A FRAMEWORK FOR PROCESS SCIENCE AND TECHNOLOGY

And its Application to Systems Concurrent Engineering

Postdoctoral Research Project

Final Report

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Sponsored by CNPq´s Program Science without Borders

SUMMARY

OVERVIEW

This technical report documents the results from a collaborative research project carried out by the author in the quality of postdoctoral researcher and academic visitor from the National Space Research Institute (INPE/Brazil) at Loughborough University, UK. The project was entitled *A Framework for Process Science and Technology and its Applications to Systems Concurrent Engineering* and it addressed the broad context of enterprises´ business process oriented modelling, both from a structural - (Business) Process Orientation (PO) - and from a managerial - Business Process Management (BPM) – points of view. These subjects are usually treated in the literature under the umbrella denomination of Business Process Maturity Models (BPMM).

TERMINOLOGY

This work makes use of some neologisms, as named in the following. The term Process Science and Technology (ProST) refers to an innovative holistic view on BPMM, considering both its knowledge content organisation (hierarchical structure and/or descriptive view) and a systematic modelling procedure for evolving the process model along its life cycle (process view and/or unified lifecycle process modelling). In order to distinguish the systematic modelling procedure proposed here from other modelling procedures already existing in the BPMM literature, the proposed unified lifecycle modelling procedure has been designated Business Process Maturity *Meta*Modelling (BPMMM). Finally, the term Framework for ProST refers to the overall approach when considering all of its components: the knowledge structure, the modelling procedure, and all existing computational tools that can be used to support the approach.

OBJECTIVES

The original project consisted of performing a critical review on the scope and the state-of-art of the BPMM research area and its branches fields, the Business Process (BP), BPM and PO, with two goals in mind. The first one of a theoretical nature, for achievement of a better understanding of its scope and delivering a contribution to the creation of a holistic view and/or framework for its application in advanced problem solving related with the broad context area of Systems Concurrent Engineering. The second one of a practical nature, for illustrating the potentialities of the approach by means of performing a case study.

The thorough understanding of the multidisciplinary nature of BPMM and of its application in the context of Systems Concurrent Engineering projects led to the inclusion in the scope of the research of other disciplines that deal with complex discrete event processes. The additional disciplines which were added for consideration in the formulation of a transdisciplinary view on BPMM applied to Systems Concurrent Engineering were Model Based Systems Engineering (MBSE) or, generically, Systems Engineering (SYSENG), Project Management (PM) and Simulation Modelling (SIMMOD), with their overlapping and complementary aspects taken into consideration.

RESULTS

The results achieved by the research work can be summarised as follows:

- The main achievement was the proposal of a transdisciplinary "Framework for Process Science and Technology (**ProST/BPMMM Framework**)", based on the integration and/or unification of existing autonomous modelling methodologies and their supporting tools, originated from the diverse disciplines that deal with complex processes, for carrying out enhanced BPMM studies. These enhanced BPMM studies aim at the systematic structuring, the search for adaptive and innovative solutions, the provision of increased performance, and the continuous improvement of the complete unified model life cycle, comprised by the product development and the organisation management processes.
- The proposed framework comprises three elements: the **knowledge architecture**, made of multifaceted modelling views; the **implementation method** for evolving the models along their life cycles; and the software tools constituent of a **supporting environment** for the approach.

- The main applications envisaged target the areas of Process Oriented Organisation Management and of Systems Engineering Project Management, but the approach is applicable to support the phases of modelling, simulating, automating, monitoring, managing, analysing and proposing solutions for complex systems´ discrete event processes in general.
- The results of the research project also pointed the need for the development of powerful and innovative integrated tools to support the holistic view formulated, although case studies can be carried out making use of the existing techniques and tools, in order to get a better insight into these issues.

