

# BENEFITS OF ADVANCED SOFTWARE TECHNIQUES FOR MISSION PLANNING SYSTEMS

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## KEY WORDS AND PHRASES

"Artificial Intelligence", "Mission Planning", "Flexibility, Genericity and Performance".

## INTRODUCTION

The increasing complexity of modern spacecraft, and the stringent requirement for maximizing their mission return, call for a new generation of Mission Planning Systems (MPS). In this paper, we discuss the requirements for the Space Mission Planning and the benefits which can be expected from Artificial Intelligence techniques through examples of applications developed by Matra Marconi Space.

## THE MISSION PLANNING PROBLEM

The term "Mission Planning" is used to refer to the process of planning and scheduling all activities and operations of the space segment (spacecraft platform and payload, e.g. power sub-system for the platform, optical instruments and tape recorder for the payload) and the ground segment (ground station activities, payload data processing and product dissemination) associated to a given mission.

The main inputs to the Mission Planning System are a set of requests of the following types :

- Spacecraft platform operation;
- End User request (e.g. observation requests for an Earth observation satellite);
- Other types of ground segment activities (e.g. data processing requests, dissemination requests).

The main outputs of the Mission Planning System are the *Service Utilization Plan* for satellite End Users, the *Final Operations Plan* uplinked to the space segment. Additional outputs include ground segments activities plans. From an operational point of view, the whole process is decomposed in the two following phases :

- Generation of the Operations plans: this phase is performed off-line and deals with the acquisition of User Requests and the detailed planning and scheduling of all space / ground operations. It includes :
  - The generation of the Preferred Exploitation Plan (PEP),
  - The integration of this first plan with the activities required by the Operations team for house keeping maneuvers, and the production of the final "executable" plan.
- Execution of the Operations plans : Once the whole planning and scheduling process has been completed, a schedule is available for execution and transmitted to the execution environment. During execution, monitoring is performed to control the evolution of the mission and detect eventual anomalies. If any disturbance on the current schedule occurs during its execution, rescheduling may be required and performed locally by the mission control center. If the rescheduling fails, a replanning session is entered on the Mission Planning System. Examples of anomalies include resource shortage (e.g. electrical power drop, unavailable ground station), activity execution failure (constraint violation, unexpected result), and changes in the satellite status due to some contingency (automatic or manual plan interruption, unexpected state transition).

## THE MISSION PLANNING REQUIREMENTS

Based on experience learnt from past developments and current studies, both on operational Mission Planning systems and on advanced prototypes, three main types of requirements on the Mission Planning system can be identified.

### Algorithmic performance

Generally, the Planning & Scheduling problem is characterized by an intrinsically high combinatorial complexity, reflecting the complexity of the spacecraft itself and the numerous utilization constraints (resource constraints, inter-instruments constraints, etc...). This is in particular the case for the first step of the Mission Planning process which deals with the definition of the PEP starting from a large number of End User requests. It is thus necessary to find powerful algorithmic techniques to deal appropriately with that complexity, in order to optimize as much as possible the utilization of the satellite, while taking into account the constraints on computing time.

Matra Marconi Space has conducted an internal study on this problem in order to evaluate the applicability of advanced algorithmic techniques on the planning & scheduling of an Earth Observation spacecraft. The objective was to optimize as much as possible the use of the satellite resources with an acceptable response time taking into account the following points :

- On one hand, the combinatorial problem due to the high number of requests to be scheduled makes the determination of a good solution difficult in a reasonable time (large space of potential solutions to be explored);
- On the other hand, the complexity of the spacecraft due to the management of tape recorders, the strategy used for ground station dump operations and the constraints imposed by the capabilities of the instruments in terms of transition between requests makes the determination of one feasible plan a time consuming step.

The activity performed in 1993-94 lead to the definition and implementation of a planning algorithm applied to the SPOT4 mission

planning problem using an iterative and "any-time" optimization strategy [1]. This approach is characterized by two phases :

- Phase 1 : Determination of a first plan (without optimization) based on a simple heuristic strategy. This phase is considered as an initialization phase being responsible for the determination of a first potential solution.
- Phase 2 (The anytime phase) : The algorithm starts a loop which explores the initial plan elaborated in Phase 1 and then optimizes this plan. This operation is done by iteratively removing some requests and inserting new requests according to heuristics driving the plan evolution toward a better plan quality. In order to avoid looping in the remove / insert process, all generated plans (up to several thousands) are stored and each new plan is checked against the history of the already generated plans.

This algorithm was integrated into a mission simulator for analysis on real problems. Testing has been performed using operational scenarios and the analyses conducted during the testing phase have lead to the following conclusions :

- A first set of initial plans can be made available at the end of the first phase, in a very short time;
- Initial plans are improved regularly and solutions are available at any time (Several plans of approximately the same "quality" are available);
- The flexibility of the iterative approach allows late insertion into the plan of new requests, which is an important advantage from an operational point of view;

This approach thus proved to be quite successful; furthermore, it is general enough to be reusable for other planning and scheduling problems. Further developments in this area now concerns the application of these techniques to a new observation satellite.

