for the same problem)
    - identifying the split of monitoring between control teams (expanded below)
- Ensuring consistency and accuracy in the operations procedures and contingency guides used by controllers to monitoring and control the MME
- Ensuring a RACI matrix (Responsible, Accountable, Consulted, Informed) for maintenance and upgrades of operational systems, ensuring any activity is well announced to all stakeholders including end users.

With regard to monitoring aspects, the type of monitoring to be performed must also be considered. If the control team is responsible for ensuring the monitoring of the data flow to end users of the service provided by the satellite, then this implies monitoring of MMEs that may overlap with the monitoring from other control teams. To start with, we must distinguish between the concept of *system* and *service* monitoring:

- *System* monitoring can be described as ascertaining the health of a system (hardware and software) fulfilling a particular function. This can either be done though periodic polling via a monitoring software for particular metrics e.g. check the remaining disk space of a server or by examining the system level or software application logs for any messages indicating issue (or indeed that no log is produced any more)

- *Service* monitoring can be described for instance, as comparing the production and dissemination status of imagery and products in terms of completeness, timeliness and quality “closed loop end-to-end” i.e. from the point of creation throughout the production and dissemination chain to confirmation of reception by the end user.

Experience has shown that in order to ensure the highest levels of availability, quality and timeliness of data to end users, it is pertinent to monitor using both methods above, however with the introduction of MMS this can cause confusion from the overlap of monitoring between teams. The problematic is described in figure 3 below.

