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Use of MBSA model for ensuring mission continuity

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Abstract

EUMETSAT is operating a system of meteorological satellites (GEO and LEO) that observe Earth’s atmosphere and ocean and land surfaces – 24 hours a day, 365 days a year.

The Data and products are supplied to the National Meteorological Services of the Organisation's Members and Cooperating States in Europe, as well as other users worldwide.

The Satellites in-orbit deployment and operations are driven among others by the following conflicting constraints:

- to ensure the mission continuity - this calls for replacing the ageing in-orbit satellites with younger/anomaly-free satellites;
- to optimize the space segment asset, i.e. to have the most efficient use/allocation of investments and resources - this calls for exploiting the in-orbit satellites for as long as safely possible and often extending their lifetime beyond that initially planned.

In order to reduce the uncertainty and support with clear inputs the relevant decisions, specific space segment availability models (one for GEO, one for LEO) have been developed for defining the predictive requested launch dates, based on the behavior of the different system elements. These behaviors are driven:

- by random failures or
- by deterministic thresholds

The output of the GEO model is the “mission availability vs time” curve for the main Operational Services provided by the Meteosat satellites, namely the Full Disk Scanning Service (FDSS-FES) and Rapid Scanning Service (RSS). This information will allow an optimized management decision for the relevant mitigation actions proposed by the Operations Team, with the most efficient use/allocation of capital and resources, in order to ensure the mission continuity.

Keywords: mission continuity, model, operational decision

Acronyms/Abbreviations

Meteosat Second Generation (MSG)
Meteosat Third Generation (MTG)
Full Earth Scan Service (FES)
Full Disk Scanning Service (FDSS)
Rapid Scanning Service (RSS)
Model-Based Safety Assessment (MBSA)
Spinning Enhanced Visible and Infra-Red Imager (SEVIRI)
Flexible combined imager (FCI)

1. Introduction

This paper presents the operational application of this method to the Meteosat satellites, currently for both the MSG and MTG series of satellites.

It gives some insights into the model developed and used in EUMETSAT, as well as the overall decision making process. Furthermore, this paper briefly presents the Meteosat satellites and missions and the main drivers considered when applying this method (and model) to their evaluation.

2. Recursive Model Presentation

The space segment system, made of several Meteosat satellites, a combination of random failures, and deterministic threshold, is quite complex to model.

Reliability Block Diagrams or Fault Trees, the usual methodologies that can be used for computing system availability, are not suitable for such a complex system. Therefore, the Markov Chains methodology is used instead, but in this case, the system model could still be complex.

The Model-Based Safety Assessment (MBSA) principle, via the AltaRica language, is a good solution to satisfy all the listed constraints. AltaRica is able to model each element of the system (e.g. each spacecraft) independently and then allows the system modularity. This kind of language is therefore able to model the system dynamic and to describe the way failures are propagating inside the system.

With the AltaRica language, each element is depicted by a block with a state-machine (Fig.1). The outputs depend on the state of the state-machine and input figures. The state-machine depends on the event that can impact the block. AltaRica allows to define an event by a probability law (e.g. in case of random failure) or a deterministic event (e.g. end of operational lifetime).

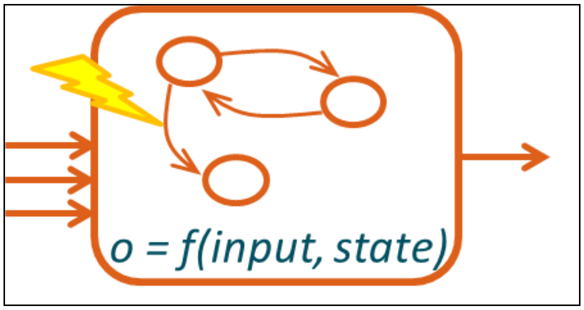


Fig. 1. Elementary Blocks depicted with AltaRica language

It's possible to link different elementary blocks between them in order to define the complete system to be modelled and analysed (Fig. 2).

