A PROCESS SCIENCE & TECHNOLOGY STUDY APPLIED TO THE SERVICES PROCESSES FOR PRODUCT QUALITY ASSURANCE IN SPACE MISSIONS

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Abstract: *This work proposes the application of a transdisciplinary approach to conduct complex discrete event processes studies, denominated Process Science & Technology (ProS&T), for the creation and analysis of a process model of the service processes for product quality assurance in space missions. The model is based on a unified multifaceted modeling approach to allow simultaneous analysis making use of process modeling, simulation and business process management techniques. The model describes a real study case involving the Product Quality Assurance Services Division of the Department of Space Engineering and Technology of the Space Research Institute.*

Keywords: *Process Science & Technology, Unified Conceptual Modeling, Simulation, Business Process Management.*

1 Introduction

Process Science & Technology (ProS&T) is a neologism created to designate an innovative and transdisciplinary study and research area, consisting of the integration and unification of concepts, methods and tools used in the whole product lifecycle management process, namely the modeling, simulation, building, execution, automation, management and continuous improvement of complex products and services development processes in general. The term was used for the first time in the article (Silva et al. 2011) as an alternative interpretation of the content and meaning of the term Design and Process Science (SDPS 2011), but it can also be seen as a process modeling view of what has long been defined as *Concurrent Engineering*.

Concurrent Engineering - sometimes called simply *Systems Engineering* - is an interdisciplinary approach to problem solving comprising an organized architecture of knowledge and a network of processes for creating a product, encompassing its complete life cycle: Problem Definition, Requirement Analysis, Options Analysis, Design Synthesis, System Implementation, System Test/Validation, Customer Training, System Maintenance, System Upgrade, System Disposal. The aim is to produce a system that satisfies the specified technical requirements within quality, cost and timeframe constraints (Loughborough University Systems Engineering Website, 2012).

In research centers and enterprises dedicated to the development of highly advanced technological products and services, as is the case of the Space Research Institute (INPE) in regard to space mission projects, one observes that the increasing number and complexity of the planned systems requires a continuous improvement of the management procedures to assure the quality of the products under development by these organizations.

The Service for Product Quality Assurance (SGP) is a Division of the Department of Space Engineering and Technology (ETE) at the Space Research Institute (INPE). The main goal of SGP is to assure the quality of products and services developed by external partners for utilization in the Brazilian Space Program, especially those related with the segment of satellite development and their applications.

As the main contractor and supervisor of the quality of products and services delivered to the space program, it is necessary that INPE inspects, through the SGP Division of its ETE Department, the quality of all product and services delivered to it, aiming at receiving the right solutions for the increasing demand of high quality products, as well as approving their corresponding manufacturing processes.

This work proposes the development of a ProS&T study of INPE/ETE´s SGP Division, to be developed in two steps: (1) the creation of a unified multifaceted process model with the description of service processes performed by SGP as part of the product life cycle management of space mission products; (2) the study of this unified process model making use of a transdisciplinary approach, denominated a unified approach for process modeling, simulation and business process management.

The general objective of the research work is to study the SGP system making use of various disciplines, model views or dimensions, which are simultaneously applied to its multifaceted unified process model in order to profit the maximum from their complementary analysis techniques, aiming at better decision taking by its managers and the introduction of improvements in the real system operation.

This article is structured as follows: Section 2 defines the ProS&T concept; Section 3 describes the problem, that is, the services performed by the SGP Division at INPE; Section 4 presents the unified approach for process modeling, simulation and business process Management used in the work; section 5 describes the unified multifaceted model of the system developed; Section 6 discusses the results achieved so far and presents the guidelines for future research and conclusions.

2 Process Science & Technology

In Concurrent Engineering the complete discrete event system under study is constituted by the products and services under development and its manufacturing enterprise. A Framework for use in Concurrent Engineering shall take into consideration these two elements when building and analyzing the process model representative of the system (Loureiro, 1999 and 2010).

ProS&T is a transdisciplinary approach to conduct a study of a complex problem involving discrete event processes based on a unified multifaceted process model of the system and on the use of various dimensions for analysis and execution of the model, corresponding to different disciplines and their techniques, to be applied simultaneously and in an integrated way.

The Framework to conduct Process Science & Technology studies or simply the ProS&T Framework comprises three elements: a Knowledge Architecture with the organized knowledge about the model structure and the dynamics of complex products and services development processes, an Implementation Method to evolve the models along their life cycles and a set of supporting tools, named Supporting Environment, to help the conduction of the studies.

The methodology makes use of a multifaceted unified communicative model building in a first phase, based on established representation formats, such as Business Process Modeling Notation (BPMN), Unified Modeling Language (UML) and Systems Modeling Language (SysML). The second phase consists of model execution and analysis according to different model views or dimensions, made by the application of different discipline and their techniques to obtain complementary results, enhancing systems analysis and the search for solution to the identified problems.

The building of a unified communicative model as a common reference right from the start of the modeling process and the attempt to assure the model consistence along the implementation, analysis and execution made according to various disciplines are the key differences of the ProS&T Framework. It is expected that with this kind of approach it will possible to anticipate the problems inherent to product development and organization management process modeling and that this will lead to reduced cycle times and increased quality of the products developed.

2.1 The Knowledge Architecture for ProS&T

The knowledge architecture representative of the complete knowledge on complex discrete event processes is the result of the integration of different knowledge domains or model views associated with the various types of agents participating in the execution of a concurrent engineering project, as shown in Figure 1. The rounded rectangles correspond to the transformation processes, the cylinders to the databases with information on the actual state of the model under development and the arrows show the direction of the flow of execution along time (Kienbaum et al, 2012).

This threedimensional knowledge architecture has some similarities with the one proposed initially by Loureiro (1999) for use in systems concurrent engineering and more recently revised in Loureiro (2010). The x or horizontal coordinate shows the evolution in time of the models representatives of the systems concurrent engineering processes (include product engineering and organization management); the y or vertical coordinate shows the duality, symmetrical nature and integration of these models; finally, the z coordinate, orthogonal to the plane of the figure, take into account the hierarchical decomposition of the processes, i.e. the level of detail used in its representation.

