Commentary on “Planning the Galileo Mission”

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Abstract. This paper raises a number of interesting questions, especially about planning during Galileo system design, and operational timing to produce contingency plans.

1 Introduction

This paper suggests 2 major questions, as well as a number of questions about the Galileo system. These questions are:
1.) How did this analysis impact design of the Galileo system?
2.) When this system is used operationally, what are the timing requirements for producing contingency plans, and how many alternate plans are produced?

2 Galileo Design Impact

Was this planning prototype used during the Galileo design process, to evaluate the suitability of the system design?

A planning constraint is applied so that satellites within a specified angular distance must be allocated to different contact sites. Section 7.6 Multiple Path to the User indicates that “the selection of the angular distance to define the satellite triplets does not seem to be adequate and must be revised”. This implies that the planning prototype was used to evaluate at least one parameter in the system design – angular separation for applying the constraint.

Was this analysis used to change the angular-separation constraint requirement? If so, did this change ripple into any other required changes in the Galileo system design? (Possible impacts: Changes in number of contact sites; changes in angular field-of-view from contact sites, etc.)

The intent of the angular-separation-constraint was to guarantee that failure of a single ULS contact site does not make a significant fraction of the integrity subconstellation “unreachable”. According to the principal author, ESTEC is examining other constraints to minimize the effect of single ULS site failure.

This suggests an interesting application of planning during the mission design period – to simulate operational mission planning, and determine which system characteristics affect the proposed operational mission planning process.

The Galileo system does not provide cross-links for communications between satellites, so that all integrity satellites must be in contact with ULS sites at all times, in order to receive integrity messages. Provision of cross-link capability might have relaxed the requirements on continuous contact; evaluation of integrity cross-link capability might have been a useful early input to the system design.

Section 7.1 states that the results of this assessment affects the dimensioning of the ground segment, although the effort was aimed at a design that fit within the existing design parameters. What aspects of ground system design could have been affected by this assessment?

Other design parameters which might be evaluated by this planning prototype include:

Number and location of S-band & C-band stations;

Number of satellites in the nav. and integrity subconstellations;

Planned pass durations and frequencies;

Planning time horizon.

Prototyping of the mission planning process could help in selection of the mission design

3. Operational Implications

The paper implies that this planning prototype will become part of the operational mission planning process. The last paragraph of the paper says that future work will cover issues related to schedule dissemination and implementation of contingency plans.

Two important questions should be addressed as part of the transition to operations.

1.) How much advance time is needed for contact planning?

2.) What is the volume of contingency plans generated at any one time?

3.1 Advance Planning Time

For contacts occurring at time T, how when does the contact planning process have to start and complete? Figure 3 indicates that automated planning takes 6 months and 1 months prior to a pass, and that scheduling sessions are performed on a daily basis. When is the contact planning process performed?

What is the planning horizon for contact planning? If contact planning is done on a daily basis, how far into the future does that plan cover? The paper refers to a 3-day cycle time for the constellation. I presume this is the time for a particular constellation pattern to nearly repeat, as seen from a particular point on Earth. Does each contact plan cover a full constellation cycle?

According to the principal author, the current design is that contact schedules are complete 24 hours before execution. There is some question whether these schedules can be delivered in time. This may also affect the time available to examine the contact schedule and generate contingency constellation configurations.

How is a new contact plan "blended" into the existing plan? If an entirely new plan is generated each day, it may not be possible to enforce the inter-contact constraints (10 hours < time between S-band TT&C contacts < 18 hours) across the boundary between plans.

Is it possible to blend an existing plan into a new plan, by taking the existing contact schedule as the early part of the new plan?

How large is the set of contingency plans delivered to ground operators? It appears that there is at least 1 contingency plan for each spacecraft for each contact segment; each plan would be executed if a particular spacecraft fails during a particular contact.

Does the future work include autonomous execution of contingency procedures to reconfigure the Galileo network? This seems like an obvious next step, given the volume of possible contingency plans and the frequency of contact segments.

According to the principal author, "The invalidity of the navigation signal broadcasted by a satellite, which may require switching over to a backup configuration must be detected and propagated across the system in less than 6 seconds via the network of sensor stations." This implies that the contingency reconfiguration plans must be executed autonomously.

4. Additional Clarifications

Since I am unfamiliar with the Galileo design, I asked a number of questions. These are presented here, with answers where available, for clarification.

Is there overlap between the navigation and integrity subconstellations? Answer: No. Comment: This seems to introduce another planning constraint: allocate the total constellation so that there are never too few navigation satellites or too few integrity satellites. The minimum number of navigation satellites is dictated by a requirement that any point on Earth (within approx. +/-56 deg. latitude) be in view of a minimum number of navigation satellites at all times. (For GPS, I believe this is 4 satellites above some horizon mask angle.) The minimum number of integrity satellites is dictated by a requirement that any point on Earth is always within view of at least 1 integrity satellite. (The requirement may actually be 2 satellites, to take into account the possibility of satellite or ULS contact station failure.)

Can S-band TT&C and C-band ULS contacts overlap for the same satellite? Answer: Yes

I had trouble understanding the entire set of satellite constraints, so I attempted to identify them.

Question: What is the entire set of ground stations, and the requirements on satellite contact with each type? Answer: 20 sensor stations to monitor satellite integrity and timing; 9 C-band Uplink Stations used for sending integrity messages; 5 S-band TT& C stations used for spacecraft health and maintenance. Contact requirements are: 1.) All spacecraft must continually be in view of a Sensor Station to monitor integrity; 2.) All integrity satellites must continually be in view of a C-band ULS; 3.) All navigation satellites must be in view of a C-band stations within some interval (typically 100 minutes); 4.) All satellites must be within view of a S-band TT&C at least once every 18 hours.

Question: Section 7.3 refers to 27 prime satellites and 3 backup satellites. Is activation of a back-up satellite included in contingency plans?

Question: What is the set of reusable components in the Mission Planning Kernel? It would be interesting to know what aspects of mission planning appear to be reusable for other missions.

5. Relevance to other missions

This work has some relation to the work being done with the MAPGEN tool on the Mars Exploration

Rover (MER) mission. The MAPGEN tool is used to take a set of requested science observations and construct a plan which meets a set of time and resource constraints.

The modeling tool which supports MAPGEN, called APGEN, has also been used on the Mars Science Lander (MSL) project for analysis of mission scenarios against time and resource limitations. The use of these planning and modeling tools is becoming a common theme in space mission design.

5. Summary

This is an interesting application of mission planning, during the development and operations phases. It raises a number of interesting questions about the system's design. It also suggests a number of designs to include autonomous responses to implement contingency plans.