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ESTRACK Scheduling Simulation – validation of operational scenario and search for optimization

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Abstract

ESTRACK tracks spacecraft from low-Earth to Jupiter orbit, including everything in between. Resource allocation must meet the requirements of low-predictability Earth orbiters, Lagrange halo orbits, planetary transfer, flybys and lunar missions.

To meet this challenge, EPS has been developed to support an exhaustive list of mission scheduling rules and constraints. The tool is used for day-to-day operations, but its performance allows long-term simulations to be carried out over several years.

The simulation of an operational scenario over a long period is used to
- evaluate the impact of orbit evolution,
- estimate the volume of outsourcing,
- detect unexpected unfavourable booking patterns.

The ability to analyse results graphically and statistically allows to identify problems before they occur. It opens the door to new ideas for solving them. Idea which in turn can be simulated to assess potential cost/benefit.

This paper aims to present ESTRACK's approach to planning simulations, as well as the most relevant results regarding optimization.

Keywords: ESTRACK, Planning, Simulation

Acronyms/Abbreviations

Basic Standing Order Period (BSOP), ESTRACK Planning System (EPS), ESA tracking Network (ESTRACK), Deep Space and Lagrange missions (DS+L), Flight Control Team (FCT), Highly Elliptical Earth Orbit missions (HLO), Low Earth Orbit missions (LEO), Multiple Spacecraft per Aperture (MSPA), Service Opportunity Window (SOW)

1. Introduction

As every service provider, ESTRACK assesses its capacity vs the demand on a regular basis.

ESTRACK network serves ESA and non-ESA missions of different natures, classified in three categories:

- Low earth orbit (<1000 km). Which requires multiple short contacts per day.
- Highly Elliptical earth orbit. Mostly the older generation of astronomical observatories. They require long duration support above very specific locations.
- Deep Space and Lagrange missions, which require typically a daily pass of 5 to 10 hours depending on the phase of the mission.

In terms of capacity, ESTRACK relies on its own Deep Space assets, a near-earth network, and multiple agreements with other providers. Reported to the categories above, it shall be noted that:

- Near Earth. This type of orbit is actually very popular and well served by commercial providers.
- Highly elliptical. This "in between" family is a niche. The availability of powerful launchers makes Lagrange orbit more attractive for the new generation of space observatories. Too demanding for near earth network, and using frequencies not supported by Deep Space terminals, it is difficult to find ground stations for this class of mission. To complete the picture, the nature of their trajectory restricts coverage to specific earth locations.
- Deep Space. This segment is today covered by National Agencies. The high cost of entry ticket combined with the absence of market is not making it attractive to commercial players. Recently, a few private

initiatives targeting Moon mission support have been made. This new class of terminal could potentially be used to support Deep Space operations in some limited cases.

To review how all this fits together, ESTRACK planning office runs various simulation analysis. They are used to answer typically three questions:

- Can you live with yourself?
- How to distribute the load?
- How painful will it be?

2. Can you live with yourself?

At project start, an initial concept is established, typically a trade-off between opposing constraints. A mission analysis is done to proof this operational scenario.

As a project gains in maturity, things get more complex and teams get bigger, making coordination more and more difficult. As time goes by, it is common that each group is relaxing its own constraints or trying to push them to other teams. The operational simulation is an efficient way to detect inconsistency.

The year preceding the launch, when the situation gets more stable, ESTRACK Scheduling Office implement the proposed scheduling rules. The exercise intends to validate the latest operational concept by testing them against a representative orbit.

No conflict analysis with other users is made at this stage. The simulation validates the mission rules alone to proof consistency. It verifies as well the capacity of ESTRACK Planning System to them automated them.

To implementation of mission planning automation rules in the EPS is abstracted in three concepts[1]:

- Basic Standing Order Period
- Service Opportunity Window
- A set of Constraints

The BSOP defines the planning problem boundary and periodicity, which is typically per day or per revolution.

The definition of the "day" is usually the first point of friction between theory and reality. What shall be the right start of a "planning" day will vary a lot between projects.