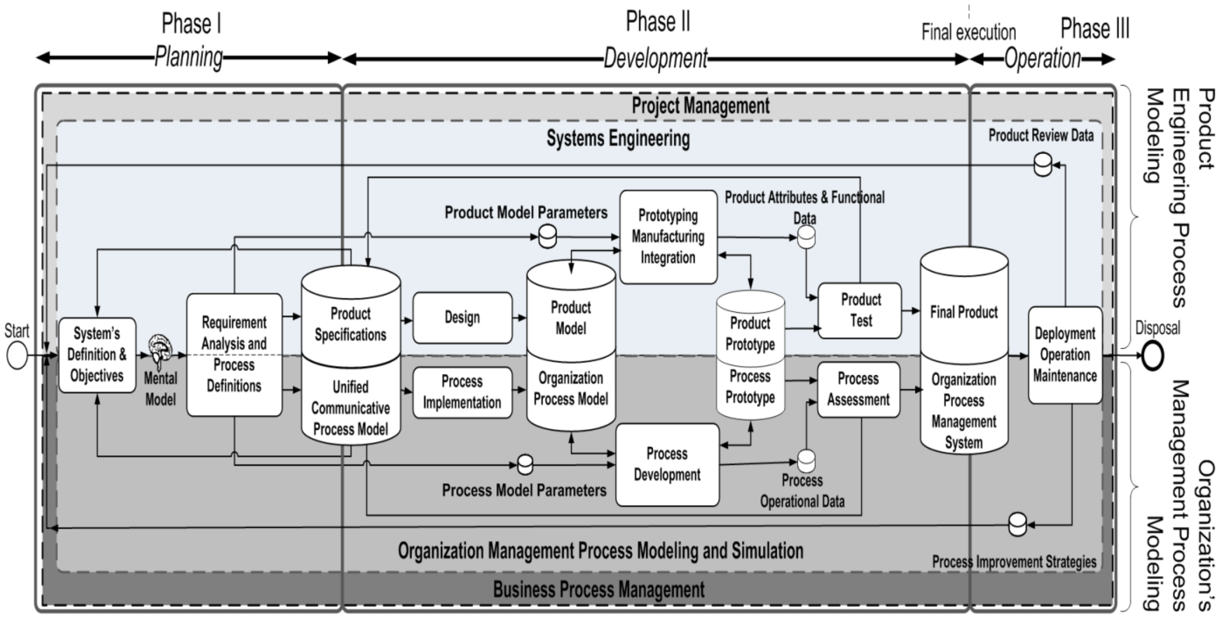

Figure 1 - Process Science & Technology Knowledge Architecture (Kienbaum et al., 2012)

In Figure 1 Systems Engineering and Project Management are represented as two complementary techniques that can be integrated for the description and the evolution of the unified product model along the complete product life cycle. Process Modeling and Simulation as a single technique and Business Process Management are also considered to be two complementary techniques that can be integrated and used for the description of a unified organization management process model and its evolution along its life cycle, whose processes keep a direct matching with those of the product life cycle development.

The shadowed areas are named dimensions and they are related with the type of knowledge of the agent involved in the complete product lifecycle. The increasingly darker shades of grey indicate a rank, starting with a more technical profile (linked with the product specification), typical of the systems engineer, who is followed by the project manager and by those with more managerial profiles (linked with the organization management process), represented by the process and simulation modelers and by the business process managers. The domain areas of each agent are depicted by these overlying layers along the entire model evolution path and the agent responsible for a model view described by an outer layer makes use of all other internal views to his own, what means that the building of his model shall succeed (or be made in parallel with) his predecessors.

3 The Services Processes for Product Quality Assurance at SGP

A space program has several space missions. The case study presented in this work was extracted from the program CBERS 3&4, a joint endeavor from Brazilian INPE and Chinese CAST – Chinese Academy for Space Technology. This program addresses the project and development of remote sensing satellites, with investments shared on a base of 50% each for the participants.

The satellites subsystems under responsibility of the Brazilian partner are developed by companies contracted by INPE. The SGP Division of ETE Department supervises these companies in order to assure that all requirements are fulfilled according to project specifications.

In a space mission projects are divided into phases for management and control purposes. These phases are collective known as the project life cycle, as shown in Figure 2. SGP takes part in the project during the phases of planning and construction of the product, that is, starting in the B Phase (Preliminary Project Defition) until the launching of the satellite (Phase E).

During project development the companies shall provide INPE with all the information on the product evolution, as well as with the complete documentation generated along the process. SGP is responsible for the verification of product attributes according to project requirements and to suggest the necessary corrections to be made by the contracted partner, if necessary.

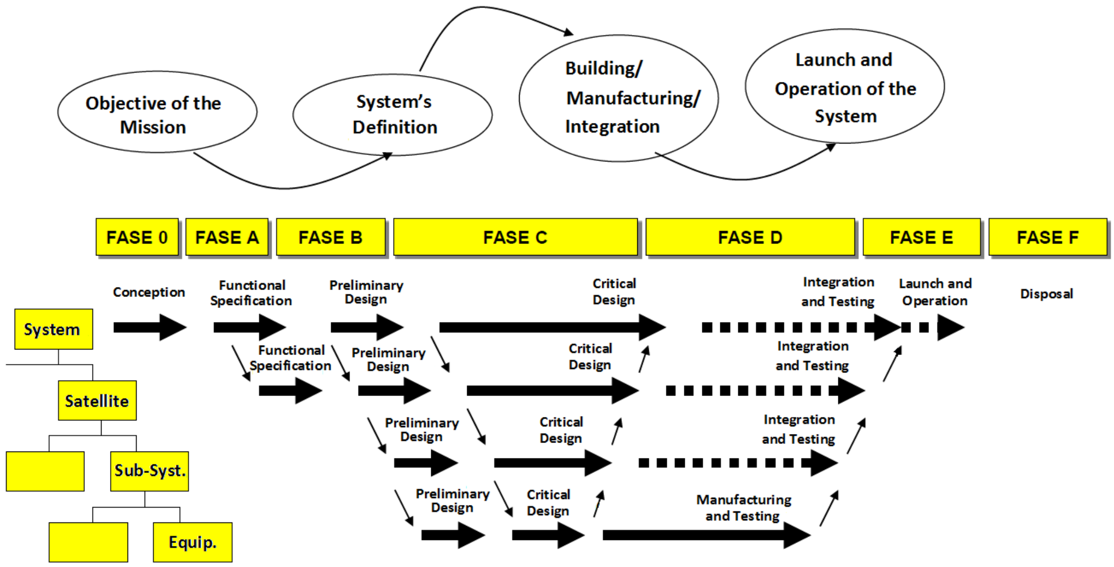

Figure 2 - Project Life Cycle in Space Missions (Souza, 2011).