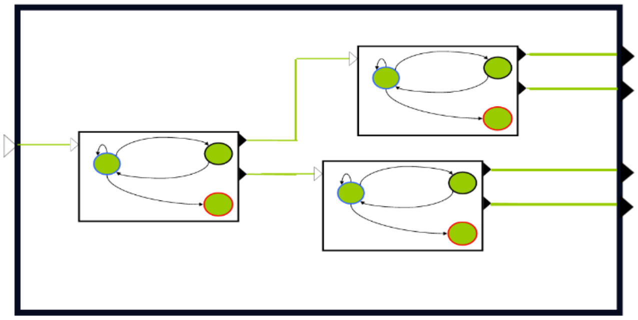
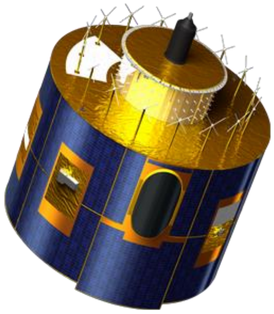


Fig. 2. Complete system with different elementary blocks

For the computation, the model is based on the principle that the system behaviour is described by specific availability curves between two moments of time, corresponding to either random changes in system state (in the case of random failure for example), or crossing over defined thresholds (e.g. satellite re-location or satellite end of life). The characteristics of the availability curves in that period of time is function of the specific assumptions that are valid between these two moments (e.g. number of satellites available, residual scanning capacity for specific missions, status of certain elements/sub-systems). As a result, the mission availability vs time line is a multi-segment curve.

3. Presentation of Meteosat satellite mission



The **Meteosat Second Generation** (MSG) fleet is composed of four (4) spin-stabilised geostationary satellites currently in orbit and launched between 2002 and 2015.

It should be noted that the first MSG spacecraft (called Met-8) was successfully re-orbited in October 2022.

Having three Meteosat satellites in orbit, EUMETSAT is delivering data to the meteorological users community by supporting the following missions:

- Full Earth Scan Service (FES);
- Rapid Scan Service (RSS);
- Indian Ocean Data Coverage (IODC).

All this services are provided via the Spinning Enhanced Visible and Infra-Red Imager (SEVIRI) instrument, which observes the Earth in 12 spectral channels (Fig.3).

A telecommunication payload (MCP) is also on-board MSG spacecraft and performs the following functions:

- Transmission of raw instrument data, and other information, from the satellite to the Primary Ground Stations (PGS);
- Retransmission of the Data Collection Platform (DCP) network information, via the satellite, to the PGS;
- Retransmission of Geostationary Search and Rescue (GEOSAR) signals.