ONGOING AND FUTURE RESEARCH

The results of the research project *A Framework for Process Science and Technology and its Application to Systems Engineering*, presented in this technical report, will be the subject of a co-edited book, entitled *Handbook on Process Science and Technology*. The book will document the continuation of the research work, which will be submitted for funding by research sponsoring agencies as a collaborative research project, to be continued between INPE/Brazil (National Space Research Institute) and the departments SEESE (School of Electronic, Electrical and Systems Engineering (SEESE) and SBE (School of Business and Economics), at Loughborough University (LU).

In order to progress with future researches in a long time basis, the project also evidenced the need for the decomposition of its original objectives in more specific goals, as listed below:

- Carry on identifying/classifying the BPMM and its branches BP/BPM/BPO concepts and techniques for assessment/comparison of their commonalities and complementariness to improve the understanding/restructuring/integration of their knowledge scope (ProST´s structural or descriptive view);
- Continue to unify/integrate the main modelling methodologies and analysis techniques from the above areas aiming at a continuous improvement of the unified process modelling approach for application in Systems Engineering (ProST´s dynamic view or BPMMM);
- Study the diverse existing process classification mechanisms (such as Zachman´s Framework, APQC, MIT Process Handbook), in order to choose one and/or to adapt their specialised reference models for use in specific case studies in the Systems Engineering area;
- Develop a complete case study of the systems engineering and organisation business management processes related with the design phase of product engineering applied to a real problem;
- Evolve the overall ProST/BPMMM approach with the application of the ProST framework in several other case studies.

ABOUT THE AUTHOR

GERMANO S. KIENBAUM graduated from ITA (Aeronautics Technological Institute/Brazil) in Aeronautical Engineering in 1983 and got his MSc degree in Systems Analysis and Applications from INPE (National Space Research Institute/Brazil) in 1989. His Ph.D. is in Computer Science from Brunel University, United Kingdom, in 1995. He is a senior researcher at LAC/INPE (Associated Laboratory for Computing and Applied Mathematics/INPE/Brazil). His research interests include Model Based Systems Engineering, Project Management, Simulation Modelling, Business Process Management and Educational Technology. His email is kienbaum@lac.inpe.br.

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CHAPTER 1: PROST! A MANIFESTO

Abstract

The general research area of Business Process Maturity Models (BPMM) and its specific branches, namely Business Process (BP) Modelling, Business Process Management (BPM) and Business Process Orientation (PO), have produced a plethora of concepts, methods, techniques, and tools to support the design, enactment, management, and analysis of the core operational business processes of organisations and their process-oriented structuring. The BPMM body of knowledge is vast and it frequently appears scattered in the literature as an extensive list of encapsulated and non-concatenated topics. This fact raises a barrier to the users from different backgrounds, who need to make sense from this information chaos, in order to be able to interpret, organise and put in practice the techniques for carrying out advanced BPMM studies in a comprehensive way in his specific area of interest. This work points out the need for creating a transdisciplinary view on the scope of the BPMM research area to organise and to improve the understanding of its concepts, methodology, techniques and tools, in order to contribute to their unification, integration and effective application in systems engineering. The transdisciplinary view on BPMM and the systematic process modelling approach proposed in this work to conduct advanced BPMM studies are, respectively, designated Process Science and Technology (ProST) and Business Process Maturity *Meta*Modelling Framework (ProST/BPMMM[1] Framework). The approach is envisioned for generic applications, but it is analysed in this work particularly in regard to its potential for applications in the areas of Systems Engineering Project Management and Process-Oriented Organisation Management.

Keywords: Discrete Event Processes, Systems (Concurrent) Engineering, Project Management, Business Process Management, Simulation Modelling, Process Science and Technology, Business Process Maturity *Meta*Modelling Framework

1.1 Introduction

Modern organizations need to perform and to evolve continuously their complex business processes, related with the product development and the advanced services they provide, in order to attend a highly demanding and competitive market in a continuously changing world.