SGP is divided into three sections or subgroups, namely: Quality Assurance, Reliability and Parts, Materials and Processes.

- **Quality Assurance** – it is responsible for the following up of tests, as well as for attesting that the testing equipment used are adequately prepared and calibrated, for keeping the registers of the tests performed and of all faults detected, as well as for making inspections during the production to prevent discrepancies that otherwise would only be detected in the phase of final tests.
- **Reliability** – it is the probability that a product work according to its specifications, under preestablished conditions and during a certain time interval. Reliability analysis for space systems encompasses all the faults which might occur during project development, including security faults (Souza, 2011).
- **Parts, Materials and Processes** – the main activity of this area is the specification of appropriate quality criteria for assessment of the parts, materials and the processes used in the space product development, to assure compliance with its expected operational life time, environmental operation conditions and potential risks (LEY et al. 2009).

4 The Unified Approach for Process Modeling, Simulation and Business Process Management

Figure 3 shows the complete process model life cycle according to the *Unified Approach for Modeling, Simulation and Business Process Management* proposed in (Kienbaum et al., 2012), which corresponds to the organization management process modeling part of the general approach presented in Figure 1 and described in section 2. It corresponds to the model views and their lifecycles created by the aggregation of the two disciplines or dimensions of Process Modeling & Simulation and Business Process Management and its application to the organization management processes.

In this approach, simulation is at the core of the life cycle, differently from traditional Plan-Do-Check-Act (PDCA) procedures, which put the simulation phase of a process model life cycle as an independent and accessory one, to be carried out near the end of the cycle, in support of the phase of analysis and improvement of model's description. In the proposed unified approach the process model and the simulation model is the same; Process Modeling and Simulation and Business Process Management are two variants of a unified procedure. There is no need to build a separate simulation model for the purpose of conducting the model's analysis and revision.

The cycle starts with the definition of the system and of the study's objectives, which determine the scope of the model to be built. The specification of the logical structure of the organization's management process model and of the study's objectives is the main product of this phase: the mental or conceptual model, together with the system's boundaries, the model control parameters and eventual additional premises and restraints. The mental or conceptual model is a concept that needs to be understood as the logical content of the system's operation and of its study's objectives, according to Nance's conical methodology for simulation modeling (Nance 1994), whereas the graphics and diagramming techniques used for model representation belongs to the next step, the building of the communicative process model.

The next step is the building of the unified communicative process model, for representation of the mental model making use of different formats, such as workflow charts and all other sorts of diagramming techniques, as exemplified by BPMN, UML activity diagrams, ACDs or Petri-Net diagrams. The definition of the entities and resources involved and their interaction to perform the chain of activities is also made in this modeling step.

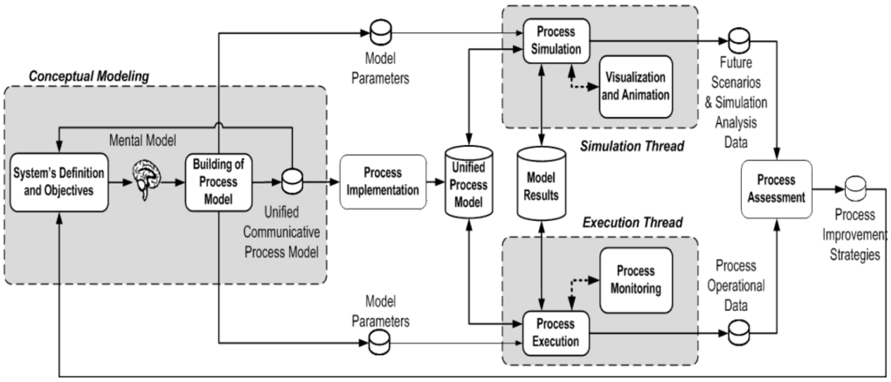

Figure 3 - The Unified Approach for Modeling, Simulation and Business Process Management; Source: modified from Silva et al. (2011)

The communicative process model undergoes a third step of transformation, the implementation or model programming, yielding the programmed model or model's applications, which might be seen as different software systems or the same system that can be executed according to two different threads, one for process enactment in production mode, with management facilities, and the other one for simulation with design of experiments, the building of scenarios and visualizations facilities embedded. Both threads are fed by the unified process model, produced from the a set of communicative models and, in case of different implementations, verified to assess its consistency and validity in regard to system's specifications. Data collected during real system's operation are used as input data for simulation model execution, making validation easier and future scenarios projections more reliable.

The results from the two threads of execution (process execution and monitoring, simulation visualization) provide information for the next phase of process analysis and assessment. The process analysis and assessment step uses appropriate metrics and results in process model improvement, restarting the cycle.

5 The Unified Process Model of SGP Services

The focus of the unified process modeling of SGP Services is the building of the organization management process model, corresponding to the lower part of picture from the knowledge architecture of ProS&T shown in Figure 1. In the study case presented in this work the systems engineering and the project management processes developed by the contracted companies are not directly supervised by SGP, who verifies them by means of the testing of products and services delivered to the space program at some points in time (milestones) equivalent to the conclusion of the development phases of the product life cycle. In the following the main services processes of SGP are represented using business process diagrams. Additional details about these processes are described in Appendices A, B e C.

5.1 Description of SGP Role in the Satellite Life Cycle

SGP starts its participation in the project life cycle in the Preliminary Design Review (PDR). This event consists in a revision of the satellite´s preliminary project design, which is jointly done by the contracted company and a board of INPE examiners. This board comprises the CBERS program managers, SGP personnel, project designers (thermal, electrical, mechanical, among others) and by contract auditors (responsible of auditing the contract between INPE and the contracted companies).