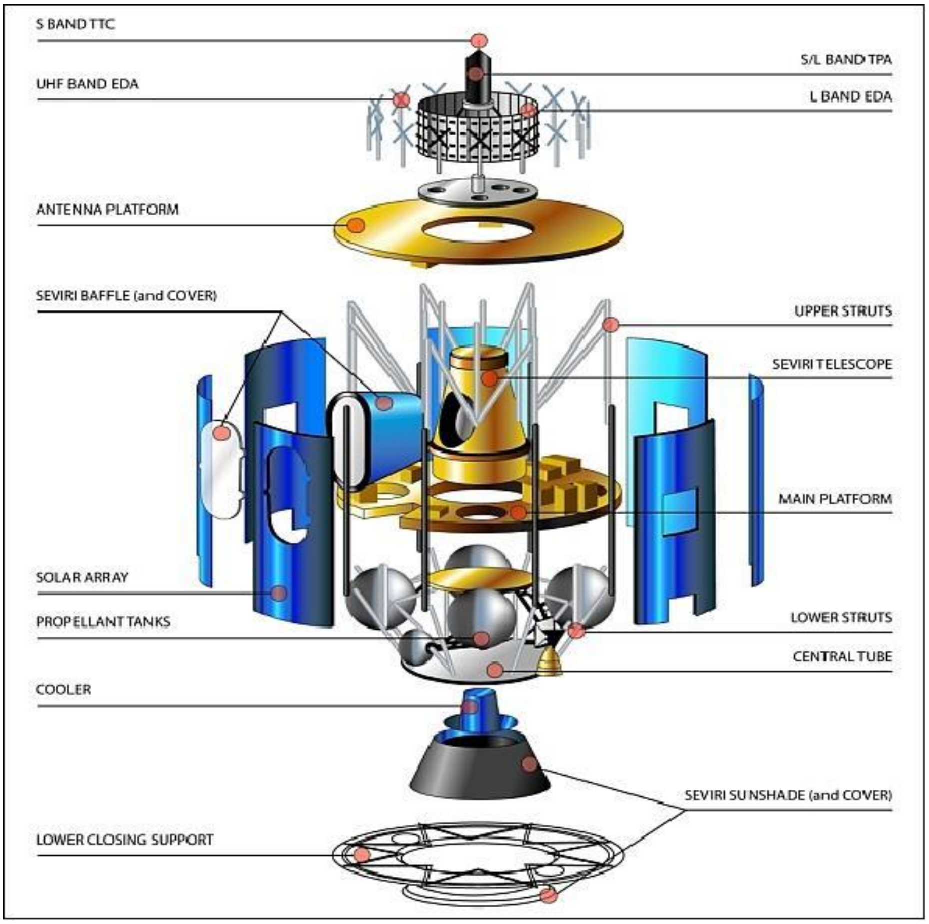


Fig. 3: Blow up of the MSG structure showing the main components of the S/C and its payload

The first **Meteosat Third Generation Imaging satellite** (MTG-I) was launched on the 13th of December 2022. It is now in the commissioning phase. MTG-I1 is the first 3-axis stabilised satellite to be operated by EUMETSAT for the geostationary Orbit (GEO).

The MTG mission comprises two different spacecraft:

- MTG-I carrying the Flexible combined imager (FCI), the Lightning imager (LI), the Data Collection System (DCS) and Search & Rescue (GEOSAR) payload, and the Radiation Monitoring Unit (RMU) payload (Fig.4);
- MTG-S carrying the Infrared Sounding Mission (IRS), the Ultraviolet Visible and NIR sounder (UVN) and the Radiation Monitoring Unit (RMU) payload.

The FCI instrument is capable of providing both FDSS-FES and RSS mission, providing continuity with SEVIRI.

In order to ensure the required mission availability during the mission lifetime, the space segment will consist of 4 MTG-I satellites and 2 MTG-S satellites. The number of MTG-I satellites is twice that of MTG-S as a hot back-up is required for the imaging satellites only.

