A Framework for Process Science & Technology Applied to Concurrent Engineering

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Abstract This work proposes the creation of a holistic and transdisciplinary process model view, named Process Science & Technology, for the unification and integration of concepts and techniques originated in various disciplines that deal with complex discrete event processes descriptions. Building upon this unified model view, the work draws some guidelines for the development of a systematic approach to conduct Process Science & Technology studies, named a Framework for Process Science & Technology, aiming at the improvement of the complete product lifecycle management process in Concurrent Engineering projects. The approach is demonstrated by means of a study case applied to the service processes for integration and testing of advanced technological products provided by the Laboratory of Integration and Testing of the Space Research Institute (LIT/INPE).

Keywords Discrete Event Processes, Unified Communicative Modeling Diagrams, Systems Engineering, Concurrent Engineering, Project Management, Process Modeling and Simulation, Business Process Modeling.

1 Introduction

Despite the great improvements that have been made recently in the field of Business Process Management, characterized by the whole theoretical basis and advanced technological resources used in the studies about complex products and services development processes, organizations still face a complex scenario for customizing and improving their business processes due to the diversity,

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incompatibility and/or incompleteness of methods, as well as the high costs of deployment of its supporting tools.

There is a need to derive alternative ways to address these problems, not just by creating new concepts and tools or by improving the diversity of existing ones, but by more effectively restructuring the knowledge base upon which they are built, looking for integration and unification. It is also useful to adopt a general systematic approach for the application of this reshaped knowledge base to develop real systems study cases and eventually discard some overhead results that might become inconsistent, duplicate or superfluous along these experiments.

The above is the equivalent of thinking about the problem as if it were a very big puzzle made up of separate subsets with some repeated or badly printed pieces. It might be better and faster to start by putting all of them together and by adopting a systematic approach to build the complete picture right from the start than by initially trying to find the partial solutions for the puzzle's subsets and then to finish it by selecting the pieces to build the correct global picture.

Process Science & Technology (ProS&T) is a neologism created by the authors 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 by the authors for the first time in previous 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 and used as *Systems Concurrent Engineering* (INCOSE 2011).

This work presents the main concepts underlying ProS&T and draws some guidelines for the creation of a general systematic approach for conducting ProS&T studies, denominated *A Framework for Process Science & Technology (ProS&T Framework),* which is expected to lead to the conduction of more complete Business Process Management studies and to the improvement of the execution of concurrent engineering projects.

The application of the proposed approach is also demonstrated in a case study involving a simplified version of the organization management process model of the services for integration and testing of complex advanced technological products provided by LIT/INPE, making use of some existing and autonomous simulation and business process software.

This article is structured as follows: Section 2 defines the ProS&T concept; Section 3 proposes the general systematic approach ProS&T Framework; Section 4 details the part of the Pros&T Framework related with the development of the organization management process model, which has been termed a *Unified Approach for Modeling, Simulation and Business Process Management*; Section 5 describes the application of the general approach in LIT's case study; Section 6 discusses the results achieved and presents the conclusions.

2 Process Science & Technology

Definition: *Process Science & Technology (ProS&T)* is a transdisciplinary science that addresses the integration and unification of concepts and techniques, which were originated and are traditionally used in several autonomous scientific areas involving a broad knowledge about complex product and service development processes, such as Systems (Concurrent) Engineering, Project Management, Process Modeling and Simulation, and Business Process Management, based on the following guidelines:

- Systems Engineering & Project Management: they are seen as two integrated techniques used for the description and the evolution along its life cycle of one unified *product model*, made of two layered counterparts, the *product engineering model* and the *project management model*. These model views are seen as different dimensions of the same unified model, which correspond to the ways the systems engineer and the project manager look at the product along its complete model life cycle.
- Process Modeling and Simulation & Business Process Management: these are similarly seen as two integrated techniques for the description and the evolution along its life cycle of one unified *organization management process model*, similarly made of two complementary counterparts, the *simulation process model* and the *business process model*, built as one single model with two different views. These models are equivalent virtual entities conceived simultaneously by the IT analyst (or process modeler) and by the business process manager to represent the organization management process along its complete model life cycle.
- Systems Concurrent Engineering: it is seen as the aggregation and unification of the four techniques, consisting of the description and the evolution of the entire *enterprise (product plus organization) business process model* or *product lifecycle management model* or *concurrent engineering model*, made of the *product model* and of the *organization management process model*.