During PDR and all other reviews which happen at the end of each development phase along the project life cycle (Critical Design Review- CDR, Qualification Review - QR and Acceptance Review - AR), SGP is responsible for verifying the fulfillment of all requirements concerning product quality assurance. Figure 4 shows a process map representative of the PDR performed by SGP, but it also serves as a model for all other reviews performed by SGP at the end of each development phase of the Project (CDR, QR, AR).

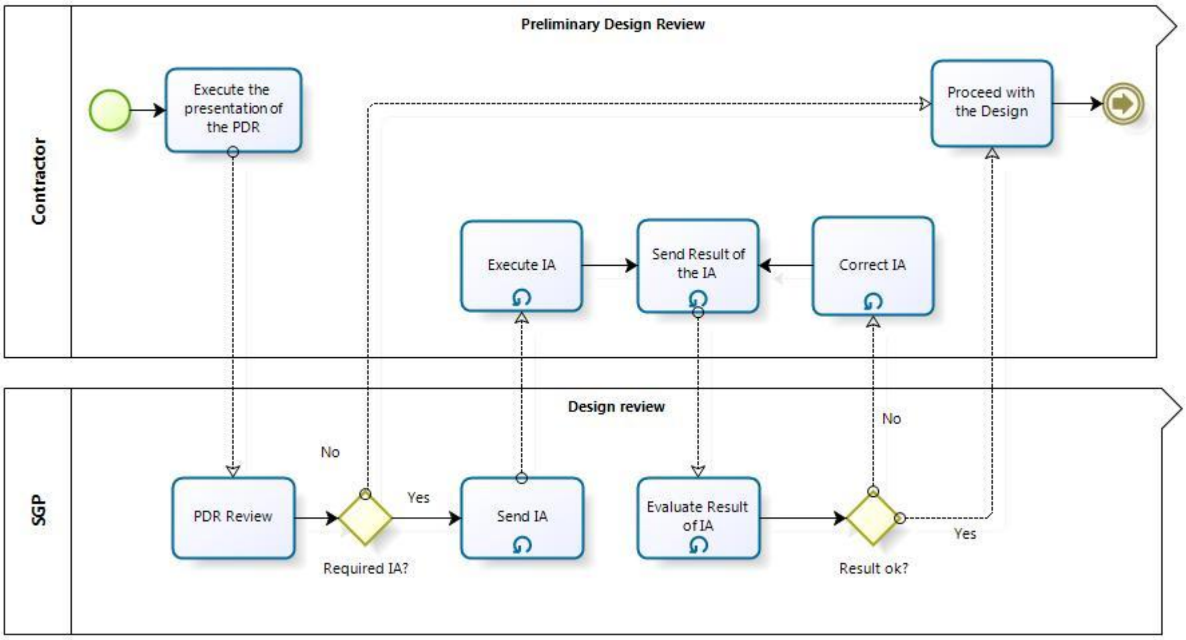

Figure 4 - Preliminary Design Review (Conclusion of B Phase).

Recommendations made by the project reviewers can generate corrective actions to be implemented by the contracted company. These actions are formally issued as modification records called action items (AI). The contracted company shall attend all AIs and present a detailed description how they were implemented and the results achieved after their accomplishment. After the approval of all results presented by the contracted party the Engineering Model starts to be manufactured.

The Engineering Model is manufactured by the contracted party having all the functionalities and satisfying all performance criteria established in the planning phase. Figure 5 shows the activities realized by SGP during the manufacturing of the Engineering Model.

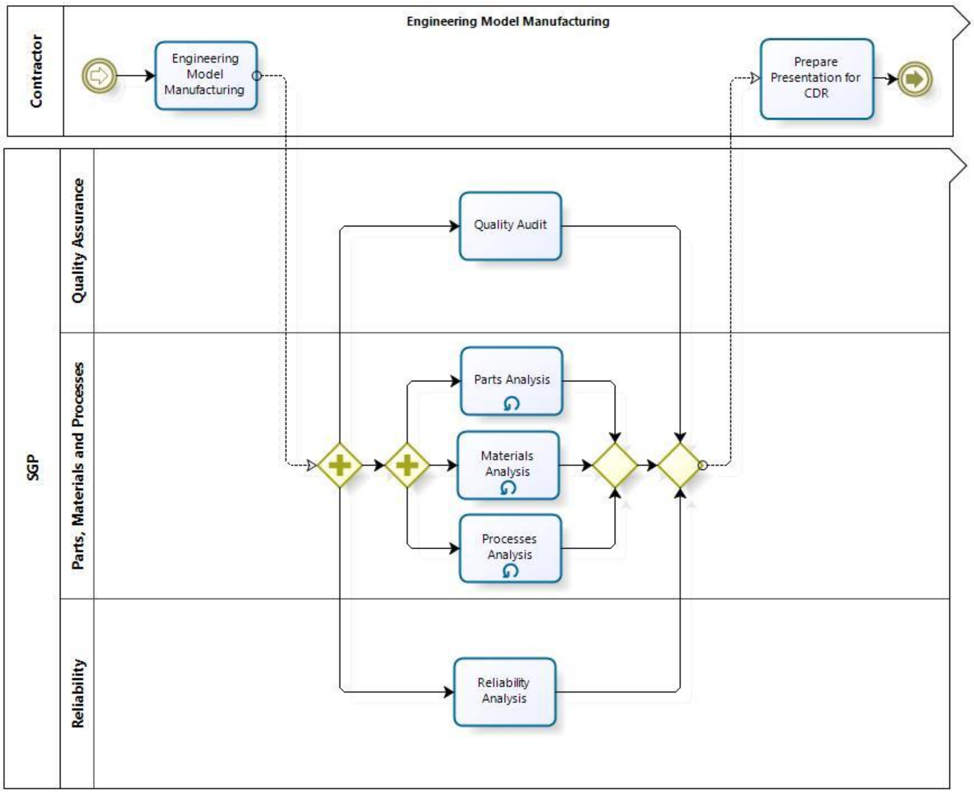

Figure 5 - Manufacturing of the Engineering Model.