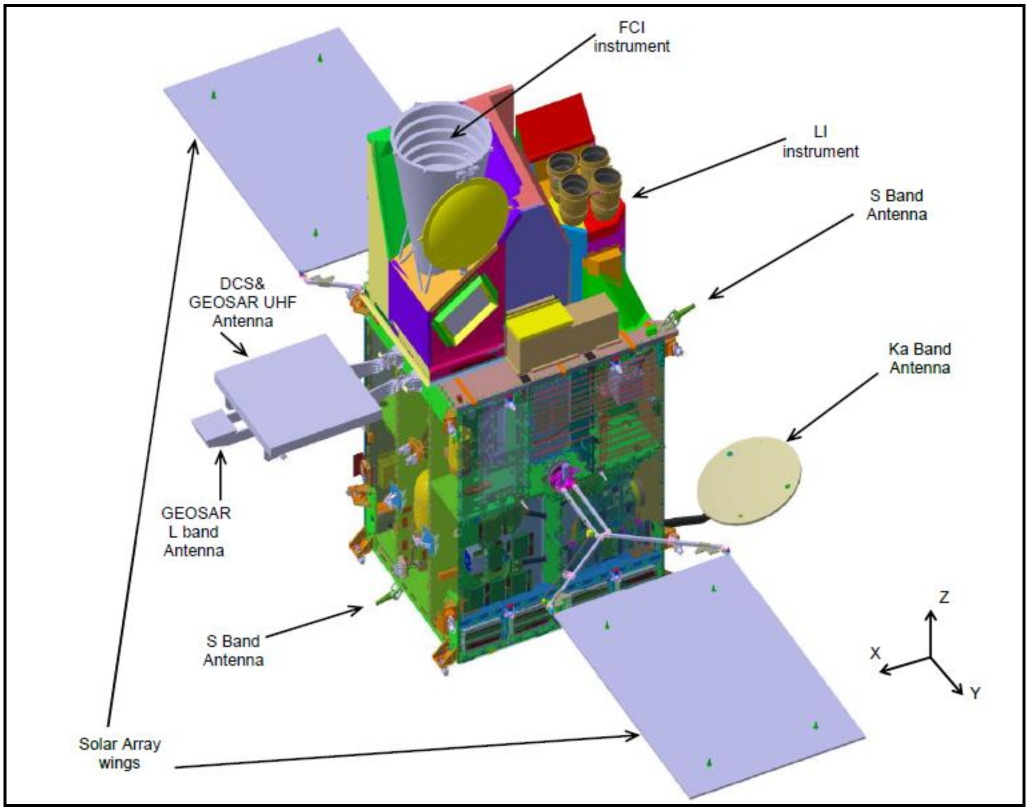


Fig. 4: Overview of the MTG-I satellite in deployed configuration

4. Presentation of the recursive Meteosat model

For the estimation of the Meteosat mission availability vs time, a dedicated model has been built accordingly with basis defined in §2, This model has two main high-level inter-linked blocks, the satellites block and the space configuration block (Fig.5)

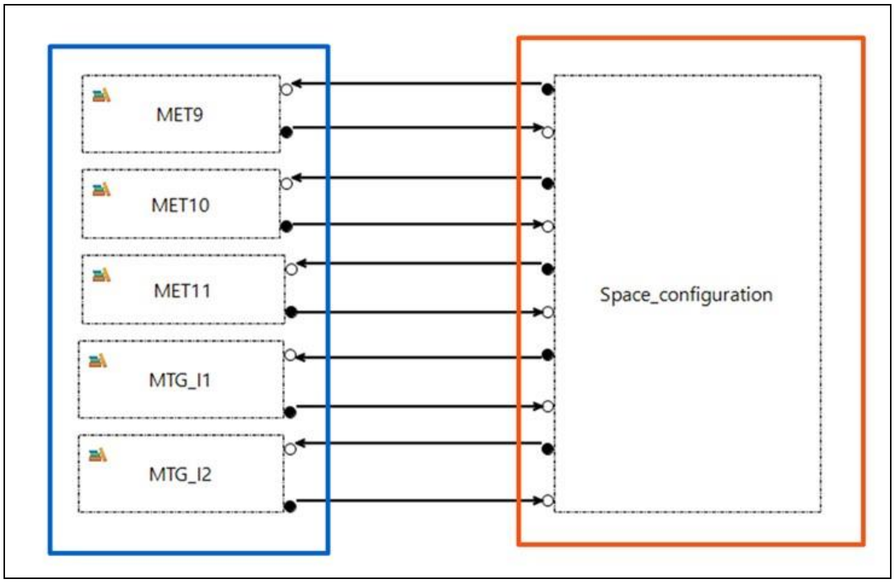


Fig.5. Complete Meteosat model

- The satellite block defines the current satellite status based on:
  - Random failure, both for platform and instrument with the simplification of the complete reliability predictive model (Fig.6);
  - The launch success rate in case the satellite is not yet launched.

