

PRELIMINARY RESULTS OF AN "A POSTERIORI" APPLICATION OF A REQUIREMENTS TRACEABILITY AUTOMATION TOOL TO A SET OF DOCUMENTS OF A SATELLITE PROJECT

Mario Celso Padovan de Almeida¹ and Marcelo Lopes de Oliveira e Souza²

Instituto Nacional de Pesquisas Espaciais-INPE
Curso de Engenharia e Tecnologia Espaciais/Engenharia e Gerenciamento de Sistemas Espaciais (ETE/CSE)
São José dos Campos, SP, 12227-010
¹mcelso@lit.inpe.br e ²marcelo@dem.inpe.br

***Abstract:** This paper presents the preliminary results of an "a posteriori" application of a Requirements Traceability Automation Tool to a set of documents of a satellite project. The documents were prepared with attention to text quality rigorously according to established Space System Engineering methodologies, but without attention to requirements traceability. This study is intended to determine some of the benefits of using a Requirements Traceability tool when compared with the previously used processes and methodologies. A summary of the status of the study and examples of requirements problems are presented. Up to now, the study has definitely demonstrated that the use of an automation tool, regardless of its functionalities, brings several advantages to the project.*

Keywords: Requirements Traceability; Space Systems Engineering.

1 Introduction

Requirements Engineering and Requirements Traceability have emerged in the late 1960s within the still emerging Software Engineering. The primary cause of the emergence of Requirements Engineering was the effects of the lack of attention to requirements in large-scale software projects. Despite Requirements Engineering methodologies have been in use in software projects since that time, only much later they were introduced in other areas of systems development. Space System Engineering, a somewhat conservative area, may be one area where Requirements Engineering methodologies were only recently introduced. A brief overview of the Brazilian Space Program at INPE and of the use of Space Systems Engineering at INPE is presented below to better understand why Requirements Engineering methodologies are not used at INPE so far.

2 A Brief Overview of the Brazilian Space Program at INPE

Systems Engineering methodologies in the western world were established and first formalized by USAF standards in the middle 1960s, during development of missiles, after a long period of development that started in the industry in the 1940s. NASA enthusiastically used those methodologies during the development of its manned space programs. Space activities in Brazil have started in 1961 with the creation of the precursor of the National Institute for Space Research (INPE). Soon after, Systems Engineering was introduced at INPE thanks to its good relationship with NASA.

Since 1963, INPE became a disseminator of Systems Engineering practices by translating and publishing books on Systems Engineering, by the installation of a graduate course in 1968, and by the organization of seminars to Brazilian government and industries organizations that could benefit from the use of Systems Engineering. By 1972, INPE had also applied Systems Engineering approaches to the development of an Interdisciplinary Applications and Communications Satellite (the SACI project), in the planning of a Remote Sensing Center (the SERE project) and in the organization of its computer databank.

In the middle 1980s, INPE's engineers received training at MATRA, Hughes Aerospace, SPAR, CNES and ESA, in satellite subsystem design and in Systems Engineering Management in support of the Brazilian Complete Space Mission (MECB). This led to the formation of a Systems Engineering Group and subsystem engineering groups organized under a modern and efficient structure that culminated with the successful launch and operation of two Data Collecting Satellites (SCD-1 and SCD-2).

In the year 1988, Brazil signed a cooperation agreement with the People's Republic of China for the development and launch of two China-Brazil Earth Resources Satellites (CBERS-1 and CBERS-2). INPE was again a disseminator of Systems Engineering methodologies because the Chinese partners accepted its use in the project and because INPE enforced the use of similar methodologies by its contractors. CBERS-1, CBERS-2 and a later spare CBERS-2B satellite were successfully launched and operated.

The combination of limited government funding and the successes of the CBERS program has curbed the involvement of INPE in space programs with foreign countries other than China; a couple of other international programs has also been short lived. This and the lack of more advanced international partners, the loss of trained employees due to retirement and low wages and many other causes, has prevented INPE to keep updated with the more recently introduced innovations in Systems Engineering, in particular, of the introduction of requirements traceability and automation tools.

So, historical reasons, lack of funding, scarce personnel, and a record of successful space missions have prevented that modern Requirements Engineering processes and methodologies had been introduced in the CBERS program.