During the engineering model manufacturing SGP audits the whole process regarding quality assurance, reliability analysis and the qualification for the use of parts, materials and processes still not certified for use in space projects. The engineering model actually does not require the qualification of parts, materials and processes, but this audit is done in anticipation, because the companies will be required to have their parts, materials and processes procedures qualified when building the Qualification Model. The reliability analysis involves the verification of all documentation regarding reliability calculus, fault analysis and Derating Analysis. After the auditing by SGP a report is issued with all RIDs (Review Item Discrepancies), describing all discrepancies found during the engineering model manufacturing. A RID, when necessary, is turned into an AI and sent to the contracted company during this project development phase. When the manufacturing of the engineering model is finished the CDR is started.

The CDR is the event where the baseline of the final product design is established. CDR is similar to PDR regarding its evaluation procedure, as described in Figure 4. The main difference is that CDR corresponds to a project evaluation that is made at a later point in time in the project life cycle, when it has achieved a greater degree of maturity. After CDR and the approval of the results presented by the contracted company, the manufacturing of the Qualification Model is started.

The Qualification Model shall demonstrate that the system under development fulfills within a reasonable margin of certainty all specifications required by the mission. In the manufacturing of the Qualification Model all parts, materials and processes have already been defined, as well as the reliability analysis need to be finished. This last one can be used as a tool for diagnosis and elimination of potential faults. During manufacturing the MIPs are performed, in order to verify parameter conformity, such as temperature, umidity and environment contamination. If a non-conformity is detected (a product specification was not fulfilled) this is reported in the documentation of system´s manufacturing and integration and one proceeds to visual inspection of the system. Figure 6 represents the activities developed by SGP during Qualification Model manufacturing.

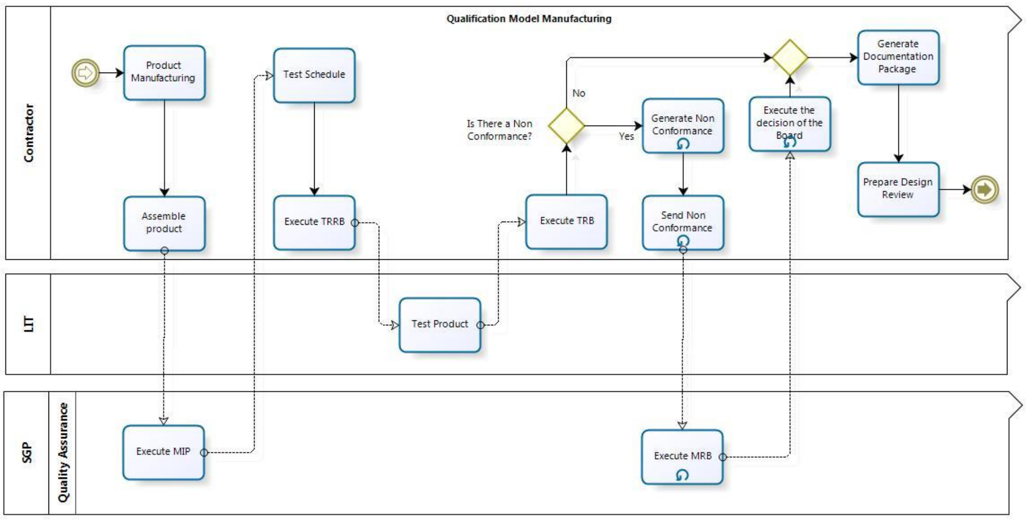

Figure 6 - Qualification Model Manufacturing.

The Material Review Board (MRB) is the board in charge of evaluating the non-conformities which occur during project implementation. This board is constituted by a representative of SGP, by a supervisor of the contracted company, by a representative of the management of the program and by other experts chosen among the technical personnel allocated to the project (mechanical, electrical, thermal projetists, among others). After manufacturing of the Qualification Model the Qualification Review (QR) is started.

The QR is similar to all other project reviews, as described in Figure 4. After approval of the results presented by the contracted company, the Flight Model starts to be produced.

The Flight Model is manufactured following the same processes used for the manufacturing of the Qualification Model, as shown in Figure 6. The contracted company shall produce 3 Flight Models.

The Manufacturing Readiness Review (MRR) has to be accomplished by SGP prior to the manufacturing of the Flight Model by the contracted company. This is the event that authorizes the contracted company to initiate the Flight Model manufacturing. It can also be anticipated and performed prior to the manufacturing of the Qualification Model, IF it is considered to be necessary, due to the weaknesses (risks) detected along project development. After Flight Model manufacturing the Acceptation Review (AR) is initiated.

The Acceptation Review is similar to all other revisions of the project, as described in Figure 4. After approval of the results presented by the contracted company during the AR revision the final satellite integration phase is started.

After acceptation of the project the contracted company delivers the satellite or final product in the form of components to be integrated. The integration and test and the launching of the satellite in case of the CBERS are responsibility of Chinese Academy of Space Technology (CAST). SGP role in the process is to act as a monitor of these activities, as shown in Figure 7.

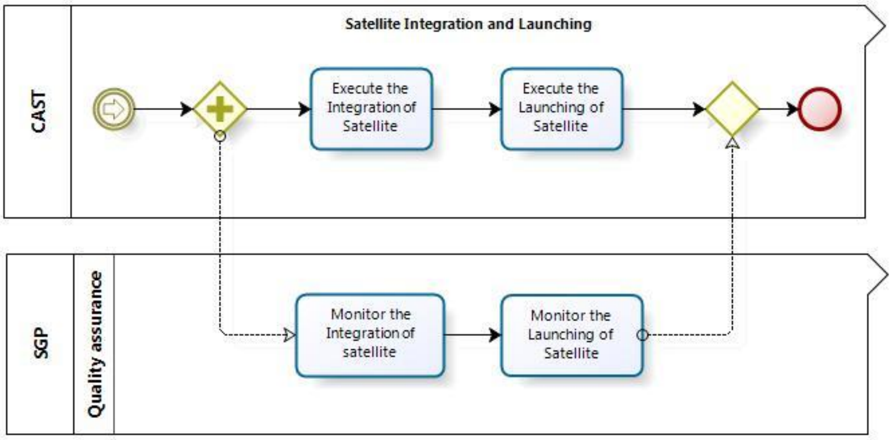

Figure 7 - SGP Satellite Integration and Launching.

