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A Transdisciplinary Process Oriented Framework to Support Generic PLM Implementation for Use by Small and Medium Enterprises

Germano S. KIENBAUM[a,1], Renato FERNANDEZ[a], Elaino K. T. SILVA[a], Rodrigo MARIA[a], Marcelo COICEV[a], Eduardo GARTENKRAUT[a], Márcio RODRIGUES[a], Alvaro Augusto NETO[b] and Maurício FERREIRA[a]
[a] *LAC/INPE, São José dos Campos, SP*
[b] *ITA, São José dos Campos, SP*

Abstract. This paper describes the application of a transdisciplinary process oriented framework named Transdisciplinary Process Science and Technology, which employs the key concepts and techniques from diverse disciplines that deal with complex discrete event processes - namely Model Based System Engineering, Project Management, Business Process Management, and Simulation - as a base for the creation and implementation of generic Product Lifecycle Management supporting systems for use by Small and Medium Enterprises. The friendly and affordable applications created can be put to work together in a Product Lifecycle Management generic environment that is used to support the automated execution and management of the essential procedures in the development of short lifecycle engineering projects, as an alternative to complete and/or tailored Product Lifecycle Management and Business Process Management systems, which are usually costly, complex, difficult to customize and to integrate with the other organisations´s legacy software applications.

Keywords. Systems Engineering, Project Management, Business Process Management, Simulation, Transdisciplinary Process Modeling

Introduction

Transdisciplinary Process Science and Technology (T-ProST) designates a holistic world view, which consists of the integration of various disciplines that deal with complex discrete event process models [1,2]: (Model Based) Systems (Concurrent) Engineering (SE) [3,4], Project Management (PM) [5], Business Process Management (BPM) [6,7], and Simulation Modeling (SIM) [8,9,10].

Transdisciplinary process-oriented organisations or transdisciplinary Small and Medium Enterprises (T-SME) is another neologism used in this work to refer both to Small and Medium Enterprises (SME) and to research and academic institutions, who need to carry out systems concurrent engineering project developments of low-cost and low to mid-level complexity advanced technology products, submitted to severe

[1] Corresponding Author, E-Mail: kienbaum@lac.inpe.br.

constraints related to small sized teams, short project lifecycles and tight budgetary limitations.

T-SME project development is characterised by highly advanced but small sized technical engineering processes and more simplified managerial challenges, reducing its needs for sophisticated techniques and tools for the execution and management of the its system´s concurrent engineering lifecycle processes.

Nowadays, there is a wide array of Product Lifecycle Management environments available to choose from in the market. The majority PLM systems, nevertheless, are very complex PLM systems, which are costly and difficult to customise, and therefore it is difficult to find friendly and affordable PLM solutions in the market that can be customised and used to support T-SME. This entails the possibility that project developments of this nature might be conducted in a very amateur way, leading to project failure regarding scope, duration, cost and/or poor quality of the products being built.

The T-ProST methodology strives towards improving the modeling and seeking better and integrated engineering and management solutions for complex discrete event problems in general. This work presents the application of the T-PROST Framework for the implementation of generic PLM systems aiming at lowering the costs and improving the success rate of the so called T-SME projects.

The rest of this work is structured according to the following. Section 1 describes the T-ProST Framework´s Architecture. Section 2 identifies the problem and sets the overall scope of the research theme. Section 3 presents the conceptual modeling phase and the resulting reference meta-model. Section 4 describes the development of the specialised models, making use of the autonomous disciplines and their supporting tools. Section 5 refers to the use of the methodology to create basic or generic PLM environments, made by the ensemble of applications resulting from the implementation of the specialised models. Finally, the Section 6 presents the conclusions and future works.

1. The T-PROST Framework´s Archictecture

A T-ProST study is performed making use of a framework (T-ProST Framework) [1,2], consisting of three elements, which constitute the pillars of the methodology: 1) Knowledge Structure, made by the transdisciplinary hierarchical process model created (conceptual or reference model) and all additional information on the system being studied; 2) Implementation Method, which is the method used for the evolution of the models along their respective lifecycles; 3) Supporting Environment, which is made by the integrated set of tools used and their applications.