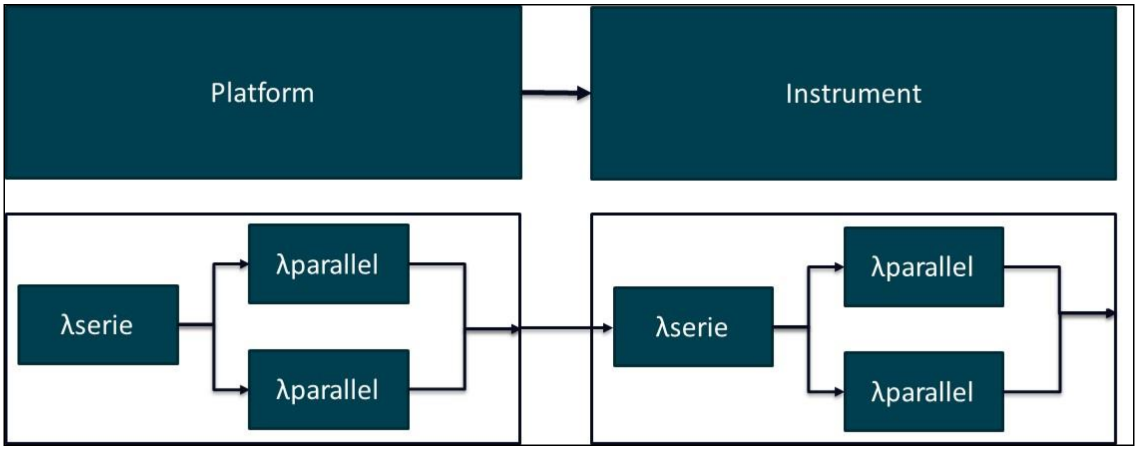


Fig. 6. Satellite model

- The space configuration block is based on the defined mission of each satellite, i.e. Ground, FDSS-FES mission, RSS mission, spare, (Indian Ocean data Coverage) and the associated rule for the fleet reconfiguration in case of spacecraft failure, accordingly with the assumed mission plan (see Table.1). This is the place for entering the different deterministic thresholds figures.

Start date	End date	FDSS-FES service	RSS Service	IODC	FDSS-FES back-up	RSS back-up
Jan-24	Apr-24	Met-10	Met-11	Met-9	Met-11	-
Apr-24	Apr-26	MTGI-1	Met-11	Met-9	Met-10 Met-11	MTGI-1
Apr-26	Nov-26	MTGI-1	MTGI-2	Met-9	MTGI-2 Met-10 Met-11	Met-11
Nov-26	Jan-27	MTGI-1	MTGI-2	Met-10	MTGI-2 Met-11	Met-11

Table 1. Assumed Mission plan

In order to run the model, the requested model inputs are the following:

- For the random figures
  - the current MSG satellites reliability model and figures. Each satellite has its own customised reliability model, taking into account its current status:
    - loss of redundancy if any. In this case, the Reliability Block Diagram is updated accordingly, and reflected in satellite model (see Fig.6);
    - for some components, an operational failure rate is computed instead of predictive failure rate. This is statistically relevant when a large number of identical components are flying in Meteosat satellite, with the use of Chi-Square method. This is the case for the LCL element for the Meteosat Second generation –type satellite;
    - platform and instrument temperature evolution. The component failure rate is therefore updated with the In-Orbit temperature instead of temperature used at the Critical Design Review.

  - the predictive MTG reliability model and figures. In the case of MTG-I1, the reliability model presented during the Critical Design Review by the satellite manufacturer is the model used;

  - the launch success rate, based on the in-service experience for Ariane 5 (Ariane 6 for MTG-I2) launcher.

- <u>For the threshold figures</u>
  - the actual and planned launch dates of each satellite (Table.2)

	Met-9	Met-10	Met-11	MTGI-1	MTGI-2
Launch date	Dec-05	Jul-12	Jul-15	Dec-22	
Planned launch date					Sept-25

Table 2. Launch dates for Meteosat satellites

  - the planned commissioning duration for the "to be launched" satellite. This duration is different per MTG-I satellite as the planned commissioning of MTG--I1 shall be longer than MTG-I2 one;

  - the estimated propellant budget, which is defined as a deterministic date in the model. This estimate is analysed and presented during the annual Lifetime review;

  - the guidelines and constraints introduced by ISO-24113 - Space systems — Space debris mitigation requirements. Even if both MSG and MTG satellite designs were not concerned by the ISO-24113 application, EUMETSAT as a social-economic responsible stakeholder has embedded this constraint in the decision. A Reliability Block Diagram covering the requested units for a successful re-orbiting is providing the probability of successful re-orbiting vs time. The defined decision making process is started sufficiently in advance before the 90% threshold is actually reached. This could also lead to another deterministic date inserted in the model, individually per satellite;