6 Expected Results

The main processes performed by SGP were described. These processes were modeled using BPD (Business Process Diagrams), allowing a better understanding of the workflow of activities performed by SGP Division at ETE department of INPE.

The research project will be continued with a refinement of the processes already modeled and the modeling of the additional processes not shown. The process model of the complete system will be implemented in Simprocess Simulation System and analyzed for identification of bottlenecks and improvement strategies.

The model makes use of an integrated approach based on simulation and business process management techniques. Besides the simulation results for performance improvement and model optimization, the use of business management applications are envisaged for achieving a better management of the real system operation.

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6 Appendix A – Quality Assurance Processes

The Quality Assurance Subsection of SGP is responsible for inspecting the product quality along its life cycle and the monitoring of the tests. In the following the main processes for quality assurance are presented: Quality Auditing and Mandatory Inspection Point.

- Quality Auditing (Figure A.1): This process aims at inspecting and assuring that all quality patterns are used in the space mission program. It is executed before the CDR.

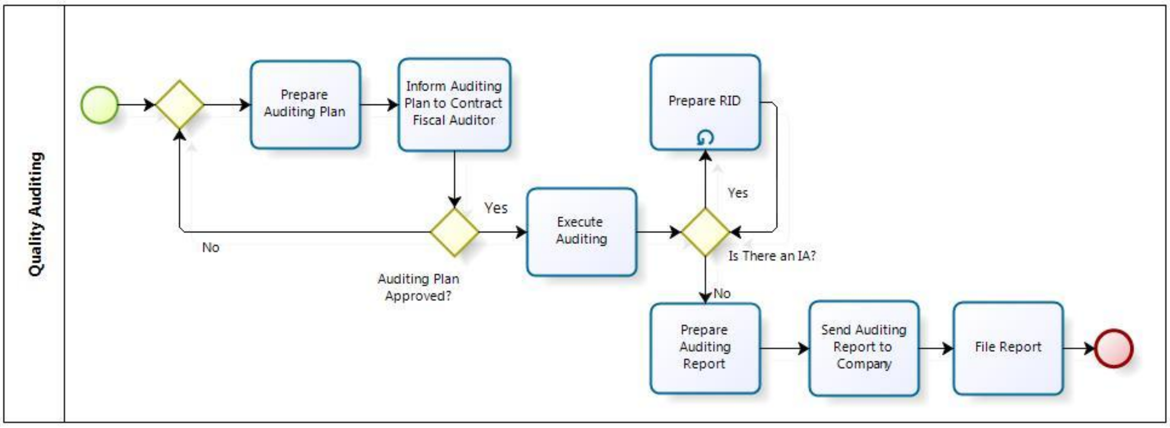

Figure A.1 - Quality Auditing Process (Paiva, 2011).

- MIP (Mandatory Inspection Point) Execution. This process is shown in Figure A.2.

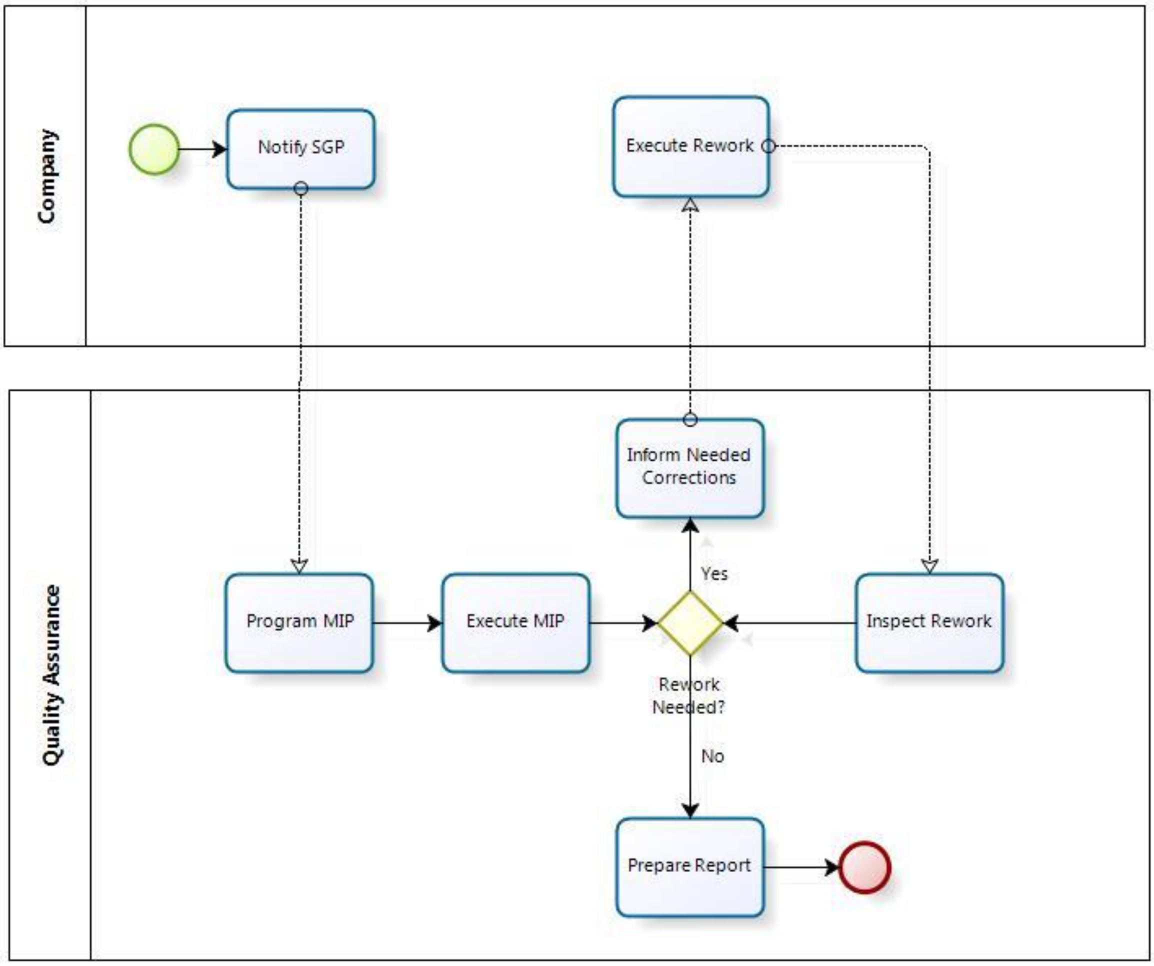

Figure A.2 - MIP Process (Paiva, 2011)

MIP Process is a key process for quality assurance, because it can prevent some discrepancies that otherwise would only be noticed during final tests (Souza, 2011). It performs the verification of parameters such as temperature, umidy and contamination of the environment. Verifies and reports all non conformities detected (an item no compliant with specification), the documentation of manufacturing and mounting and finally realizes a visual inspection of the product.