For low earth orbit missions with short passes, 00:00 UTC is a good option. But for a deep space mission with long visibility orbiting an outer planet, it is better to define planning period which optimises the coverage.

For ESTRACK Deep Space network, the recommendation is to synchronize the planning cycle with the pacific coverage gap by using the ascending 10-degree elevation event at New Norcia. This natural gap minimizes visibility overlap loses.

For a planning-based solver, BSOP definition has a huge impact on performance and quality of the solution.

The SOW defines the solver solution space or "valid visibility". To be useable, a ground station visibility must respect properties which vary between projects. Typically, the visibility duration must ensure enough uplink time for commanding. To save on cost, it is may happen that a project request support to be restricted to working hours. It shall also be free of adverse events such has antenna keyhole or planetary occultation.

Figure 1 shows an example of low earth orbit mission visibility marking. Only the dark green marker are eligible for booking (sufficient duration, within working hours and no keyhole). Visibilities too short or with keyhole are not part of the SOW list.

The SOW concept allows to reduce the solver search domain to the essential.

Figure 1 Low earth orbit view period

On the opposite, a mission may express preferences. For planetary missions, planetary occultation can be a science opportunity. The perturbations caused by the planet on the radio waves are used to measure its atmosphere property or gravity field.

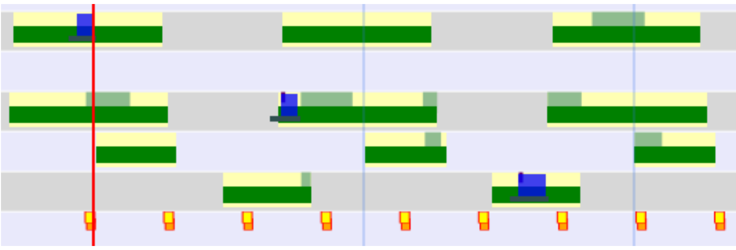

Figure 2 Mars visibility from ESTRACK, including Occultation and Eclipse

Figure 2 shows an example of a Mars mission planning. For low earth orbit, the question was "which visibility to select?", for a Deep Space mission it is "which part of the visibility should be selected?". Depending on the scientific objectives of the planning period, planning around planetary occultation may be required or avoided.

Link budget constraints may also forbid usage of part of the orbit or define an optimal communication window. This type of constraint is also driven by individual station performance. In such cases, the no-go and optimal range are station dependant.

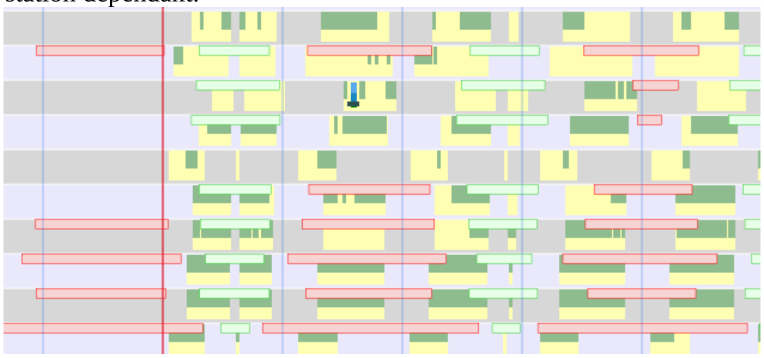

Figure 3 Link budget constraints. The out-of-range (red) and high-rate period (green) are correlated with terminal individual performances

Figure 3 provides a visualization of link budget for a highly elliptical orbit. The usable part of the orbit is the perigee, which has unfortunately the shorter visibility. And most of the long apogee visibilities are un-usable.

Highly elliptical orbits are difficult to serve. Low earth orbit network performance may not be sufficient to cover the apogee.

A simulation also assesses the effect of the orbit evolution over time. ESA mission lifetimes usually extend far beyond the original objective. To adapt or optimise on-board fuel management, the orbit control law may be revised, changing completely the network coverage. The visibility to prime stations may vanish, and a new network must be identified. As it takes more than a year to go through the legal framework to contract and validate a terminal, it is critical to detect the issue as early as possible.