The study, research, development and application of tools for the solution of problems related with complex business processes have been traditionally organised into autonomous knowledge areas or disciplines, such as (Model Based) Systems Engineering (SYSENG), Project Management (PM), Business Process Management (BPM) and Simulation Modelling (SIMMOD). Each of these disciplines presents its own independent theoretical basis, methodologies and its advanced technological support tools.

The knowledge areas and disciplines listed above experienced great improvements in recent years, among them the advent of BPM itself, which has arisen and is undergoing a rapid evolution to become the discipline par excellence to deal with this type of problems. Nevertheless, the organisations still face a complex scenario for customizing and improving their business processes, due to the diversity, incompatibility and/or incompleteness of methods, as well as the high costs of deployment of their supporting tools.

The common link among these disciplines, which is sometimes overlooked as such ("the missing link"), is the fact that they all make use of the concept of discrete event systems and of process model life cycles, necessary for the description of products and services engineering and management processes.

An interesting alternative way to improve the solution of problems involving complex business processes is by making use of that common link not just as the basis for creating new concepts and tools for these individual disciplines and/or for improving the already existing ones, but for more effectively (re)structuring, integrating and unifying the knowledge base underlying them. That is, to search for a holistic approach, which could consolidate all these knowledge areas under a single umbrella, capable of covering the entire problem domain and covering the complete process model life cycle.

An innovative holistic view, to be devised for the reorganisation of the existing knowledge base about discrete event processes, needs to address both the restructuring of the knowledge content (descriptive view) and the

[1] The Acronym ProST/BPMMM Framework is used throughout the work to distinguish the proposed approach from other traditional modelling procedures used in the BPMM subject area.

creation of a general systematic modelling procedure (unified process view), in order to allow the individual or combined use of these disciplines. The objective would be to progress towards the integration and the unification of the concepts, methods and tools from these diverse areas, seeking to apply them simultaneously in an easy and consistent way, thereby achieving the same complementary benefits from their individual use, and at the same time avoiding any overheads, inconsistencies and duplications related with their joint application.

The idea of proposing a holistic view on these subjects is the equivalent of thinking about the problem as if it was a very big puzzle, made up of separate subsets with some repeated or badly printed pieces. One is faced with the challenge of considering two ways to try to solve the problem. The first one is to put all pieces together and to adopt a systematic approach to build the complete puzzle right from the start, based on an idealised reference image of the whole (the holistic view). The second one is to try to find the partial solutions for each puzzle's subsets (the equivalent of independently applying the autonomous disciplines) and only then to try to build the correct global picture (to obtain the complete results) from these partial solutions. It might be better and faster to choose alternative one if the idealised reference image of the puzzle (the holistic view) really exists.

This work describes a research project, entitled *A Framework for Process Science and Technology and its Application to Systems Concurrent Engineering*, carried out in the quality of a postdoctoral research work, aiming at the restructuring of the knowledge related with the solution of complex business processes and the creation of a holistic view of the kind suggested above. The author´s expectation is that it will bring a contribution to the efforts towards the restructuring and the integration of the knowledge base and the creation of a systematic modelling approach that will improve the quality of the applications developed in the BPMM (Business Process Maturity Model) research and study area in general.

The holistic view on BPMM has been designated ProST (Process Science and Technology) and the systematic modelling procedure for the evolution of the models along their life cycle has been named BPMMM (Business Process Maturity *Meta*Modelling). Finally, the term Framework for ProST refers to the overall approach when considering all of its components, the knowledge structure, the modelling procedure and all existing support computational tools. The Framework for ProST was divised primarily to conduct advanced studies and to improve the solution of complex problems involving systems concurrent engineering, project management and process-oriented organisation management, but it can be used for application in complex BPMM studies in general.

The current work has been structured according to the following. Section 2 presents the objectives of this research work. Section 3 gives the definitions of the concepts *ProST* and of the *ProST/BPMMM Framework* used in this work. Section 4 discusses the cross effects (benefits and disadvantages) derived from the application of the proposed multidisciplinary approach. Section 5 summarises the actual state of the efforts towards the materialization of the ProST/BPMMM Framework, draws some conclusions and points out some topics for future research.