T-ProST Framework´s architecture is described in detail in article [1] and its three model building phases, namely Mission Definition, Conceptual Modeling and Model Development phases, used to create the specialised models and evolve them along their lifecycles, is shown in Figure 1.

The horizontal axis depicts the evolution of the models along their lifecycles. The rectangles correspond to transformation processes or simple activities and the rounded icons to data reposity of some kind, that is, complete models or objects and artifacts of some kind, which are gradually transformed along the complete process model lifecycle.

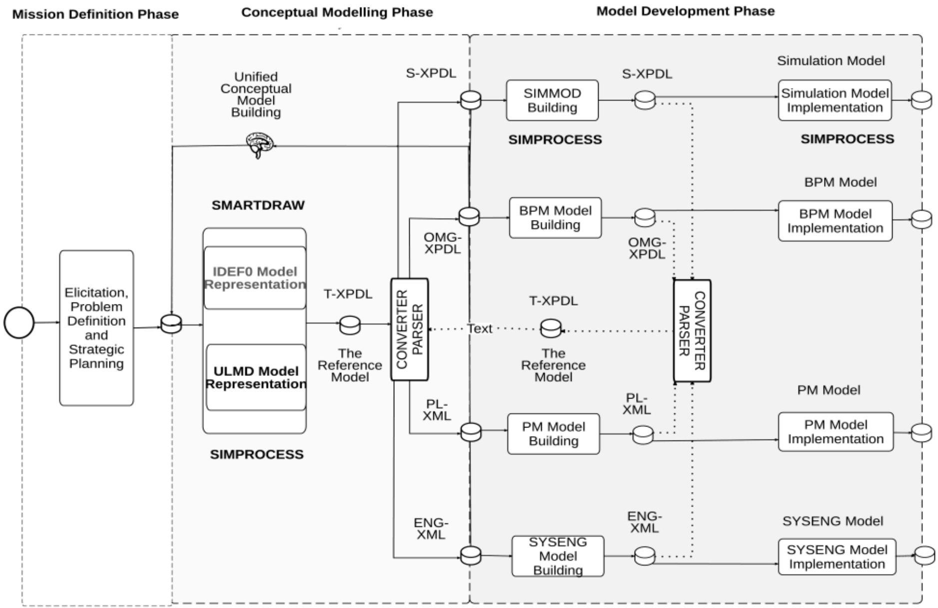

Figure 1. The T-PROST Framework´s Architecture.

The use of the T-ProST approach for the implementation of generic PLM environments is demonstrated hereafter in a stepwise way, by applying the methodology described in [1] to the design phase of the SE lifecycle.

2. Mission Definition

The mission definition phase of the methodology consists in identifying the problem domain for the application of the T-PROST Framework in a specific case study. The problem domain of interest for the case study conducted in this work is the design phase of the SE Lifecycle. The design phase of the SE Lifecycle is shown in Figure 2.