The last parameters for the solver are the planning constraints. They specify minimum and maximum values to implement a service. Typical elements are:

- Number of passes
- Handover (if required)
- Individual support duration
- Overall service duration (if service can be implemented over multiple supports)
- Separation between supports

Once the problem is set, ESTRACK Scheduling Office runs a long-term simulation from a year up to a decade to detect potential issues. Using a smart planning solver[2][3], ensure that all planning constraint are respected. If the evolution results in an impossibility to find a solution, the system informs the operator. The failure cause can then be analysed and a new support scenario established.

The typical points checked are:

- Cost saving measures which may create other costs e.g. working hours can only be implemented by outsourcing.

- Minimum elevation and seasonal location not compatible
- Pacific gap impact
- Blind orbits
- Alignment to surface rover visibility
- 24/7 coverage requirements

3. Distributing the load

Once individual scenarios are validated, they are run together to check that their foreseen networks have the capacity to support. The outcome defines the sharing between external providers (to size contract volume) and early identification of limitations such as coverage gap, and maximum number of terminals needed.

For a low earth orbiter (500~1000km) is sufficient to generate one year of planning data for statistical analysis. This encompasses the impact of ground pattern repetitions, the combination of these repetitions, and the constraints imposed by working hours.

Daily ratio																			
Kiruna																			
All	CRY	SWA	AEOL	ECAR	BIOM	FLEX	SN1A	SN1B	SN1C	SN1D	SN2A	SN2B	SN2C	SN2D	SN3A	SN3B	SN3C	SN3D	SN5P
26.8	12.25	4.79	1.33	0.00	0.00	0.00	1.25	1.24	1.23	0.00	1.16	1.17	0.00	0.00	0.86	1.00	0.00	0.00	0.47
29.9	12.25	5.66	0.00	0.00	0.00	0.00	1.98	0.00	1.99	0.00	1.89	1.94	0.00	0.00	1.06	1.88	0.00	0.00	1.21
31.7	12.25	5.03	0.00	1.71	0.00	0.00	1.72	0.00	1.44	0.00	1.76	1.78	1.78	0.00	1.59	1.65	0.00	0.00	1.02
36.6	12.25	5.65	0.00	2.00	1.48	0.00	1.75	0.00	1.77	1.81	1.85	1.88	1.87	0.00	0.75	1.74	0.72	0.00	1.05
31.5	12.25	5.66	0.00	2.00	0.00	0.00	1.94	0.00	1.93	0.00	1.85	1.90	0.00	0.00	0.96	1.85	0.00	0.00	1.13
34.1	12.25	5.66	0.00	2.00	0.00	0.00	1.94	0.00	1.93	0.00	1.85	1.90	1.88	0.00	0.90	1.84	0.87	0.00	1.11
35.0	12.25	5.65	0.00	2.00	1.48	0.00	1.76	0.00	1.77	0.00	1.85	1.88	1.87	0.00	0.82	1.80	0.79	0.00	1.11
25.1	12.25	4.85	0.00	0.00	0.00	0.00	1.45	1.47	0.00	0.00	1.17	1.18	0.00	0.00	1.03	1.12	0.00	0.00	0.60
26.7	12.25	4.85	0.00	1.06	0.00	0.00	1.09	0.00	1.08	0.00	1.17	1.18	1.18	0.00	1.02	1.17	0.00	0.00	0.62
24.5	12.25	3.74	0.00	1.78	0.00	0.00	1.25	0.00	0.00	0.00	1.07	1.09	0.00	0.00	1.29	1.29	0.00	0.00	0.75
25.2	12.25	3.84	0.00	1.99	0.00	0.00	1.32	0.00	0.00	0.00	1.10	1.15	0.00	0.00	1.35	1.36	0.00	0.00	0.81

Figure 4 Daily support averaged demand

To account for the effect of repeat cycles combination, the simulation range must be adequate. For low earth orbit missions with repeat cycle typically between 14 to 30 days, a full year simulation is run. For each simulation, a daily average figure demand (Figure 4) is computed for each mission at every provider. Each case represents a virtual scenario with a fix selection of missions with a stable demand profile. They are run individually over the full year to provide enough data for a statistical analysis.