3 The Satellite Project chosen as our Case Study

The CBERS-3 satellite project was chosen for this study because it is the largest and the most completely documented project of the Institute and because the documentation is prepared in digital formats. The Electrical Power Subsystem (EPS) was selected because: 1) it is a subsystem under INPE's responsibility; 2) there is an in-house technical capability in this subsystem since 1980's; and 3) it is the subsystem where the author had a managing position during 18 years.

The set of documents under analysis were prepared by CAST, INPE, and INPE's contractor. The English language was chosen for writing most of the documents because they must be understood by all parties. Since neither Brazilians nor Chinese are fully proficient in English, errors in the text are common.

The documents were prepared with care for text clarity and other qualities as they are part of contracts. On the other hand, since the methodologies in use did not require it, the documents do not pay attention to individual requirements. So, before entering the document in the tool, the document had to be modified to identify individual requirements and the inclusion of the tracing information.

This paper presents the preliminary results of a larger study in progress. The requirements traceability automation tool (RT) Requirements Gateway by National Instruments has been chosen because it is compatible with most of the commonly used text editors (txt, doc, pdf, xls, etc). Similarly to other computer-aided requirements traceability automation tools, Requirements Gateway does not analyze the text; it only stores and displays the documents, the requirements and its attributes, and the array of relationships between the requirements in an organized fashion.

The part of the satellite specification tree concerned with this study is presented in Figure 1. There, red frames represent documents under CAST responsibility, blue frames represent documents under INPE's responsibility, red and blue frames represent documents under shared responsibility. Grayed boxes represent documents that have been introduced in the requirements traceability tool.