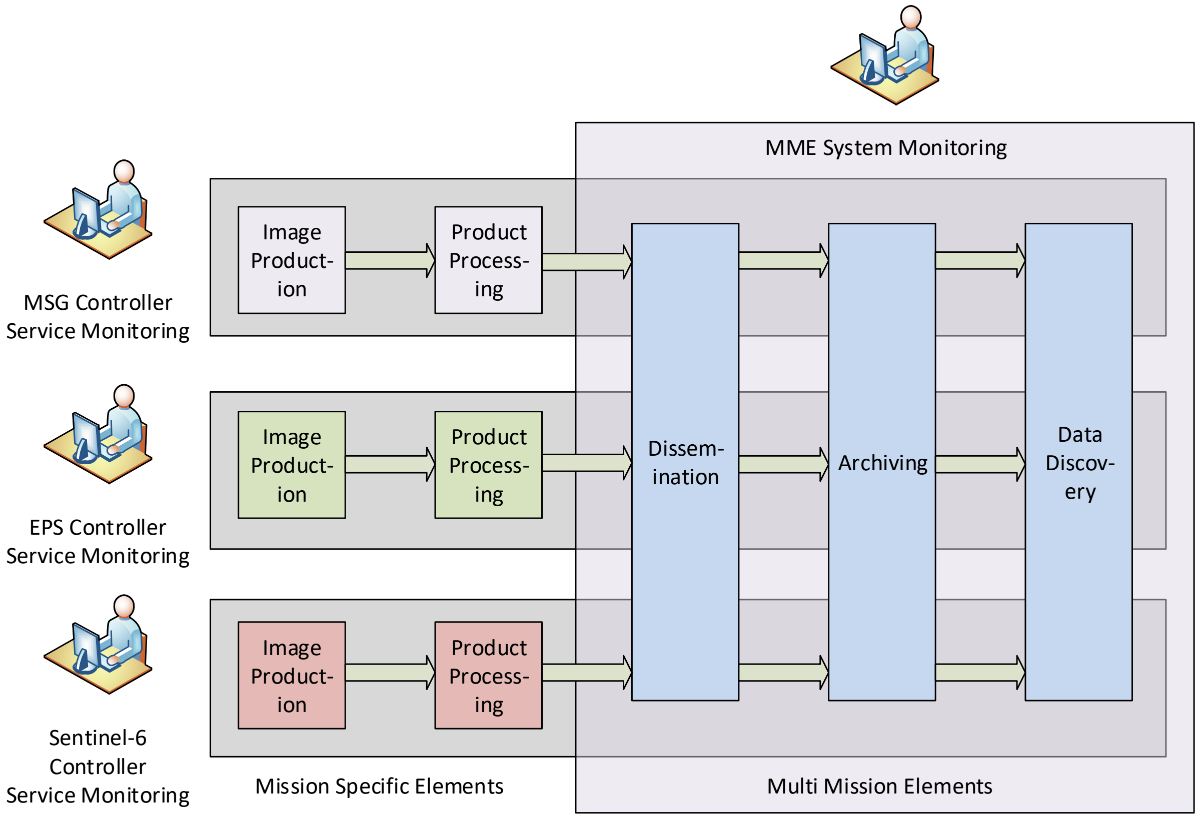

Figure 3: Data-Flow vs MME monitoring

This figure shows the baseline monitoring strategy between three different control teams, each one monitoring dataflow (represented by arrows) through their respective individual ground segments into the MMEs, as well as the system monitoring of mission specific servers and functions. Additionally, a team must take care of system monitoring of the various MMEs that form part of the data chain. If care is not taken, this can cause confusion in event of an issue with the system, for example an engineering team only advises the MME monitoring controller of a maintenance, then the mission specific controller escalates a problem because they were not advised of an expected outage.

The issue is somewhat compounded when also considering the large amount of data received from operational partners and third party. The data flows for these must also be monitored as a service, however these can be purely reliant on MMS and therefore the decision as to where these data flows can be monitored may be arbitrary. In this instance, it could be considered to have a dedicated control team for such scenarios.

The overarching recommendation based on the above is that any system with a similar architecture to the above develops a robust operations concept considering the architecture and resources involved, and agreed by all stakeholders. This MMS concept should be considered complimentary to the operations concept for the mission (and vice versa), as such it is important during mission design that the MMS concept is considered as a part of a service declaration to them.

5. Considerations and Lessons Learned for MMS in Programme Development

As well as the considerations above, the MMS concept has to be carefully factored in to any new mission designed in order to stand some chance of success. Experience of integrating MMS into recent missions including MTG and Sentinel-6 has lent itself towards noting the following:

Identification and involvement of stakeholders at an early stage: The EUMETSAT approach is to define an "MME upgrade team" within their Technical Support department, who act as an overall liaison between different teams to ensure the programme requirements are met. It is also essential that representatives from the Operations, as well as responsible Maintenance teams are included to consult on the application of any delta requirements and realism or usefulness of any verification or validation testing to be performed. This will allow that foreseen MME changes are also compatible with current programmes, as well as mission-specific Interface Control Documents (ICDs).

Creation of Service Declarations and Definitions: These two documents help create a useful interface between the current operations concept/requirements and the ground segment requirements document for the future programme. The definition of what is required from the programme is compared against the definition of what is currently possible from the MMS, and from this analysis a set of delta requirements can be produced as the earliest possible opportunity in order to allow sufficient time to develop the MME to meet any specific programme needs. A diagram of the full relationship between programme, operations and maintenance requirements, definitions, and test documentation leading up to operational deployment of the programme compatible MME is shown below in figure 4.