Every time a new mission arrives, a new combination of cases must be run. When the launch order changes, new cases shall be run. The load profile, either routine or commissioning can also be considered as a typical commissioning for ESA missions last between 3 to 6 months.

Processing wise, running a one-year simulation on EPS takes between 6 to 8 hours.

Case													366	Total summary			
	Ref	SN1C	ECAR	BIOM	SN2C	SN3C	FLEX	SN1D	SN2D	SN3D	Start	End	Days	Kiruna	Svalbard	Troll	ESRG
21	R	R											0	0.0	0.0	0.0	0.0
41	R	R											0	0.0	0.0	0.0	0.0
45	R	R	R		R								0	0.0	0.0	0.0	0.0
51	R	R	R	R	R	R		R					0	0.0	0.0	0.0	0.0
43	R	R	R										0	0.0	0.0	0.0	0.0
47	R	R	R		R	R							0	0.0	0.0	0.0	0.0
49	R	R	R	R	R	R							0	0.0	0.0	0.0	0.0
28	R										01/01/2024	01/06/2024	152	3817.9	849.5	0.0	417.3
35	R	R	R		R								0	0.0	0.0	0.0	0.0
22	R		C								01/06/2024	01/01/2025	214	5248.6	1741.9	474.3	525.9
22C	R		C										0	0.0	0.0	0.0	0.0

Figure 5 Case and Scenario definition

To compute the realistic plan forecast, the individual cases are combined by extrapolating individual cases result. The global forecast result is produced (**Error! Reference source not found.**) as a combination of the relevant scenarios applied for the relevant time range. When a launch date changes, as long as the planning problem configuration is composed of already simulated cases, the table can be immediately updated.

Number of pass to be requested					366	days period														
	All	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	SC11	SC12	SC13	SC14	SC15	SC16	SC17	SC18	SC19
Kiruna	9066	4484	1538	0	382	0	0	488	223	0	0	407	414	0	0	432	447	0	0	252
Provider1	2591	0	658	0	0	0	0	244	808	0	0	66	155	0	0	152	285	0	0	223
Provider2	474	0	0	0	474	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Provider3	1200	7	0	0	0	0	0	366	0	0	0	259	164	0	0	147	0	0	0	257
Average	36	12	6	0	2	0	0	3	3	0	0	2	2	0	0	2	2	0	0	2
total	13332	4491	2196	0	856	0	0	1098	1031	0	0	732	732	0	0	732	732	0	0	732

Figure 6 Yearly simulation summary

This output is used to estimate outsourcing contract volume (Figure 6). The accuracy of the figure is expected to be within a 15% error margin. Based on sample review most of the error is caused by late changes of mission requirements.

Simulation for Highly Elliptical Orbit would be possible with this approach as they have repeat cycle shorter than 3 days. However, this is currently not needed for ESTRACK. Their pool of this mission category is too small and using a dedicated network. Support volume estimation can be done easily with simple math.

ESTRACK has also considered the idea to run multiple years simulation for Deep Space missions. The EPS design supports this functionality. So far the project is blocked by two hard points.

First, it is very difficult to establish a scenario. Planetary exploration imposes launch windows opening only a couple of months every now and then. If a launch window is missed, the new opportunity may be in a couple of years. And the mission demand profile will have to be completely revised as well as its impact on other users.

To be meaningful, simulations shall be run for each case, which implies to maintain parallel scenarios, including different orbits, for all of them. If doing it for one is already a difficulty, doing it for many is currently out of reach. Not even mentioning the fact it is common that even with a launch on time, initial plan changes significantly for budgetary or technical reasons. Invalidating any simulation previously ran.

Second, a heavy processing constraints-based simulation makes sense only there is a solution. Otherwise, the only result you get from your expensive and complex tool is: "There is no solution. Please ask another question."