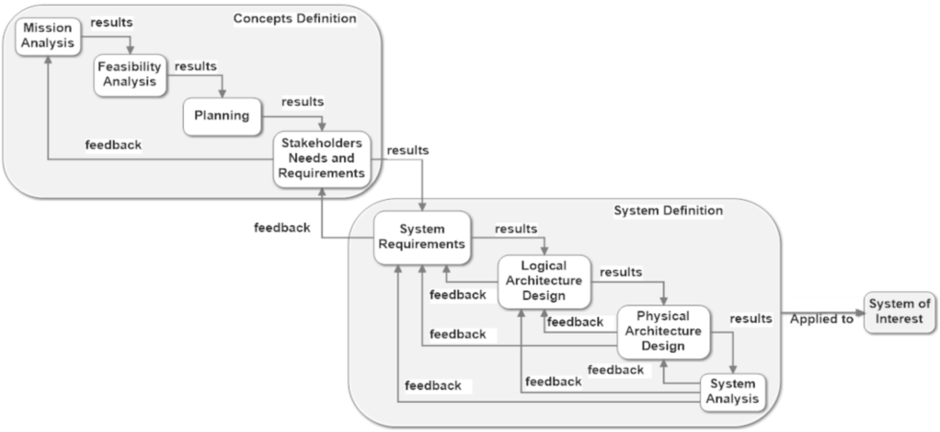

Figure 2. SEBoK[2] SE´s design phase processes modified by the authors.

The Design Phase of the SE Process Lifecycle is the phase of the project in which the system is being conceived and specified. It comprises the following two main processes: (1) the Concepts Definition process, which can be divided, on its turn, into four sub-processes designated by Mission Analysis, Feasibility Analysis, Planning and Stakeholders Needs and Requirements; and (2) Systems Definition process, consisting on its turn of four other sub-processes denominated Systems Requirements, Logical Architecture, Physical Architecture, and Systems Analysis.

The process Mission Analysis existed in SEBOK [4], but it was directed to the organisation´s mission definition and was replaced by Mission Analysis and Feasibility Analysis, defined according to ECSS [11,12], to introduce an assessment of the product´s conceptual model and its technical feasibility, before the start of the project (creation of the opening term or project charter). The macroprocess Planning did not belong to the original definition of the SE´s Process Lifecycle in [4], and it was added by the authors in order to adjust the model to project management standards [5].

Any enterprise that has (Model Based) Systems Engineering (MBSE or SE) as the main driver of its production processes may well make use of the concepts and definitions given in SEBoK, and the modifications above mentioned introduced by the authors, to describe the their product´s conceptual design phase, according to the structure shown in Figure 2.

3. Conceptual Model Building

The Conceptual Modeling procedure consists in the formal description of the model through the realization of two activities, namely The IDEF0 [13] model creation and the Reference Meta-Model Creation, using a graphical notation denominated Unified Lifecycle Modeling Diagrams (ULMD) [1,2]. This modeling phase is the subject of a detailed description in another article submitted by the authors to ISPE 2016 [1], and it will not be reproduced here, due to the lack of space and one is invited to refer to the referred article for more detailed information on the subject, if deemed necessary.

The complete reference meta-model comprises: hierarchically displayed component processes; their main actors or agents designated as entities; their respective individual process lifecycles with their time sequencing; the complete description of the inputs and outputs (artifacts and messages consumed or generated by the processes); the control rules and norms used for the transformations; the human and material resources or mechanisms used by the processes; the interactions and connections links displayed inside the lanes or crossing over their borders. All of that is used as a baseline model to evolve to the next phase of model representation, known as the Specialised Models Development.

Ideally, the input data for these models should be determined by people with previous experience in this type of project. In the absence of such persons, examples from similar projects available in scientific papers can be used. As a last resort, one can propose the use of random variables for estimating the activities´ duration in the simulation model and the use of these results for parameterizing the Project Management model.

A survey on the subject small satellites project development was conducted to assist in determining the duration of the phases of Concepts Definition and Systems Definition, with the aim of finding data related to the type of satellites being analysed.

As a matter of fact, little information was found on the complete configuration of the satellites, the precise definition of their real project network of activities, their number of participants, activities´ duration and/or associated costs and additional relevant data.

The lack of information on the design phase process generated from real project development scenarios led to another approach for model parameterisation. Instead of searching for data from previous projects, one decided to fix them taking into account the nature of a small satellite project development to be executed by a group of undergraduate in an university program consisting of an academic semester for the design phase and two to three years for the complete project execution.

The human resources estimated based on the approach adopted were set to be twenty participants, three project managers and seventeen product development engineers. Project managers also act as engineers, supporting the development of the satellites, if necessary. The group of engineers consists of seven doctoral students and ten master's students. The reference for the cost of these resources was assumed to be the values of monthly scholarships granted by CAPES for M.Sc. students (R$ 1,500.00) and Ph.D. students (R$ 2,200.00). The number of working hours per day was considered to be eight hours.