Aiming at: modeling, building, simulating, automating and continuously improving the systems concurrent engineering process, described as the integration of the production and management processes of complex products and services, by means of creating a unified methodology and developing its supporting tools.

The development of a ProS&T study is an exercise of directly building and applying theoretical and practical integrated and unified (transdisciplinary) knowledge and techniques to a complex discrete event process problem. The main focus is on the development of a unified communicative model of the system and on its use for carrying out multidimensional analysis, according to the various disciplines mentioned, along the model complete lifecycle. The building of a unified communicative model as a common reference and the assurance of its consistence across the diverse implementations and analysis made according to various disciplines dimensions is the key difference of the approach. This shall be contrasted with the conventional way the majority of systems analysis studies are made, based on the treatment of the same problem making use of *n* different and usually independent (multidisciplinary) knowledge areas and their techniques for achieving a variety of insights and results, followed by their juxtaposition to build the full *n*-dimensional picture of the solution.

3 A Framework for Process Science & Technology

The Framework to conduct Process Science & Technology studies or simply the *ProS&T Framework* is defined as a methodology comprising 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 main guidelines on which it is based are:

- The attempt to build integrated and unified systems concurrent engineering process models, from conception to disposal, making use of distinct model views, based on the knowledge domains typical of the different agents involved in the project: the Systems (Concurrent) Engineer, the Project Manager, the IT/Simulation Analyst/Process Modeler, and the Business Process Manager;
- The use of these unified process models for simultaneous integrated process execution and simulation analysis directly linked with the operation of the real system (the enterprise), with its production and management processes, defined as the *concurrent engineering process* or *product lifecycle management process* or complete *enterprise's business process*.

The main components of the ProS&T Framework are described as follows:

The Knowledge Architecture

Figure 1 shows the general knowledge architecture resulting from the integration of the distinct knowledge domains and model views associated with the different agents involved in a ProS&T study. 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.

The upper and lower parts of the picture show the product lifecycle of complex products developed by an enterprise, made by the product development process and the corresponding organization management process, both seen as parts of the enterprise business process, which has been divided into the phases of planning, development and operation, comprising the tasks: modeling, building, execution, automation, monitoring, analysis and continuous improvement of the processes.

The processes described are those related with the manufacturing enterprise: the design and the engineering of the product and the workflow of production (technical processes), the management of the project, the organization management process modeling and its simulation, and the additional business process management operations, with their interface to third party support (supply chain and maintenance).

This three dimensional 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.

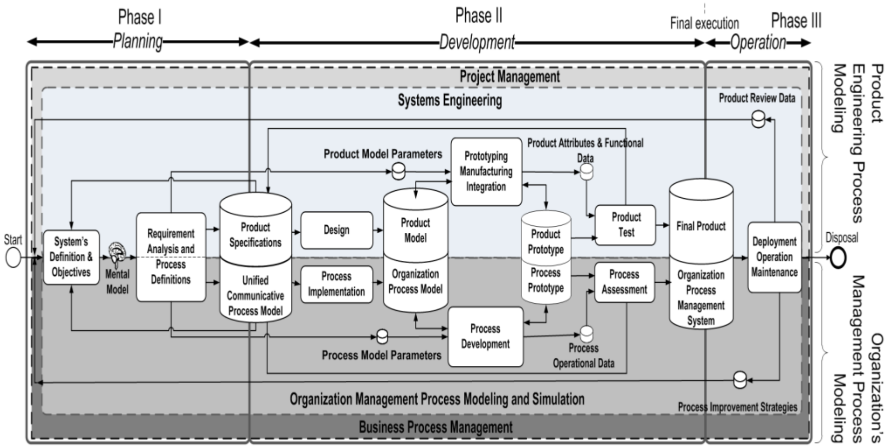

Fig. 1.: The Process Science & Technology Knowledge Architecture

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.