With the saturation of Deep Space assets, it is not possible to fulfil nominal mission requirements. The solution has to come from a long and careful give-and-take negotiation between users. Currently it takes one month of all involved party combined effort to create six months of planning.

As the first point was that the long-term scenarios are not clearly defined in the long run, it is not worth to spend effort to run simulations beyond one year in the future with the current process.

The idea to simulate beyond the 12 months horizon is not abandoned. As more Deep Space terminals will become available, interest in simulations will raise.

Until then, the only meaningful outcome of Deep Space simulation is to measure the pain.

4. Measure the pain

The third type of analysis targets a rough estimation of the demand. It is used to assess the need to invest in additional infrastructure, or the potential consequence of not doing so. In the context of Deep Space mission scenarios, where resources are limited and investment time very long, it allows to estimate the oversubscription level.

The approach is simple, the yearly tracking demand, including tear down and set up time is plotted against the capacity. For Deep Space assets, the "serving" capacity is estimated at 5800 hours per year. This represents 2/3 of the total available time.

In normal circumstances, over one year, one third of the time a terminal is not usable due to lack of opportunity. The geometrical visibility of planetary missions aligns on regular basis. Either all users are visible at the same time or no one is.

The distance from earth imposes in addition a high minimum support duration. With a round-trip light time of 40min and one hour setup/tear down time, support windows shorter than 3 hours are of little use. For that reason, users request minimum tracking duration which is not optimal for the network loading.

In Figure 7, it can be seen that ESTRACK Deep Space network has saturated for the first time in 2016 for the Rosetta Landing. And since 2023 capacity is not able to answer the demand. It is expected that the introduction of a fourth terminal in 2026 will alleviate the situation for a short period of time.

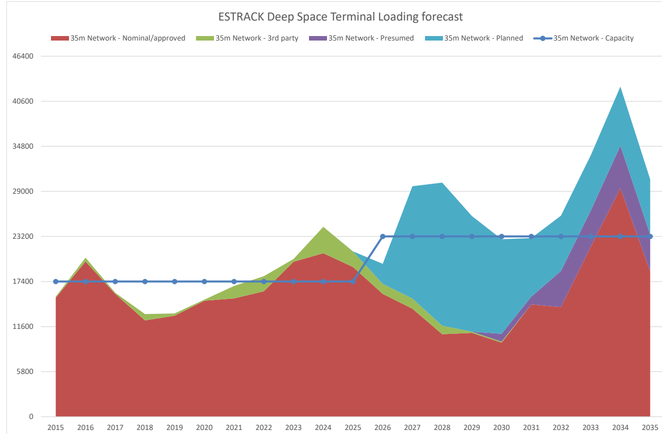

Figure 7 ESTRACK Deep Space Tracking Demand

Figure 8 demonstrates the pertinence of the 2/3 saturation threshold definition.

In 2016, the served hours level has stopped right at 66% load level (red line).

In 2023, the served hours goes beyond the threshold, but there is a good reason for it. In the last year, ESTRACK has implemented the Multiple Spacecraft Per Aperture service. It has allowed to serve two or more Mars missions in parallel with the same asset, increasing ESTRACK capacity in this very specific configuration.

MSPA is a cost-efficient way to increase resource, but very restricted in usage as it can only be used if the spacecraft are in the same position in the sky, typically by orbiting the same planet. It is beneficial, but this is no a solution to oversubscription.

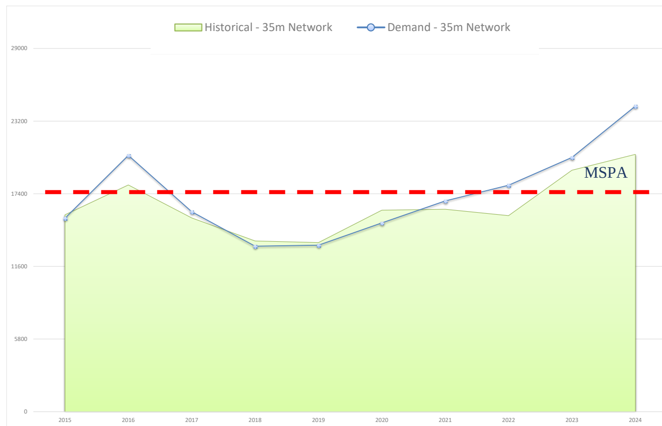

Figure 8 Served Hours vs Demand

This new capacity has been very helpful to serve Mars orbiters and will likely be re-used at Mercury in the near future.