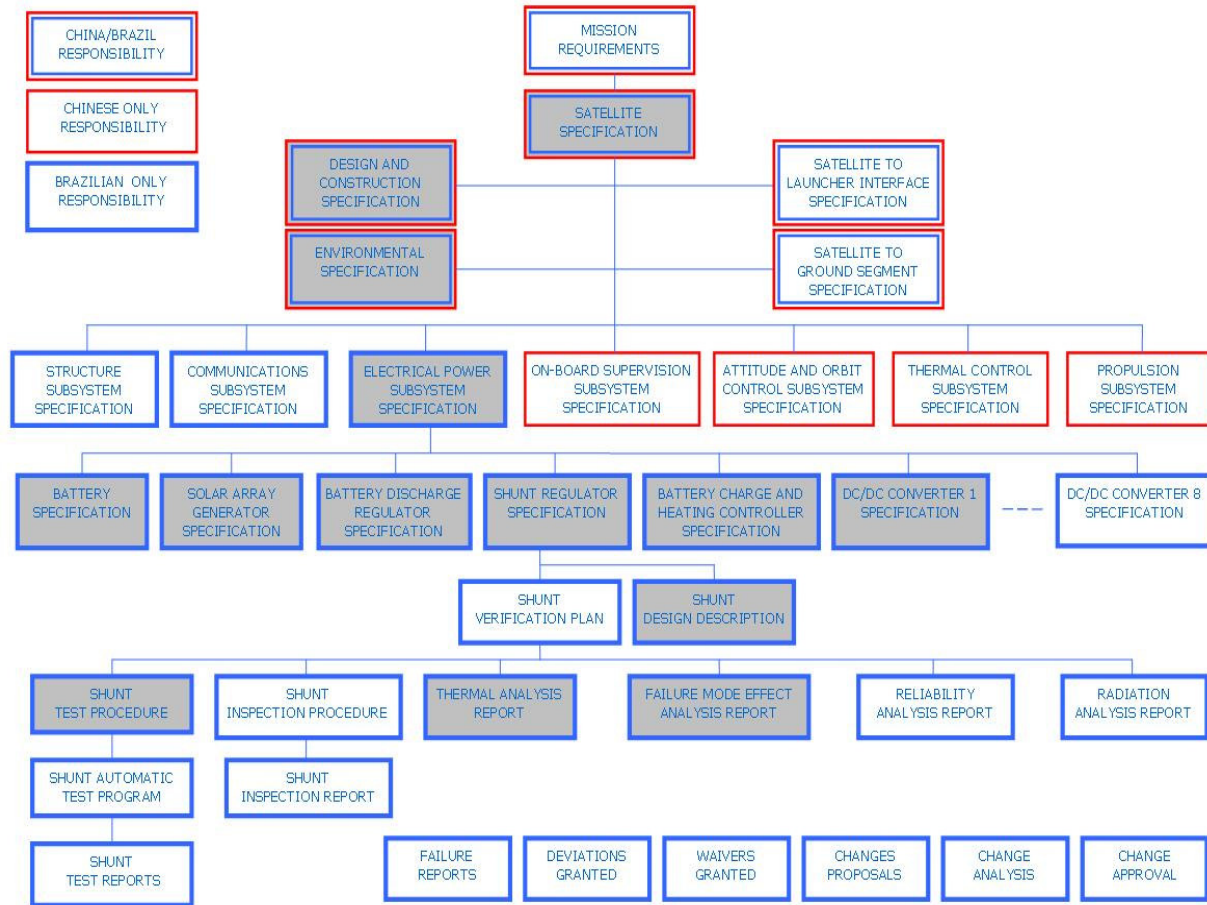


Figure 1: Part of CBERS-3 specification tree subject to our analysis.

4 Preliminary Results

It takes several days to carefully review and prepare a document to be entered in the tool. The tool helps this task by displaying the requirements IDs and texts as soon as they are added, simplifying the inclusion of references in the text of the covering documents. The tool also highlights requirements that are not covered, graphically shows the links between requirements, and detects several types of errors, etc.

4.1 Examples of Requirements Problems

Examples of problems encountered during the analysis of the documents before entering them in the tool are presented below:

- a) Requirements at improper level of hierarchy
Document: RB-HDS-0023 - CBERS 3 & 4 Satellite Specification
Paragraph: 3.5.3 - Electrical Power Supply Subsystem (EPSS)
- d) SAG power output (EOL) > 2300 W
- e) Main bus voltage range 28.0 V +/-0.6V
- f) DC/DC converters efficiency > 73%
- g) DC/DC voltage regulation +/-1%
- h) Battery capacity > 90 Ah
- i) Battery DOD < 20%

Comments: There is no reason to specify details of the EPS equipment in a system level document when almost nothing is known about the to-be-developed system. This may cause problems in the future, such as difficulty in compliance, request-for-waivers, etc. If some data are necessary as inputs for calculations it would be better to provide these data in other types of documents instead of a specification document.

b) Requirement applicable to other subsystem

Document: RBDD-HDS-1004 - Power Supply Subsystem Specification

Paragraph: 3.1.4.3.3 - Battery Pack Thermal Gradient

The Thermal subsystem shall provide means so that when the whole Batteries (four packs) are installed on the satellite and the maximum thermal gradient between packs shall be lower than 5 °C.

Comments: It is clearly stated that this is not a requirement to the EPS subsystem but a requirement to the Thermal Control Subsystem.

c) Requirements not individualized and not uniquely identified

Document: RB-HDS-0023 - CBERES 3 & 4 Satellite Specification

Paragraph: 3.5.3 - Electrical Power Supply Subsystem (EPSS)

The EPSS shall convert the sun light energy into electric energy using a Solar Array Generator (SAG), condition the electric energy and store this energy in batteries.

Comments: There are clearly three requirements on the EPS Subsystem in this paragraph: to generate primary energy using a solar array generator; to condition the electric power using electronic conditioners; and to store energy in batteries. This type of text construction does not allow making references to individual requirements and brings difficulties to verification.

e) Non-specified validity conditions

Document: RBD-HDS-0004 - Electrical Power Subsystem Specification

Paragraph: 3.2.3 Battery Packs

i) Battery Thermal Gradient

The Battery Pack design shall be such that the maximum thermal gradient between cells of a pack shall be lower than 2 °C.

Comments: There is a lack of the conditions for the fulfillment of this requirement.

4.2 Screenshots of Requirements Gateway

Figures 2 to 5 shows screenshots of the RT displays. Figure 2 shows the Configuration View, the documents under analysis and their relations currently entered in the RT tool. As can be seen, the system, subsystem and 6 equipment specifications documents, besides other types of documents, are currently present.