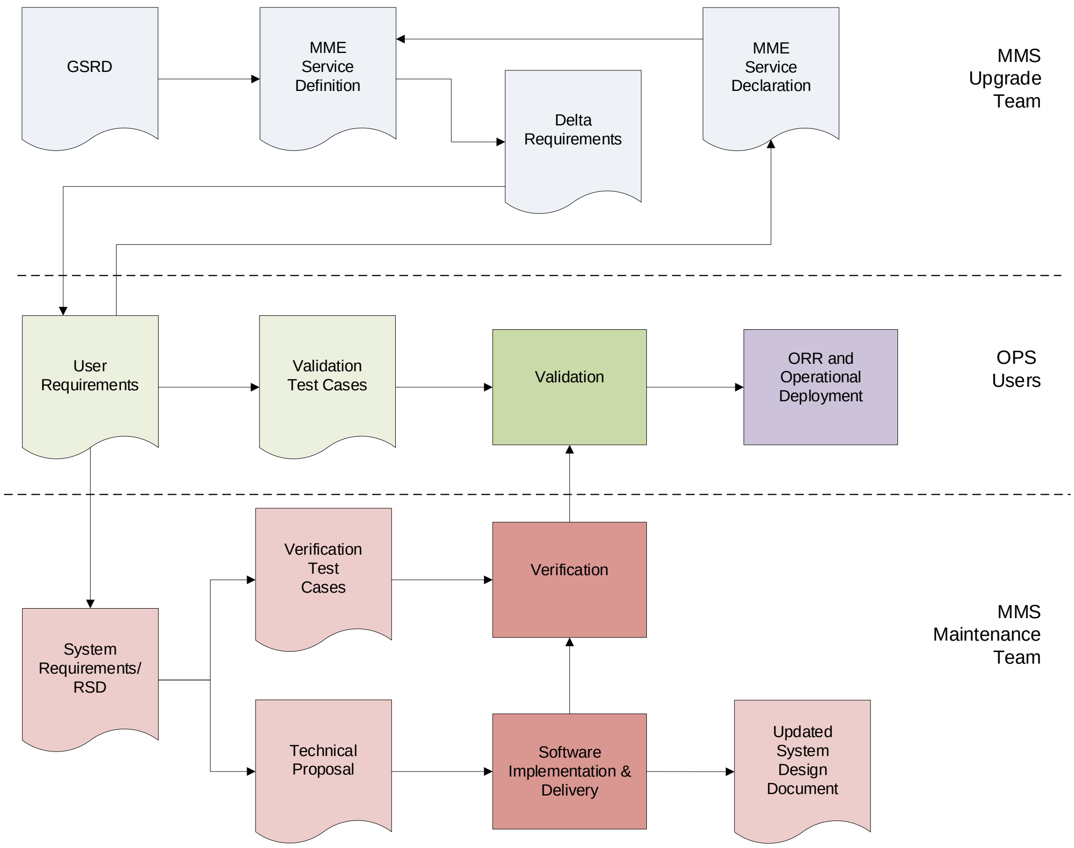

Figure 4: Programme and MME functional relationships

A full understanding of MMS capabilities by programme procurement teams and requirements engineers: A common issue in the early stages of programme development is a lack of good understanding by the programme as to the true MMS capability or a simple mis-interpretation of the requirement. For example, a requirement on the mission control system in the Ground Segment Requirements Document (GSRD), could state that it shall be monitored by a periodic system monitoring, and such is delivered by the vendor already including such a tool, having not been appreciated by either party that in fact the MMS will already provide such a function.

Pre-empting natural evolution or re-engineering of MMS: As the path of programme development from the earliest involvement of the MME concept to operational handover can take many years, it is natural then to plan for the possibility that the MME might be independently developed in the meantime, due to the needs of current programmes or other ongoing future programmes. It is prudent therefore to ensure the MME has a realistic evolution roadmap in place considering likely evolutions that can be integrated into the service definition. Meanwhile, it is important that the programme is accepting the fact of the MME concept might evolve during the programme development lifecycle and requirements based on original assumptions or current operations concept be superseded by new ones. Finally, it is important to consider the use of an integration environment to avoid a new version of a MMS, unrelated to the program not being able to be verified or validated because the MME validation or verification environment is blocked by the future programme for their testing.

Carryover of unnecessary or conflicting requirements from other programmes: There may be a temptation by programme requirements engineering to mimic requirements from similar programmes, or ask for a wealth of features just in case they are needed. For example, it may be stated as a requirement that the system monitoring is able to ingest a file created by mission planning in order to set expectations for what products are to be produced. The end design however might be simplistic enough that actually this mission planning file is not needed, as the expectations for the product schedule follow a simple cyclic pattern. The problem comes when the programme still insists due to the complexity of removing the requirement, that a mission planning schedule must be ingested by the MMS monitoring, even though it is not used

Customer Furnished Items: A complexity might come from the fact that the MMS might try and impose the use of CFIs in the new ground segment, for example a monitoring client application to collect information from the ground segment server to interface with the MME. This might be unpalatable for any new programme contracting out implementation of a ground segment function to industry, as it creates a risk in terms of supporting the CFI and any potential blame on poor performance of the facility on the CFI that is imposed on it. It is therefore important that any MMS design imposes the lightest possible requirements on interfacing with the facility. For example, if a log file monitoring MME extracts information from the client, adds metadata etc. and before sending to the MME in a custom format, the vendor might have to write their own version of this client in order to fulfil the formats described in an ICD, without having to install the CFI. Instead, standard interfaces such as a simple RESTful HTTP to transmit events, or a native tool to most systems e.g. Syslog should be investigated in order to keep the interface as easy as possible.

Use of Integration Environments: There are various factors to consider on the topic of using a separate integration environment for the MMS. On the positive side, this enables the future programme to do early dry run testing of their new ground segment with a representative version of the MMS rather than just a stub, at the same time not exposing the OPE or VAL environments of the MMS from any destructive outcome of the testing while they are supporting current programmes. Indeed, the design of the MMS may not foresee it to be used to support testing of new ground segments; that their VAL system is predominantly there to test new versions of the MMS software. On the negative side however, programme management might be keen to push for the operational baseline as soon as possible, especially if the integration environment is not fully representative, or is itself acting as an MMS, supporting multiple future projects. Care must be taken therefore to properly declare the stipulations of the integration environment in the service declaration including a plan for migration to the operational system ready for the programme operational readiness.