The Implementation Method

In a ProS&T study the implementation method makes simultaneous use of various modeling techniques in an integrated way and on a real time basis along the complete model development life cycle. The simultaneous use of diverse representations techniques to build transdisciplinary unified process models of the enterprise or complete real system (product plus organization) is the cornerstone of the approach, thereby exploring the complementariness and the strengths of the various disciplines and allowing their simultaneous use in the applications developed. One should think of this implementation method as the orchestration of different services, each one related to a specific model view, corresponding to the type of agent involved in the complete real system development processes.

Creating this kind of unified conceptual model is certainly the most difficult part of any discrete event system study and it is the objective of many current research endeavors, as one can see in the literature of the area (Robinson et al. 2011; Embley and Thalheim 2011), just to name two recent works. There are no conclusive results about the definition and the format of the minimum content for building and representing unified conceptual models and it is not the purpose of this work to claim that the modeling procedure adopted in its case study constitutes a definitive solution either. The need to create a sufficient and generic solution is expressed by many authors, though, and one expects that the ProS&T Framework proposed in this work and its repeated application will also contribute towards this goal.

The Supporting Environment

All of the integrated and unified techniques involved in a ProS&T study need to be supported by computer aided hardware and software engineering tools, ranging from computer aided design and manufacturing systems, software engineering environments, communication interfaces, verification mechanisms, and applications to perform automatic model transcriptions and implementations, in order to assure consistency and compatibility across different model formats and the complete interoperability of its component tools. This variety of software tools should be ideally integrated in an environment to support all phases of the integrated and unified model life cycle (*product model* plus *organization management process model*), ranging from: the modeling phase (conceptual mapping tools and process modelers); the building (hardware and software engineering systems, project management, simulation modeling, business process management tools, automatic verification and validation tools); the execution (the applications developed), the management (again the applications developed), and the process continuous development (analysis tools, configuration and version control tools, conceptual mapping, presentation and documentation tools).

The use of Process Modeling, Simulation and BPMS systems play a special role in support of the modeling, simulation, automated execution and management of the processes, especially when linked to the real system operation (constituted by the enterprise with its production and management processes). The data generated by the real system operation, which might be orchestrated by some BPMS applications, is used as the source for model input data, definition of control parameters and the validation of the simulation models.

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

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

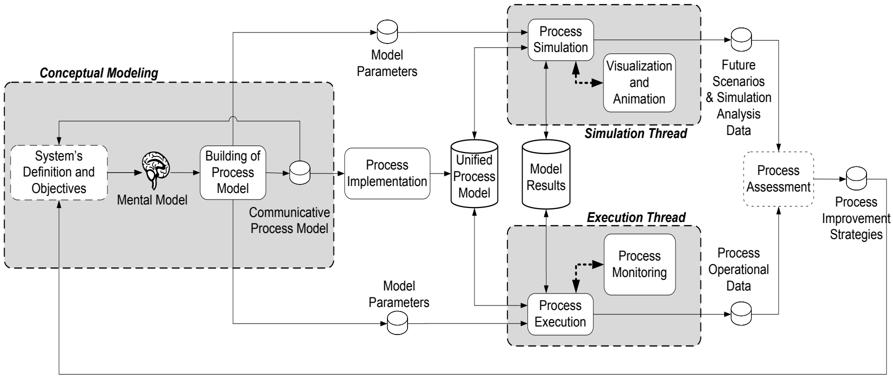

Fig. 2. The Unified Approach for Modeling, Simulation and Business Process Management; Source: modified from Silva et al. (2011)

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.