7 Appendix B – Reliability Process

The whole of the reliability study is not executed by SGP, not even by INPE. The contracted companies develop the mathematical models and conduct the reliability studies by themselves. The responsibility of INPE, and specifically that of SGP, is to analyse all documentation about this process generated by the contracted companies.

- Reliability Analysis (Figure B.1): This process covers the development of the reliability study of the product and its documentation review, concerning the reliability calculus, fault analysis and Derating Analysis.

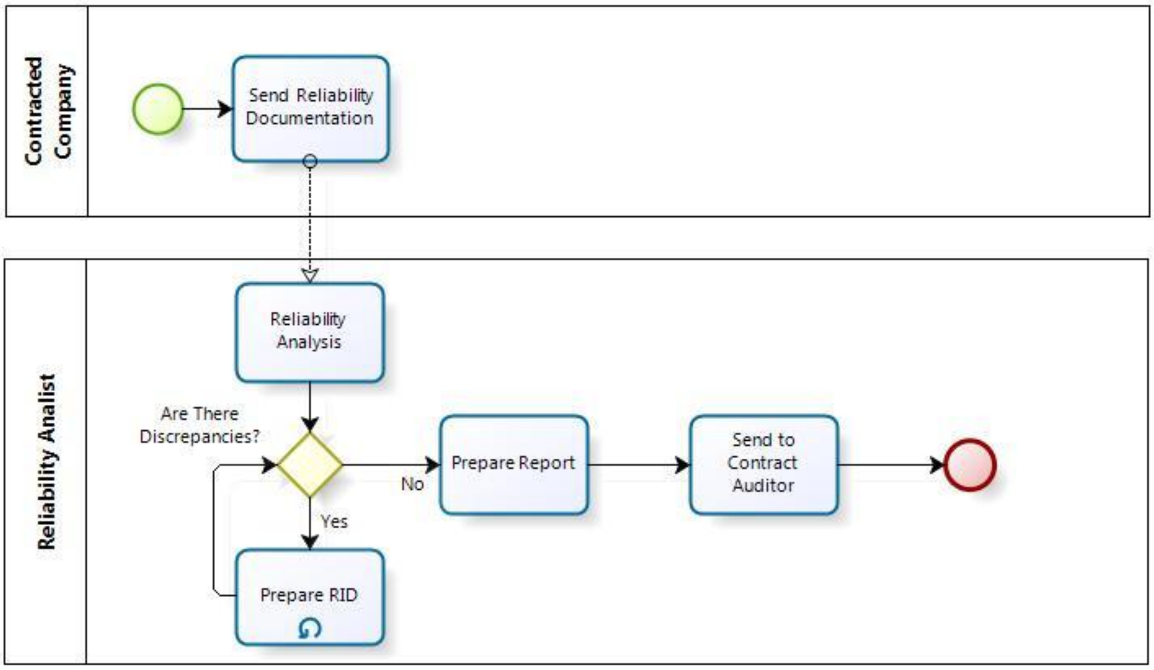

Figure B.1 - Reliability Analysis Process.

8 Appendix C – The Qualification Plan: Parts, Materials and Processes

The Qualification Plan describes the processes for verification and acreditation of the parts, materials and processes used by the contracted companies and it is their responsibility. SGP has the task of validating the qualification plan, when it is presented by the third parties. The individual processes comprised by the Qualification Plan are presented in the following:

- Parts Qualification Processes (Figure C.1): This process aims at the qualification of the parts for their use in space missions.

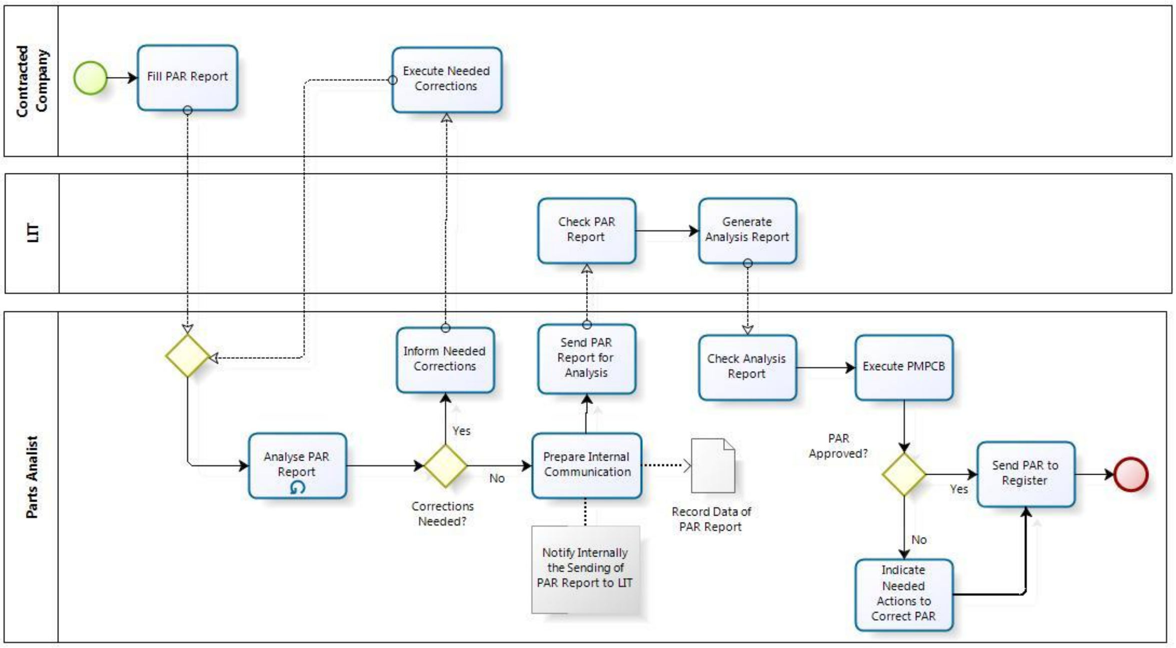

Figure C.1 - Parts Qualification Process (Paiva, 2011).