This method analysis assumes a stable demand. A mission requesting 8 tracking hours per day for a yearly volume of 3000 hours fits well in this model. For peak demand, this approach will not work as it will not detect problem. This is especially true for today's popular moon missions. Moon projects require full-time support for a month per year. For a network provider this is extremely unbalanced load profile is problematic. Similar peak activities are also present for Deep Space mission, typically during the planetary transfer phases. Fuel efficient transfer requires multiple flybys, in addition to the launch itself and the planetary capture phase.

To model this short duration critical events a more targeted measurement is needed. One option is to request from user a more granular demand profile, such as weekly user loading profile. But this requires a significant effort from all users to create and maintain them[4].

To keep things simple, ESTRACK scheduling office maintain a catalogue of high intensity activity loading profiles.

Each type of activity is modelled by a standard artificial demand profile. E.g.:

- Launch and Early Operation requires a lower intensity preparation phase, then proceeds with ~10 days of 24/7 support, and requires one month of initial high demand commissioning.
- Fly by requires a high volume of support for navigation purpose before and after the fly-by support itself.
- Moon mission requires maximal support for at least the travel phase and a Moon Day
- Or special profiles such as GAIA Galactic Scan pattern

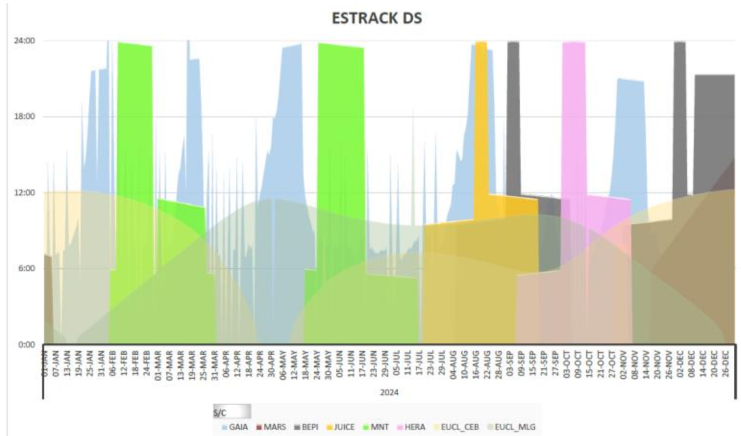

Figure 9 ESTRACK 2024 Critical Activities

As example Figure 9 illustrate ESTRACK Deep Space network critical activities prediction done for 2024

The typical use case of this chart is to identify quieter period for antenna downtime. The green blocks in the charts indicate the negotiated full and partial downtime. By properly selecting low activity period, the impact of downtime on the network capacity is negligible.

By comparing with the actual network utilisation, it is possible to assess the pertinence of the method.

Figure 10 shows the planned critical activity planned in 2025 based on the simple patterns model in a spreadsheet. There are 4 fly-bys and one Moon Landing support. The last activity is under negotiation.

Figure 11 is the actual committed supports for 2025. The highs and lows for each mission are clearly visible.

It shall be noted that even if a mission has routine demand, the visualisation of the operation criticality is an additional information essential to ESTRACK planning priority. In the Figure 10 example, the "Sun" missions February fly-by is not clearly visible from the routine demand.

Plotting only the allocated support, operational in this case, or from a simulation would not highlight the criticality information.

This demonstrates the efficiency of a simple spreadsheet approach easily maintainable over expensive and time-consuming methods.

The frequency of the simulation update shall be consistent with the corrective action implementation time. From decision to operation, the introduction of a deep space terminal takes around 3 years. For that purpose, a yearly update is sufficient. To cover financial aspect, more frequent revision may be needed to ensure that actual usage is in line with contractual agreement.