1.2 Objectives

This work proposes the creation of a transdisciplinary view, named a Framework for Process Science and Technology (ProST), to organise and to improve the understanding on the scope of BPMM, its concepts, methodology, techniques and tools, in order to contribute to their unification, integration and effective application in the areas of systems concurrent engineering, project management and process-oriented organisation management. ProST is a contribution to BPMM making use of concepts originated from different disciplines, namely (Model Based) Systems Engineering, Project Management, Business Process Management and Simulation Modelling, targeting both the theoretical and practical aspects related with the development of a unified process modelling methodology, as well as the building of its integrated supporting environment.

1.3 Process Science and Technology - Definitions

Process Science and Technology (ProST) 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 process model life cycle of complex products and services development and organisation management processes in general. The complete process model life cycle comprises the modelling, the building, the execution, the automation, the monitoring, the management and the continuous process model improvement.

The ProST concept was introduced for the first time in an article by Silva (Silva et al. 2011), as an alternative interpretation of the meaning of the term *Design and Process Science* (SDPS 2011), but it can also be seen as a holistic view on BPMM for application in the area of *Systems Concurrent Engineering* (INCOSE 2011).

ProST seeks to integrate and to unify the knowledge base of diverse research areas or disciplines, and to create a generic systematic modelling approach for its application to the systems engineering and organisation management processes. The concepts and techniques are those originated in diverse autonomous process study and research branches, such as (Model Based) Systems Engineering, Business Process (Re) Engineering, Project Management (PM), Business Process Management (BPM) and Simulation Modelling (SIMMOD).

A *ProST Framework* is a systematic modelling approach to conduct ProST studies, made of: (1) A *Knowledge Architecture*; (2) An *Implementation Method*, covering the product´s development and the organisation management life cycle processes; (3) A *Supporting Environment*.

1.4 The Knowledge Architecture

To start with, a comprehensive definition of BPMM is taken, as proposed by Van Looy et. al. (2011). The comprehensive definitions of BPMM formulated by these authors consists of the aggregation of the generic definitions of BP, BPM and BPO and their structuring as layered components to form an encompassing generic research area – traditionally designated in the literature as BPMM. This work builds upon this definition of BPMM and extends it with the addition of some other components, originated from other disciplines closely related with the conduction of advanced studies on complex business processes problems.

The additional disciplines included in the holistic view of BPMM presented in this work are the disciplines of SYSENG, PM and SIMMOD. The BPMM research area is portrayed henceforth as an aggregate of all these independent techniques, with their complementary and overlapping aspects, i.e. a holistic view, based on a common element (reference model). The use of the reference model is a cornerstone of the approach and allows the joint application of the different disciplines and the exploration of their complementary benefits, as well as the overcome of their individual gaps.

Systems Engineering and Project Management are considered 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. Business Process Management and Simulation Modelling are also considered as two complementary techniques that can be integrated and used for the description of a unified organisation management process model and its evolution along its life cycle, whose processes keep a direct matching with those of the product life cycle development.

1.4.1 Descriptive View

The complete knowledge domain is formed by a layered hierarchical structure, starting from the most specific to the most generic component, each one depicting a part of the knowledge base and extending its predecessor, until they form the complete image of the scope of the ProST research area. Figure 1 below depicts the elements and their funnel structure representative of the complete knowledge base involved in ProST.