Scheduling of verification testing and operations support: It may be necessary for the MME integration and programme teams to rely on the extensive experience of the MME OPS team to support the development of test specifications and the testing itself, to ensure the testing accurately reflects the objectives of the system as translated into requirements. However, the operations team may not been following the programme development particularly closely due to their own priorities in and therefore be unaware that a major test campaign is upcoming. It is important therefore for the MME upgrade team to keep a long-term single integrated plan covering programme and operations needs with any updates communicated to the operations and maintenance teams, to ensure they have the resources to support at the necessary time and provision for early dry run campaigns in case of issues.

Load Test Campaigns: Isolated verification or validation of the MMS function to support the programme should be deemed insufficient in case of performance testing, as it is natural that the MMS should be tested in a representative way i.e. running the function supporting the future programme at the same time of routine processing of current programmes. Previously, it has been attempted to run “overall MME load test campaigns” whereby a full simulation is run of the programme and all the MMS – however the coordination of this is found to be extremely complex, with more exceptions to the scenario than there are rules. Moreover, it is found that the ultimate simulated data rehearsal is still not representative of the loading from the actual mission data chain. It is therefore recommended to do such type of representative testing using each individual MME rather than in combination.

Agreements on process management in operations preparation phase: It is important to include in the operations concept for the programme how change and anomaly management shall be handled between the programme and operations in the later stages of programme development. From the change management perspective, the programme might been keen to review any change to the MME baseline during times where they might be relying on it for e.g. a formal rehearsal. This desire is understood, however must also be approached with pragmatism and the same efficiency as is used for current programmes, to avoid unnecessary delay in the approval of changes. All parties should also understand if there are configurable items on the MME that need routine changes but have no impact on the future programme, only a current one. These changes should then be descoped from the future programme review. In the consideration of anomaly and non-conformance management, again there might be a natural interest in a future programme to review any anomalies on an MME that might affect them, however much like for change management, any independent review of such anomalies should be done in such a way that does not interfere with the usual MMS process. The future programme may try for example to re-prioritise an anomaly affecting their test campaign, but the MME cannot fulfil this with their current resources or a current programme has a more pressing matter. It is therefore advisable that a representative from the future programme is invited to the regular MME anomaly review board rather than a separate review or members from the MMS having to be present in each future mission ARB.

6. Conclusions

From the above discussed, it is clear that while the employment of multi-mission systems and elements can yield significant efficiency in routine operations, care must be taken in the planning of the integration with future programmes. Overall, MMS is welcomed at EUMETSAT as an efficient way of supporting operations; however, there have been many pitfalls that resulted in the lessons learned, as explored above.

These lessons learned and the resulting consideration can be summarised in terms of ensuring clear interfaces between teams, service declarations/definitions and an operations concept such that agreement with all stakeholders is documented and can be used as a source of reference.

MMS are essential for organizations like EUMETSAT, which operate various missions that share great similarities. In components where the pros outweigh the cons (i.e. when they bring a clear long term value despite the added complexity), its use is highly recommended in order to reduce the overall cost of development for new programmes, as well as long term operations and maintenance.

One of the most important lessons that the development of future missions has left us is that it is essential to establish coordination mechanisms right from the start between the development teams (such as MME upgrade team) and current users (representatives from Operations and Maintenance teams). Both the definition of new requirements and ICDs must result from an agreement between both parties, in order to avoid extra costs and unnecessary work in the future.

Finally, a notable challenge for the MME responsible teams is the use of these components to support current missions, MME validation campaigns and future missions in parallel, who may have completely different needs. EUMETSAT is currently defining a new operations concept at division level in order to establish the responsibilities between different control rooms, the use of MME environments to support both current and future missions (as well as any test campaign), and eliminate uncertainties at a key moment such as the handover to operations of future missions.

References

[1] Marston, Kevin: Multi-Mission Elements: “White Elephant or Essential
[2] “Business Sense?” 2016 SpaceOps Conference https://arc.aiaa.org/doi/pdf/10.2514/6.2016-2608