### Flexibility

The lifetime of modern spacecraft combined with the complexity of the current missions call for highly flexible and evolutive planning systems, enabling users to adapt the planning system to the evolutions of the planning problem (new planning constraints derived from satellite degradation, new planning strategies

because of evolution of spacecraft utilization or increased planning experience, etc...). In conventional Mission Planning System, information is more or less hard-coded, making changes and corrections difficult. For instance, the evolutions of conceptual information concerning strategies for resolving conflicts cannot be modified by the operator and requires software modification. In order to solve this problem, Knowledge Based Systems (KBS) have a more declarative approach which brings a high degree of flexibility in the system.

An illustration of this approach is given by PlanErs [2]. PlanErs is a mission planning system developed by MMS (France), CRI (Denmark) and AIAI (University of Edimburgh) for the European Earth Resource Observation satellite ERS-1. It has been developed during an ESA R & D project from 1987 to 1990. Its first objective was the modeling of the planning & scheduling process in order to optimize various strategies (usage of recorder, record / dump strategy and selection of the ground station dedicated to the dump operation, priority mechanism between requests in order to cope resource shortage, etc). One of the main features of the system is the use of high level, user accessible formalisms for representing the different areas of the planning knowledge.

A simple example is the rule formalism used to define the transition modes for instrument:

*From Mode Measurement\_1 to Mode Measurement\_2*

- *Goto Mode Standby\_1 during 10 seconds*
- *Goto Mode Standby\_2 during 20 seconds*
- *Goto Next\_Mode*

Thanks to this approach, the PlanErs system has been used (in 1991-1992) by the European Space Agency (ESA) as a Mission Analysis tool for interactively simulating the impact of various strategies and constraints on the mission output of the satellite. PlanErs allowed to demonstrate a high potential in the adequation with the problem domain evolutivity by providing a very modular and declarative representation of the different types of knowledge involved in the scheduling problem, including for instance the possibility to account for evolutions in satellite utilization constraints, ground segment resources, tape recorder utilization strategies, etc.

PlanErs is going to be reused for the ERS-1 and ERS-2 mission analysis at ESA / ESRIN.

## Genericity

The need to reduce mission-specific software development costs requires to develop Generic Mission Planning functions, from which a mission-specific Mission Planning system can be derived at low cost. In this case, the use of an object oriented representation for both the spacecraft model and the definition of the planning and scheduling methods participate to the genericity of the planning system by offering a more natural and reusable decomposition of the planning & scheduling world and of the methods governing the planning process.

This issue is addressed in the Generic Mission Planning Facilities (GMPF) project [3] which is currently performed by Cray Systems (UK) and Matra Marconi Space (France) for the European Space Agency (ESA/ESOC). The objective of this project is to analyze the commonalities between the large variety of Mission Planning Systems dedicated to specific missions and, by identifying the plan elements and the planning and scheduling process required by several types of mission, to define a common planning & scheduling kernel which can be customized to a given application. The GMPF project should contribute to the definition of the new generation of Spacecraft Control Center (SCOS II) which is conducted by ESA / ESOC.

The envisaged types of missions to be supported by GMPF are :

- Observatory Missions: The spacecraft has one main instrument. End Users are allocated observing time windows during which they have dedicated usage of the instrument.
- Survey Missions: The spacecraft has a single or a small number of payloads. The spacecraft and payload are normally operated by a centralized agency on behalf of a number of End Users who request specific observations that are planned according a high level mission definition.
- Multi-Instrument Missions: The spacecraft has a number of independent experiments, each provided by a separate Principal Investigator (PI). The platform is operated by a centralized agency but PIs are responsible for operation of their experiments, submitting requests to the control center.

- **Telecommunication Missions:** The spacecraft has a number of transponders to provide communications between ground stations (fixed service) or between another spacecraft and ground (data relay service). The spacecraft and its payload are operated by a centralized agency on behalf of the End Users. Transponders communication channels are allocated to Users.

The result of the GMPF study will be the definition and prototyping of :

- an objects library defining all the planning & scheduling elements and methods. These objects can be later reused or customized (by subclassing) for a specific application.
- a set of tools used to customize the library for a given application. These tools include a User Interface Builder, a Class Library Browser, a Mission Specific Information Editor and a Rule / Constraint Editor

At the current stage, the definition of the requirements for the GMPF tool kit has been performed. The project will lead to the

implementation of those facilities and to a first application demonstrator.

## CONCLUSIONS

In this paper, we have presented three main areas where advanced software techniques can contribute to solve the requirements raised by Mission Planning systems : performance, flexibility and genericity. These issues are taking an increasing importance with the growing complexity of space systems.

## REFERENCES

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