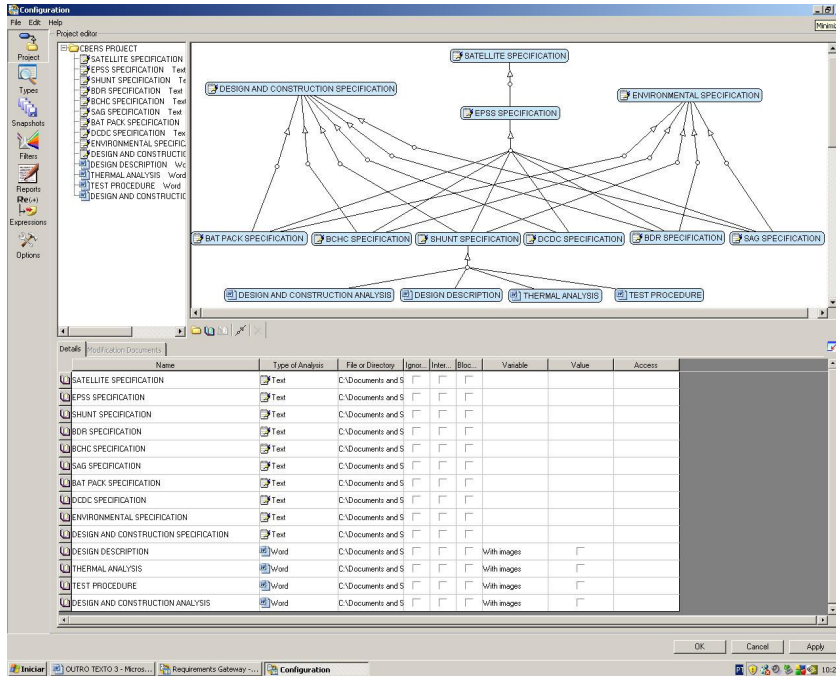


Figure 2: Configuration View, showing the documents and relations currently entered in the RT Tool.

Figure 3 shows the Management View, a summary of the current status of this study, displaying the total number of documents already entered in the tool, the total number of requirements, the percent fraction of requirements coverage for each specification document, etc.

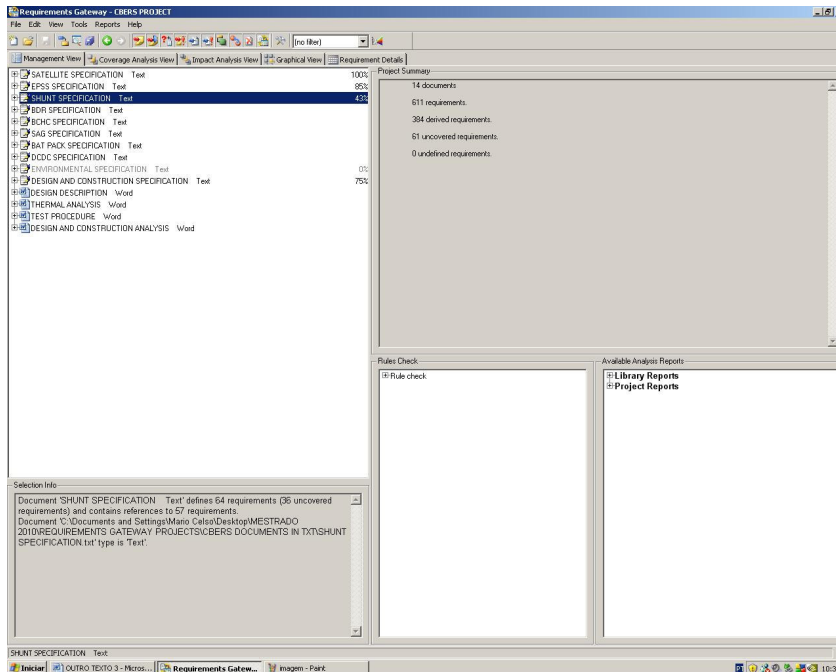


Figure 3: Management View, showing a summary of the current status of this study.

Figure 4 shows the Impact Analysis View, presenting the requirement text and upstream and downstream impact information.