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 LIT´s Case Study

The Laboratory for Integration and Testing (LIT) is a complex composed of several small laboratory units located in the same building, conceived for mounting, integrating and testing spatial devices for the Brazilian Space Program (LIT 2011). The main Brazilian satellites and some satellites developed in cooperation with foreign partners, such as China, Argentina and USA, have been built and tested in this plant. LIT's lab units are equipped with advanced technological devices and are staffed with highly specialized personnel (technicians and engineers) and they perform, to a certain extent, autonomous and complementary activities, to attend INPE's space mission and commercial service orders from the external industrial sector. Some of these labs are: (EMI/EMC) Eletromagnetic Interference / Compatibility Measurements Laboratory; Antennae Laboratory; Mass Properties Measurements Laboratory; Metrological Laboratory; Components Qualification Laboratory; Thermal Vacuum Laboratory

The main activities developed by LIT are related with the fulfillment of the Brazilian Space Program, conducted by INPE. LIT's interface with the space program is carried out by a senior member of the staff, usually an engineer with participation in former space missions. Usually there is a different member of the team responsible for each mission. The way LIT communicates with the space mission is by means of Gantt charts, showing resources allocation and the timetable for all activities of the individual labs.

Besides the activities related with the space program, LIT provides commercial services to the industrial sector, offering the know how acquired by its participation in the Brazilian Space Program to support the development of the advanced technology national industry. These activities occur simultaneously with those of the space program, the last of them receiving a higher priority, whenever there is a conflict or competition for resources.

There is a special sector of LIT called PAC – Planning, Analysis and Costs – which is in charge of the communication with the commercial client, dealing with the proposal's assessment (for generation of a service order), as well as the messaging regarding acceptance and invoicing. Another sector, called Warehousing, is responsible for the reception, the storage and the return of all equipment sent for testing by the commercial clients. A third important sector deals with the filing and control of all documentation generated by the processes or received from the external world.

For the purpose of the case study, the commercial services have been grouped in three phases, each one addressing a part of the model life cycle of the system, from the proposal reception, passing by the execution of the service order, to the final phase of payment and the issuing of the invoice and the receipt for the services provided. These processes have been described in more detail in Silva et al. (2011) and this description will not be repeated here.

The initial phase of modeling of LIT´s service processes consisted in the representation of the system making use of both ACD diagrams and BPMN notation. Besides BPMN and ACD diagrams, a synthesis of these representations was used, denominated UCMD (Unified Communicative Modeling Diagrams). UCMD is a graphical representation form proposed in (Travassos, 2007), originally denominated USMD (Unified Simulation Modeling Diagrams), devised for unifying model descriptions of the network of activities in discrete event processes, such as these created in the disciplines of Project Management, Systems Simulation and Business Process Management.

The UCMD diagrams were used to help extracting the knowledge content regarding the kinds of resources involved and the logic of their operation, that is, the network of activities performed by the various agents to accomplish their respective part of the overall service process. The models have been progressively built using the three representation formats, whereby UCMD were used mainly as a common base of unified modeling for verification of model´s logic content and to assure the cross consistency between the two other modeling representation formats.

The model with the BPMN description of the system was performed by making use of Bizagi Process Modeler (Bizagi 2011). In this model two macro processes have been defined (pools), namely the client and the LIT processes, the last one divided into lanes, represented by the Commercial Sector, the Documentation Sector, the Head Office, the Laboratory (an aggregate of unit labs) and the Storage Room. BPMS Suite BizAgi was then used to create a preliminary executable version of the system from the BPMN description of the model created using the Process Modeler, but the original BPMN model had to be altered and complemented for this to be accomplished.