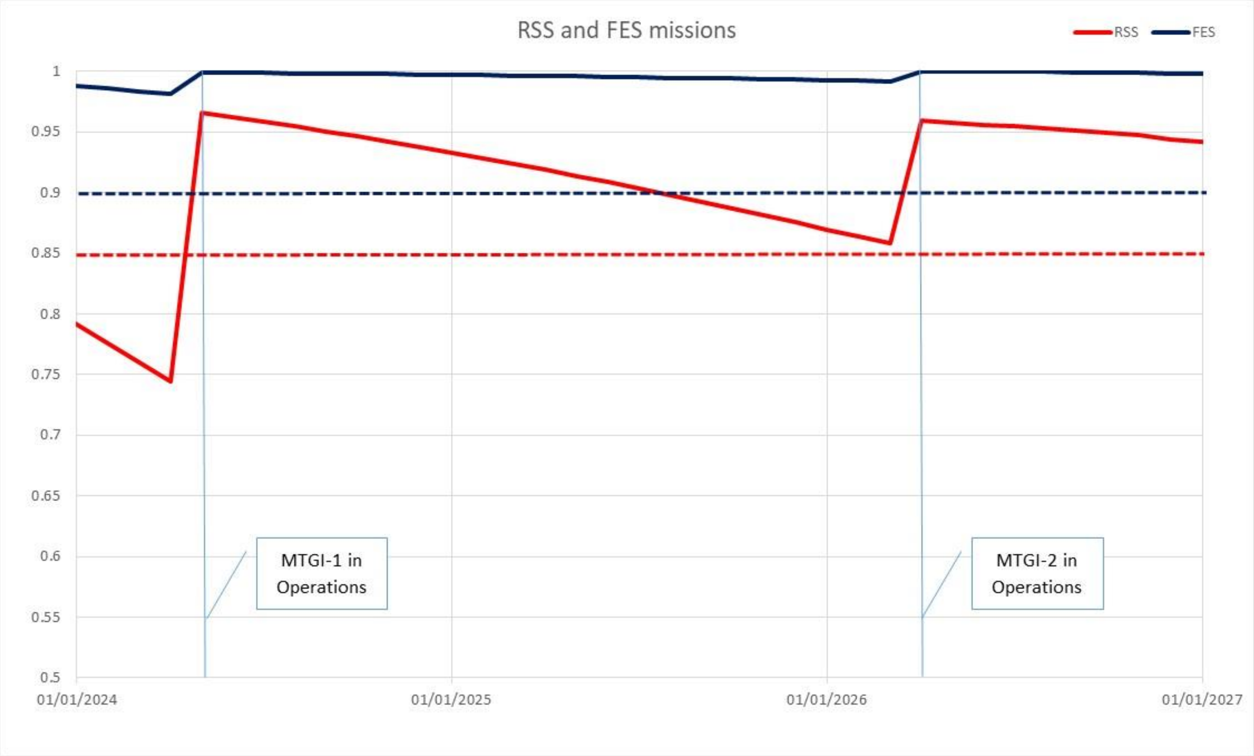
  - The estimate end of Satellite lifetime. There is a design lifetime defined by requirement (7.5 years), and based on experience and expertise, an extended design lifetime is also defined (around 20 years). In order to detect ageing phenomena for the satellite platform or instrument (means that constant failure rate for a unit shall be replaced by failure rate time-dependant –Weibull law instead of exponential law), a health monitoring of some units affected by potential ageing is in place. This could also lead to another deterministic date inserted in the model, individually per satellite.

5. Mission availability vs time result

After filling-in the Meteosat model with all the requested figures, a stochastic simulation based on Monte-Carlo is performed. The number of simulations is high (at least 500000 stories) in order to reduce the uncertainty of results. The events are triggered randomly (depending on their laws), and an event with a high probability of occurrence will be more frequently triggered than an event with a low probability of occurrence.
At the end of each simulation, the value of so-called observers (in our case both the FDSS-FES and RSS mission availability per month) is computed, defining the average mission availability per month (pace of computation).