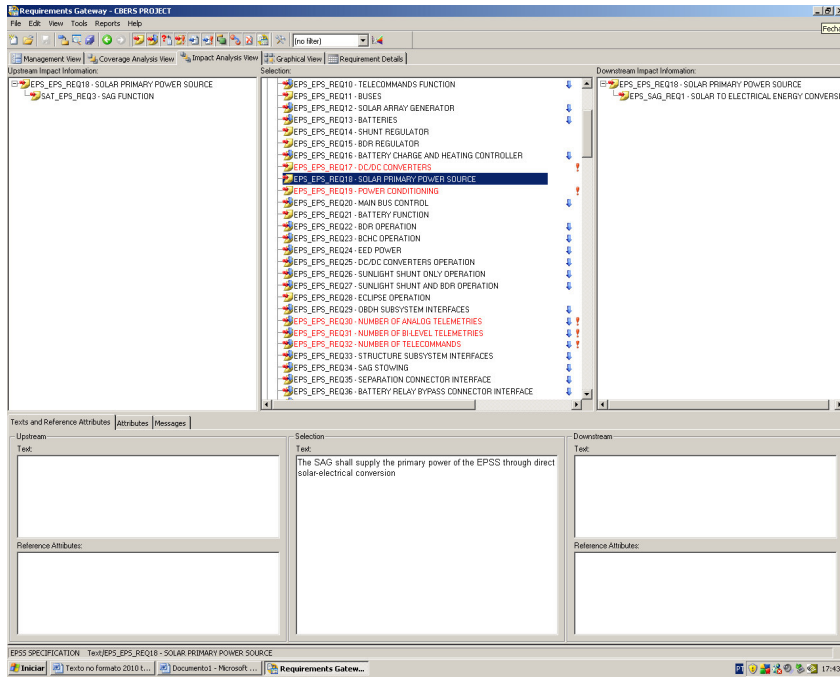


Figure 4: Impact Analysis View, showing requirement text and upstream and downstream impacts.

Figure 5 shows the Graphical View, presenting the links between requirements in different hierarchical levels.

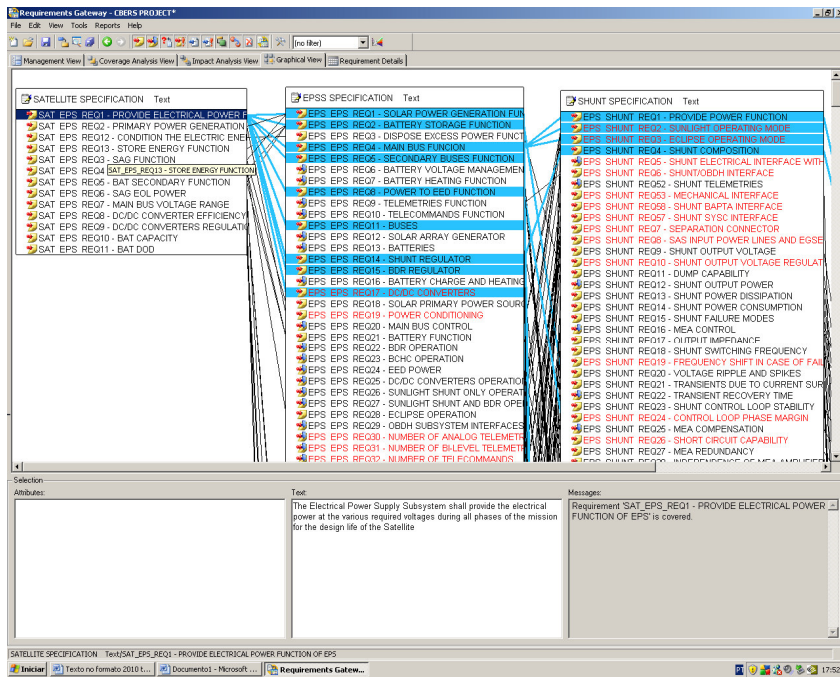


Figure 5: Graphical View, showing the links between the requirements in different hierarchical levels.

5 Conclusions

A spacecraft mission is one of the most complex, risky and expensive human endeavors. To increase the chance of mission success, great attention must be paid to planning and management. Maintaining and managing all this information is a complex, error prone, and time demanding task that is hardly possible without the use automation tools.

We observed the following items when performing this study:

- There are more than 600 requirements in the three levels of EPS related documents;
- Despite carefully written, the documents used a style and format that is not suitable for documenting requirements;
- The current process of managing the documentation, by hand and without attention to requirements, is more subject to errors and does not allow detailed and continuous management;
- Requirements should be completely specified - their text should not refer to other requirements in other documents as this complicates traceability and verification;
- The use of a RT tool forces a simple and standardized format, more appropriate to documenting requirements;
- The use a RT tool, coupled with the current requirements engineering methodologies, would simplify the information management, improving the quality of the final product and optimizing the use of the Institute workforce, always in short supply.

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