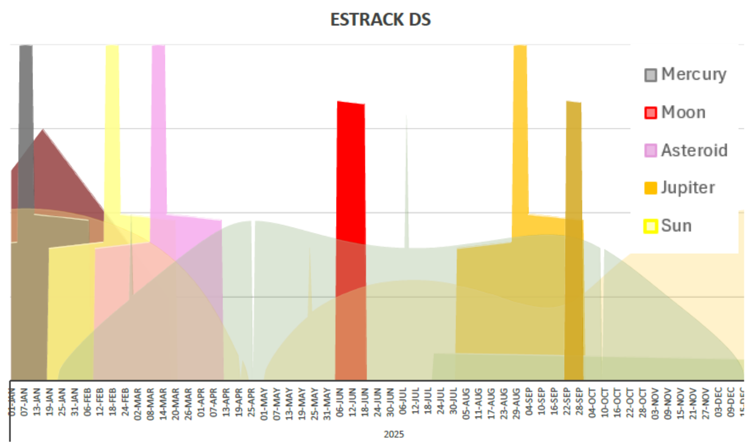

Figure 10 ESTRACK 2025 Critical Activities simple model

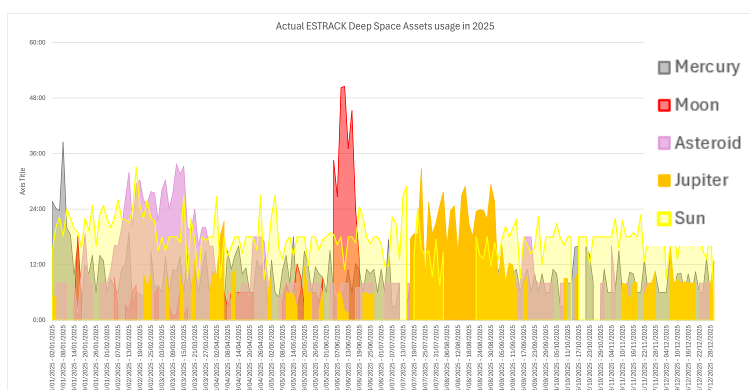

Figure 11 Committed 2025 Supports

5. Going beyond

5.1 Getting the question right.

A very detailed simulation is only useful in a stable context. When user requirements are permanently changing, it is of little value to identify a problem likely to disappear by itself.

Various methods are available to assess and visualize a tracking network load. There is no good and bad one. It all depends on the question you are trying to answer.

Simulation using a solver is good to explore complexity. EPS is a very powerful tool on that regard. But it currently has two weaknesses.

The configuration of the tool is extremely complex. It requires a very specific expertise that takes a long time to build up. One of the challenges for the next generation of ESTRACK planning system is to make configuration more user-friendly. This is typically the type of application well suited to be software as a service.

Another key aspect is that irrelevant of the tool performance, the quality of the result relies on the quality of the inputs. A space network planning problem requires accurate view period data and a complete user defined scenario. For ESTRACK, the in-house expertise of the flight dynamics department ensures an excellent quality of the predictions for all type of orbit.

Today concern lies in the user scenarios definition. A user lists draft planning requirements. ESTRACK scheduling office converts them in a machine-readable input, runs a simulation, shares finding with user, and revised requirements are produced. This process is highly iterative and requires a significant recurring effort on both sides.

There is a need for tool supporting user in building up operational planning scenarios. This would be helpful in the design of planetary transfer scenarios. Currently a user must list all the key events, such as launch, commissioning and fly-bys, and translate them into a user loading profile, usually in a spreadsheet. This spreadsheet is used as input to create the machine-readable inputs for each day.

Most of these key events have many similarities. They can be modelized into a standard profile linked to the central key date (e.g. fly-by) or a range (e.g. commissioning). A user could use these templates to create personalized implementation. A full mission profile could then be created by a score of such events. The output being directly machine-readable could then be used to generate user loading profiles in multiple formats or to run simulations. The user would have the possibility to visualize the result of his decision immediately and adapt scenario directly.