Some specifications were still originated from real scenario, such as the findings that the length of the Concepts Definition phase for the satellite AESP14 [14], developed by the Technological Institute of Aeronautics (ITA), was approximately twice longer than the Systems Definition phase. This parameter was used to define the time for other activities within each of these phases.

Three types of small satellites were considered for analysis, namely, satellites of types pico, nano and micro. For the duration of the activities, it was estimated that the total time of the Concepts Definition and Systems Definition phases for a micro satellite, more complex, would be six months, corresponding to the duration of one semester at a university. The remaining satellites, less complex, have the times of their activities reduced to reflect the lower effort involved in their project development.

4. Specialised Models Development

In the Development Phase of the T-ProST approach, the Reference Meta-Model is implemented into different applications, one for each of its component disciplines: (Model Based) Systems Engineering, Project Management, Business Process Management and Simulation Modeling. This section presents the Model Development Phase of the proposed System Lifecycle, related to the activities of Specialised Building and Implementation for each discipline.

4.1. The Systems Engineering Modeling and Application

Model-Based Systems Engineering (MBSE) [3] is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout product´s development and later lifecycle phases.

The basic designation of systems engineering model is used in this work to refer to the transformation (core production) processes through which passes the product, from conception to disposal (lifecycle), which is used as a basis for structuring all information available on the development of the system, documented as hierarchical processes.

The systems engineering model is a “descriptive” model and it makes use of the IDEF0 diagrams and of the reference model as its structural element. The systems engineering model, nevertheless, extends the descriptive information on the model far beyond the data in the IDEF0 diagram notation [13], such as inputs, products, resources and controls pertaining to the activities, and the workflow of processes represented in the reference model.

The systems engineering model shall provide information on the artifacts that are generated over the system lifecycle, as well as keeping control of system configuration as a whole, that is, the final systems engineering model represents the most complete description of the system being developed. Another important observation that needs to be made is that this type of model is a “descriptive model”, that is, it is not intended to be executed as a process, it is intended to document the system with the complete information on its product development lifecycle, similar to a “recipe” on “how to produce the system”, under an engineering point of view.

A software tool, denominated Smartdraw® [15], has been used to support the systems engineering model building and documentation. The use of Smartdraw® turned out to be a very friendly and efficient way to create graphical representations to document the systems engineering model of the complete product development lifecycle.

The other types of models described in the following are “process models”, that is, they also describe the evolution of the product along its lifecycle, but they are “executable”, that is, they are applications used to support the management during real systems project executions.

4.2. The Project Management Modeling and Application

The project management aims to plan and coordinate the necessary activities to provide a satisfactory product, service or business venture, within the limits set by the schedule, budget, resources, infrastructure, human resources and technology available.

The modeling in project management is considered as the application of project management techniques using a process-oriented view [4], supported by software tools, to expand the SE model with the necessary activities related to the management of product development throughout the entire product lifecycle.

The specialised project management model is created based on the reference meta-model representation in ULMD diagrams. The sequencing of activities (serial or parallel) in the project management model follows the same pattern already established in ULMD models. The feedbacks were considered as complementary activities at the end of each process. The time spent in feedbacks was considered as approximately 30% of the original total time spent in the process as a whole since the time required to review an activity previously performed is shorter than the original time.

The building / implementation of the Project Management specialised model makes use of the Projectlibre [16] environment, an open source tool, which presents itself as an alternative to Microsoft Project® [17]. An example of the Projectlibre graphical interface showing examples of activities and their respective durations, allocated resources and sequencing between them can be seen in Figure 3.

The sequencing of activities (serial or parallel) in the project management model followed the same pattern already established in ULMD models. The sequencing of activities in Projectlibre is accomplished by identifying the predecessor activity of each activity. The activity feedbacks were considered as complementary activities at the end of each process. The duration of each activity was adjusted so that the durations of the Concepts Definition and System Definition phases were in accordance with the previously specified durations.