The result is depicted in a curve "mission availability vs time". The curve.1 below presents the result for the timeframe Jan-24 to Jan-27 (period of time with transition from Meteosat Second Generation to Meteosat Third Generation), for both FDSS-FES and RSS missions.

The 90% (for FDSS-FES) threshold was defined by the end-users ("As a goal, the planning of Meteosat launches should maintain the availability of the Meteosat system above a threshold of 90%"). The 85% threshold (for RSS) was defined internally.



Curve 1. FDSS-FES and RSS mission availability vs time

6. Definition of next satellites launch date

The Meteosat model can be used not only to assess the probability of the expected service availability at any given point in time, but also in order to define the optimised launch date for the next satellites.

In fact, excluding from the model the next satellite to be launched, one can observe at which time the mission availability curve is crossing the 90% (for FDSS-FES) or 85% (RSS) line, which are used as operational service requirements. The date when this requirement is violated is the latest (but also optimal) time when the following satellite (in this study case MTG--I2) shall become operational in order to ensure the mission continuity as defined per users. The launch date is therefore defined accordingly taken into account the commissioning duration.

In defining the overall mission exploitation plan, while it is clear that a later launch date is not desirable because this would imply a larger risk of not being able to respect the service availability, one shall also consider that an earlier launch date (apart from the physiological margin required) is also undesirable, because it would create an unnecessary double redundancy in orbit and under-utilise the overall lifetime of the satellite series.

Based on curve 1, the decision driver is the RSS mission availability, crossing the 85% threshold in March 2026. Therefore, the launch date of MTGI-2 is defined to be Sept 2025, taken into account the planned 6 months of commissioning which are required to declare the satellite fully operational in orbit.

7. Lifetime review process

A Lifetime review at management level is organised every year (or on request in case of particular events affecting the satellite health or performance. The most relevant events are loss of redundancy or launch failure).

This process is mainly aimed at defining the optimal mission exploitation plan and is based on the assessment of the overall status of the satellites and of the systems used to perform the different missions.

In this context, the FDSS-FES and RSS mission availability curve, output of the recursive model, plays a particularly important role, together with the key elements of the mission, described hereafter:

- Health status of the satellites components and operability (including required orbit maintenance capability);

- Predicted Satellites reliability;
- Performance of all on-board equipment, especially for the payloads;
- Status of the on board consumables (e.g. propellant) and other specific lifetime constraints (e.g. qualification limit of particular mechanisms or equipment);
- Status and maintainability of the ground systems;
- Human resources, Financial and contractual aspects.

8. Conclusions

Based on the above elements, among which the results of the recursive model play an important role, the Spacecraft Operations Manager (SOM), is able to define with his/her Team an optimised mission exploitation plan, which is presented on an annual basis to the EUMETSAT Management Board.

In this way, the EUMETSAT Management Board:

- is made aware of the current status for the main mission continuity fulfilment;
- is made aware of the current trend and foreseeable predictions;
- is able to take informed decision on the relevant mitigation actions proposed by the Operations Team with the most efficient use/allocation of capital and resources;
- is able to endorse or request to modify the proposed mission exploitation plan, which then becomes the reference operations plan for the specific mission and used in several other aspect of the management of the Organisation (strategic planning, funding, new services)

The modelling has proven to be very useful to EUMETSAT, allowing to maximise the use of our assets whilst minimising the risk of service degradation.

Appendix A EUMETSAT Presentation

EUMETSAT is the European Organisation for Exploitation of Meteorological Satellites (www.eumetsat.int).

The primary objective of the Organisation is to Establish, maintain and exploit European systems of operational meteorological satellites, taking into account as far as possible the recommendations of the World Meteorological Organization.

The Further objective is to contribute to the operational monitoring of the climate and the detection of global climatic changes (EUMETSAT is a world leader in providing the robust scientific data from space needed to understand climate variability and change. Our long-term, multi-satellite programmes provide an increasing portfolio of observations that are key contributions to climate monitoring).

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