- Materials Qualification Processes (Figure C.2): These processes address the verification and certification of materials for use in space missions.

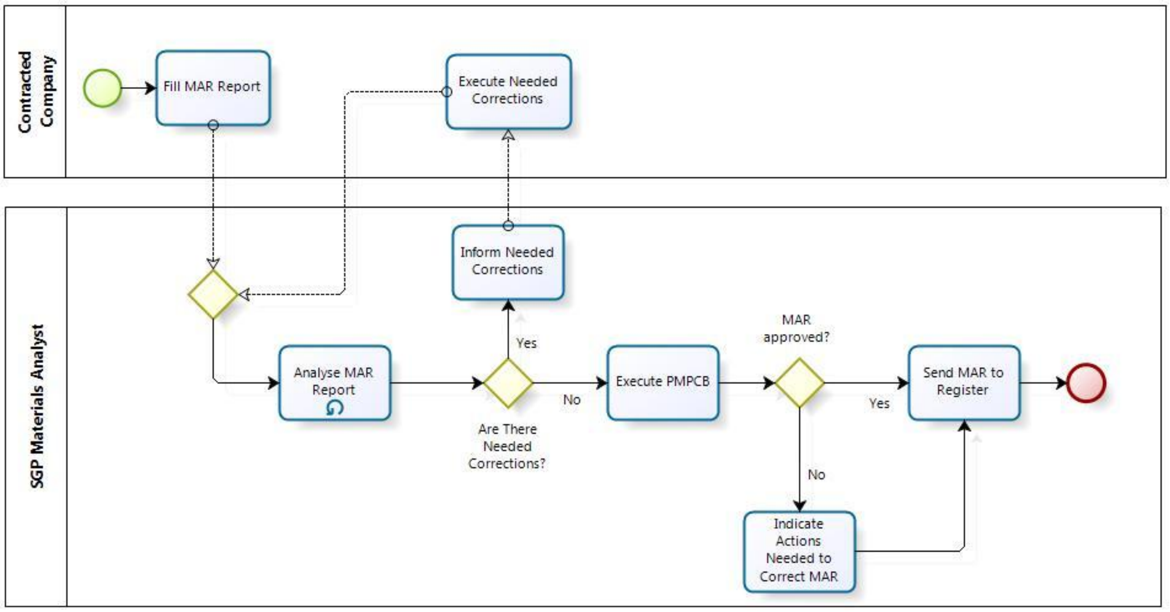

Figure C.2 - Materials Qualification Processes.

- Processes for Qualification of Processes (Figure C.3): These processes address the qualification of processes for use in space missions.

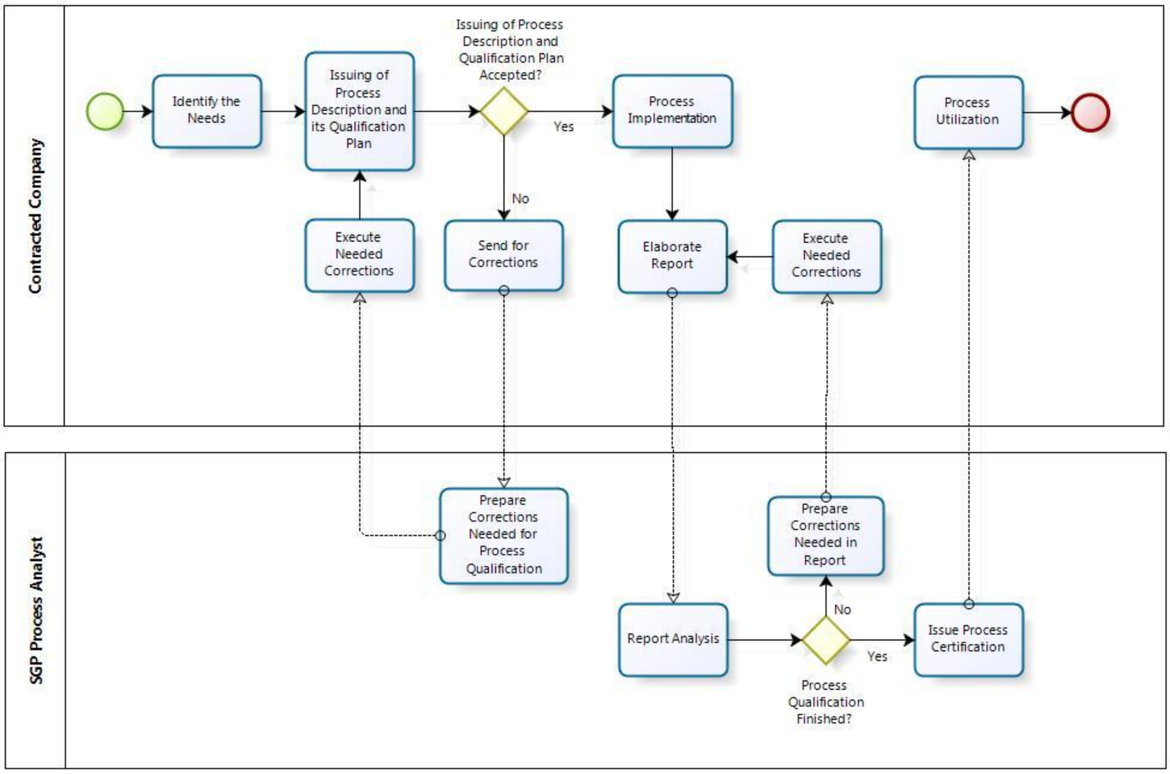

Figure C.3 - Processes for Qualification of Processes.