Twenty resources were created in Projectlibre. Each resource was given a name with the first letter corresponding to one of the letters of the alphabet, to facilitate the allocation of activities. These resources were allocated to the activities in Projectlibre.

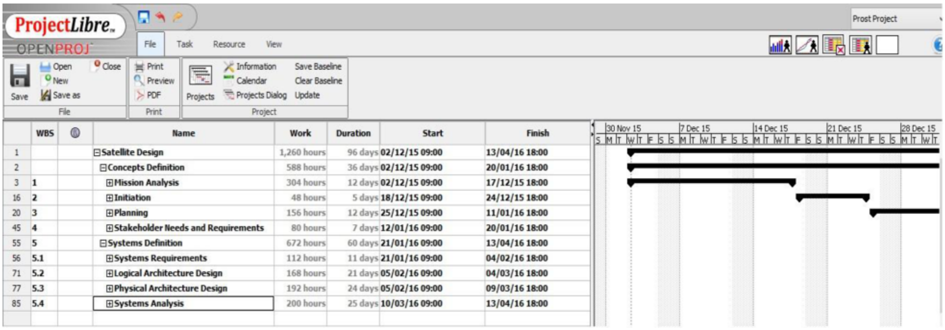

Figure 3. Projectlibre: support environment for the building of the PM model.

This allocation followed the indications established in the ULMD reference models. For example, the Mission Analysis process contains two columns, engineering and management, each one posessing its own entity´s lifecycle processo and separate flow of control. Management activities should be performed by project managers only, but engineers and managers are allow to perform engineering activities (managers here are senior employes or professors and they are capable of executing all kinds of activities).

With this approach, one can determine the number of hours of each activity, as well as the total number of hours for the project as well as its cost. The Projectlibre support environment also allows the visualization of details of the use of resources, showing graphs of changes in the cost of a given resource throughout the course of the project.

4.3. Business Process Management Modeling and Application

BPM is a structured and systematic approach for conducting modeling, analysis, automatic execution and control, management and continuous improvement of processes used in the product engineering and production management of complex product and services [5,6].

Business Process Modeling is the main activity associated with the initiatives to improve Business Process Management (BPM), because it deals with the way the enterprise organizes its production and management processes used for the development of its products and services. It allows a better understanding of its processes, their analysis, simulation and their improvement or optimization. The processes are represented making use of models, commonly created with the GUI interfaces of special computer tools developed for this purpose with different sophistication levels, making use of a special diagramming technique known as Business Process Diagrams (BPDs).

BPDs are just the start of a BPM project lifecycle. Their modeling tools are usually integrated with more complete development environments known as Business Process Management Systems (BPMS), which gives support to the complete process model lifecycle in studies carried out in Business Process Management, providing a complete environment and the development of applications that will act as a part of the real time mechanisms of real systems operation, monitoring and control. These applications contribute decisively to the continuous improvement of the process models and systems performance. Its model based approach allows for joint and collaborative teamwork among the professionals of the Information Technology (IT) area, through the entire product development lifecycle. The complete set of software tools to support the BPM methodology is known as Business Process Management Systems (BPMS) [5,6].

The BPM tool chosen to create the Business Process Diagrams (BPDs) was the BIZAGI Modeler [19], which allows for friendly graphical manipulation of the models and their exportation to other existing proprietary tools by means of XPDL model representations. The models created may also be simulated in order to analyze its adherence to the reference model, verify its consistency and evaluate model improvement strategies.

4.4. Simulation Modeling and Application

Simulation can be seen as the study of the real system behavior by means of exercise models. A model incorporates features that allow representation of the actual system behavior. It can be used when the solution of a problem is very expensive or even impossible through experiments, or when problems are too complex for analytic treatment. When using simulation coupled with stochastic characteristics, systems can have their behavior represented with greater fidelity and realism.