In parallel, the process model made using Activity Cycle Diagrams, together with the model built in UCMD representation, were also used to guide the elaboration of the simulation model to be implemented in the Simprocess simulation system (Simprocess, 2011), since these representations show a better description of the network of queues and activities and the interaction between the resources in the model of the commercial services provided by LIT.

The next step was to determine the statistical distributions to be used to represent the duration of each activity, what was again facilitated by the use of the application ExpertFit. This tool comes together with Simprocess simulation system and it allowed that data from the operation of the real system, extracted from LIT's information system (eLIT), could be used to find the best distribution which fits each activity duration.

The products yielded by the research so far were: a simplified process model of the commercial services provided by LIT (industrial sector supporting activities), modeled in BPMN, UCMD and ACD notations; the corresponding unified model implementations, both in the BPMS Suite Bizagi and in the Simprocess simulation system; some facilities for experimenting with the simulation model, such as the curves distribution fits for the duration of each activity; and a technical report, summarizing all analysis and conclusions about the problem drawn until now.

6 Result Analysis and Conclusions

The unified approach devised to conduct a ProS&T study applied to LIT's services processes shown in this work was based on two methodological fundamentals: the use of UCMD diagrams for building the organization management process model representations of the system and the use of a Unified Approach for Modeling, Simulation and Business Process Management for its implementation. The product model (systems engineering and project management models) was not explicitly dealt with in the present study, because the focus was on the organization management process and the "product under development" was not really a product, just a set of unconnected service orders.

The choice of the representation formats based on ACD and BPMN representations was made due to their ease of understanding and because they are patterns traditionally used in its respective knowledge area and, in the case of BPMN, widely supported and maintained. Representations made using UML activity diagrams and other kinds of modeling format can be used and they can also be mapped to UCMDs for the purpose of consistency checks.

The case study conducted on a real problem, the commercial services provided by LIT in support to the Brazilian industrial sector, demonstrated the benefits of the approach. These benefits include:

- Different views of the model are created: the BPMN model shows its logical structural aspects, and the ACD representation and simulation model show its dynamic behavior and the interaction between the system's resources for the accomplishment of the processes.
- The use of a multifaceted modeling aids better visualization and communication of the model among the participants, as well as in the documentation of the model.
- The essentials aspects of the model are identified in the beginning of the modeling process, but these aspects need (and ought to) be enhanced during the next steps performed by the analyst, while he/she implements the models in the business process management and simulation systems.
- As a consequence and a synthesis of the above, a better understanding of the problem is achieved and there is a considerable speed up in the complete model's development life cycle.

The simulation study of the model produced a series of preliminary results, which were consistent with those of the real system, helping to understand better the commercial services processes provided by LIT and to identify some of their deficiencies.

The non-existence of a formal methodology and of a completely integrated and unified supporting environment to conduct ProS&T studies was overcome by the creation of independent models making use of ACDs, UCMDs and BPMN and manually checking their consistency and equivalence in the modeling phase, followed by the independent application of Simprocess and Bizagi for the implementation of these models.

The application of a unified modeling approach right from the start of the model lifecycle resulted to some extent in an overhead, represented by the procedures needed to maintain model consistency and compatibility across the whole model development life cycle. This is the drawback of the transdisciplinary approach proposed when it is applied based on autonomous, already existing software tools. But, rather than constituting an additional problem, this is seen as the result of the anticipation and of the attempt to solve future problems, which might arise if one would follow the traditional way, that is, the separate application of these techniques with independent models and the gathering and interpretation of their results to build a global solution thereafter.

The drawback identified in the modeling process can further be reduced in future studies of this kind by the use of formal verification procedures and of software mechanisms to improve process model consistency and compatibility. The authors advocate further that a more encompassing and definitive solution to this problem can only be achieved through the evolution of the ProS&T Framework and the improvement of its supporting tools, aiming at its transformation into a complete methodology for conducting complex process studies in general. The foundations and guidelines for implementation of this methodology have been presented in sections 3 and 4 and they will be pursued and extended in future research work.

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