Getting the question right from a single user perspective is a pre-requisite to complex multi-user conflict analysis simulation. Currently only basic stable demand (e.g. 8 tracking hours /day) are manageable. As there is no proper tool for it, any demand which evolves over time requires multiple iterations and efforts. Only GAIA mission, which had an extremely complex demand profile, had invested in a dedicated tool. The flight control team has generated two daily demands for each day of the 11 years mission lifetime, covering both nominal and degraded case. The availability of around 8000 machine readable inputs had allowed full automation of the mission planning. With a proper input, the full mission ten years lifetime planning was done in less than 2 hours.

A similar tool is currently missing to build planetary transfer scenario. However, building such a tool is complex. It represents too much effort for a single user for which this phase is only a small part of the mission lifetime. If the effort is not worth from a single mission perspective, for ESTRACK it is a recurring problem. For that reason, ESTRACK scheduling office is considering the development of a generic Deep Space transfer profiling application.

5.2 Answering the impossible

Another common problem is addressing a scenario impossible to fulfil. A solver will try degrading within the authorized mission minimal boundary. But if these minima are still too demanding, it will simply fail.

A simple method will show that capacity is exceeded but will not give any information on what the real impact will be. Today, only a real planning exercise allows a thorough analysis on the situation and the potential solutions. However, this is time consuming.

When forced to run "impossible" scenarios, ESTRACK has two options: Artificially lowering the demand or adding "virtual" resources.

The lowering of the demand requirement, going up to "nothing is acceptable", allows the solver to go quickly to a "solution" showing the gap. This solution will be used as a starting point for negotiation. The main drawback is it imposes to alter the operational configuration by derogating from the contractual requirements. If one alteration can be confirmed by negotiation, there is no guarantee this will be the case for another scenario. Each iteration will require a new negotiation.

The addition of virtual resources is another way to use a solver to return a solution. If they are carefully chosen, the booking on these extra resources gives an information on where to look for a solution. This is a valid approach to identify the best outsourcing or investment options.

These two methods currently require a significant effort to "cheat" with the configuration in a smart and (hopefully) controlled manner. All that could be handled much better with a proper application layer managing the "alteration" in an automated way. It shall be possible to define strategy when the solver reports an impossibility to allow automatic refining of the scenario configuration. Depending on the objective, the planning system could then automatically return a proposal on how to share the impact between users, or suggest the optimal location to invest on additional resources.

The development of this functionality is in the ESTRACK scheduling office roadmap, but with no defined target date.

6. Conclusions

There is no best way. Forecasting the future is and will always be a challenge. As ESTRACK is supporting a wide range of mission profiles, many different aspects have to be considered. Specific methods must be used to address specific questions [5].

Validation of operational scenario requires a planning solver powerful enough to address the mission complexity over long time range. This is an extremely useful tool to test and validate mission operational concept. However, solvers are complex tools. The expertise level required to configured them properly make them challenging to operate.

When the mission profile varies over time, the user demand profile must be converted into a machine-readable input to be of any use. This has been done successfully only for GAIA mission so far. Other missions rely on the ESTRACK Scheduling Office generic application to generate them.

Generic applications are suited to do everything but are usually not adapted for any. ESTRACK scheduling office is considering the development of new user interfaces targeting Deep Space cruise phase planning profile. This would allow to create and maintain planetary transfer scenarios in a format directly usable by a planning solver. If this could be done in a more user-friendly way than now, that would be beneficial to all.

Simulation for ESTRACK is also paving the way for operation automation. By running simulations over long periods, it proves the capacity of the planning system automation to handle them.

But not all questions need a complex and expensive tool to be answered. Common sense and simple maths can do a lot. It is important to have a good understanding of the nature of the orbit and basics of celestial mechanics to address this type of problem. Graphical representations are helpful to support this phase.

When accuracy can accept 15% uncertainty, a simple computation can be very efficient to estimate the future. But it will not allow to validate a complex scenario or detect peak load.

For the study of the complexity of a problem, a powerful solver remains essential. However, if the problem contains too much uncertainty a simplified method is more efficient.

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