The use of SIM in T-ProST follows the traditional definition of simulation with the remark that one is addressing the aggregate of the processes representative of the systems engineering and of the organization management lifecycles [7]. The only special feature is the use of the reference meta-model, represented in the ULMD notation, to base model development in the proprietary simulation system offered by the different manufacturers. The complete simulation application requires the creation of the facilities needed for the experimentation (design of experiments) and of any other additional features for analysis and presentation of results.

In this work, only the Concepts Definition phase was modeled and studied for analysis purposes. In the creation of the specialised simulation model, the reference model in ULMD was used for the mapping of the processes into the Simprocess® GUI interface [18], and the introduction of Activity Based Costing (ABC) estimates.

5. The Integrated Generic PLM Environment and Global Assessment

The Global Assessment makes use of the generic PLM environmento to perform the joint or integrated assessment of the results produced by the individual specialised models during their independent execution, aiming at the consolidation of the results.

The potentialities of the T-PROST Framework for the implementation of generic PLMs environments was demonstrated by means of a pilot project, conducted by the students of the postgraduate Course on Systems Engineering and Management (CSE-331/ETE/INPE).

The case study was developed as a class project, making use of the following support tools: ProjectLibre [13], to support project management applications; BIZAGI [18], to support the application of BPM techniques; and SIMPROCESS [19], to build simulation models and conduct their analysis of results.

The resulting PLM environment was created with the application of the above commercial off-the-shelf systems, which were put to work together as an integrated environment of interoperable tools, and used to support the product lifecycle engineering and management processes.

The main reason for choosing these tools was their availability in the form of open source or low cost academic licenses. They can be easily substituted by similar systems, since the great majority of them can cope with the implementation of the specialised models described in the SE, PM, BPM and SIM categories presented in this work.

After performing the general assessment activity once, several repetitions of this procedure can be made, if necessary, until one is assured that the initial requirements established for the product lifecycle management process model satisfactory operation have been reached.

6. Conclusions and Future Researches

The present work shows the potentialities of the T-PROST Framework to create generic PLM environments. The transdisciplinary process-oriented methodology was used to develop applications, which were put to work in an interoperable way, aiming at the integration and the exploitation of their complimentary advantages, to create an environment capable to support the design phase processes of the systems concurrent engineering lifecycle.

The environment created is seen as a valuable asset for use in real applications, in a scenery in which few support COTS software systems exist for this purpose. The similar systems known to the participants (proprietary PLM environments), which could have been be used to perform similar functionalities, were considered to be too complex, too big or too expensive. These systems have not been designed for the less demanding level of complexity, regarding both the technical engineering requirements and the managerial aspects, involved in small satellites project developments.

In particular, the pilot project conducted by the students of the CSE-331 postgraduate course on systems engineering and management has demonstrated the potentiality of the methodology and its supporting environment to make a great jump start in the quantity and quality of the knowledge acquired about the conduction of small satellites space missions.

Other case studies have been previously conducted on other types of discrete event problems, such as a steelworks problem used as a class project, which is an example of a serial production process, typical of the SIM study area. Another example of application was on a house construction process, typical of the PM study area, which has been modeled and studied as a hybrid PM and SIM problem, showing the diversity of systems that can be represented using the notation.

Another direction for future research is to use the methodology to create generic PLM made from different bundles of systems, with Simprocess used as the central component for the creation of the reference meta-models, which can be exported/imported in a variety of Extensible Markup Language (XML) and XML Process Defintion Language (XPDL) formats, used by the different proprietary tools existing in the market. Finally, the creation of mechanisms to facilitate the execution of the global analysis might also be the subject of further research endeavors.

In summary, the approach seems to be very promissing, and further publications will report on the advances of T-PROST. The expectation is that it will evolve to become a complete mature methodology with different types of supporting environments, capable of application in a variety of real scenarios from different study areas, and to deal with complex discrete event process problems in general.

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