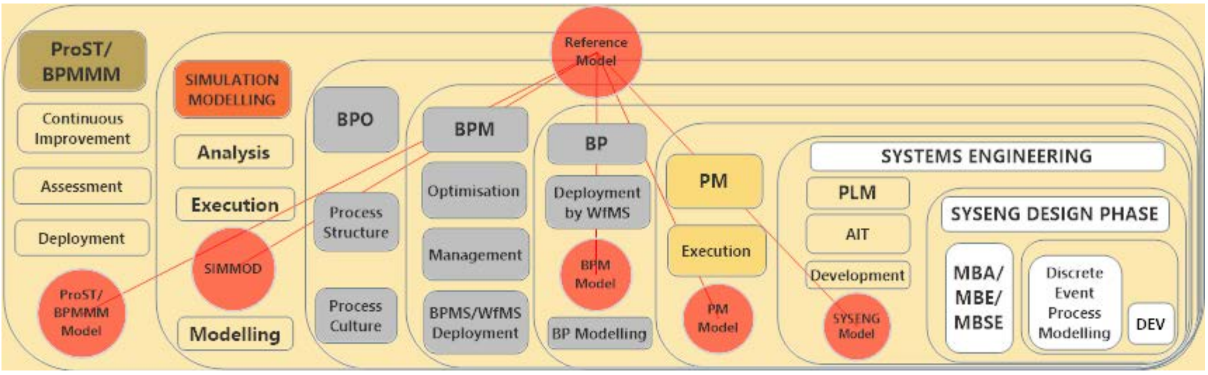

Figure 1 – **The Descriptive View of the Knowledge Architecture in ProST**

The descriptive view shown in Figure 1 conveys not only the notion of hierarchy – from the simplest, most specific, to the most general or complex element - but also a precedence in the way one should progress in the understanding and application of the various techniques presented in the literature.

Another relevant aspect of the graphical representation in Figure 1 is that the “life cycle process” of the various modelling techniques being described, that is the evolution of the models along their life cycle, is represented by the vertical display of some concepts, showing the phases of design, model building, deployment, execution and analysis existing in each of them.

1.4.2 **Process View**

Figure 2 elaborates on this idea of unified process modelling and shows the structured modelling procedure (process view) proposed for their simultaneous application to problem solving in a ProST study. In Figure 2 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).

The disciplines of Systems Engineering, Project Management, Business Process Management and Simulation Modelling are represented as complementary techniques that can be gradually applied for the description and the evolution of the unified product engineering and the organisation management models along their complete life cycles. They are disposed in layers, meaning that they present some precedence while they are being built, although iterations is the main drive of the whole development process. All process models make use of the same reference model and they evolve gradually, making use of a systematic approach for the development of the progressively detailed hierarchical layers by means of repeated iterations for model evolution throughout its life cycle.

The upper and lower parts of the picture show the complete product lifecycle of complex products under development by an enterprise. 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 design and management of the project, the complete organisation management process modelling with additional operations. These last ones takes also in account the interfaces to third party support (supply chain and maintenance). One should think of this modelling approach as the orchestration of different services, each one related to a specific model view, corresponding to the type of technique involved in the complete real system life cycle development process.

Another important point to be remarked here is that the multi-layered process model with its different types of representations is created based on a reference model that is produced right from the start of the modelling procedure and that is used consistently across all levels associated with the various disciplines. This multi-layered process model can be created making use of a round-trip procedure. The bottom up pathway starts with the systems engineering macro process map and the top down approach starts with an overview of the organisation´s management processes.

The multi-layered process structure and modelling methodology mirrors that described in De Backer and Nuffel (2011)[2] for multi abstraction layered process modelling, with the difference that the layers here are associated with specific disciplines, which impacts on the choice of the model representation technique used in it. In other words, it is not just the fine-grading of the overall process model decomposition, which is being considered, but the discipline associated with each layer, ranging from the engineering view in the innermost layer, passing by the project management and the business process management views in the intermediary layers and finally reaching the simulation view in the outermost layer.

The shadowed areas associated with the disciplines 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 design and 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 business process managers and the simulation modellers.

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2 Manu De Backer, Dieter Van Nuffel. Multi-abstraction layered business process modelling. Computers in Industry. Vol 63, Issue 2, pp. 131-147.

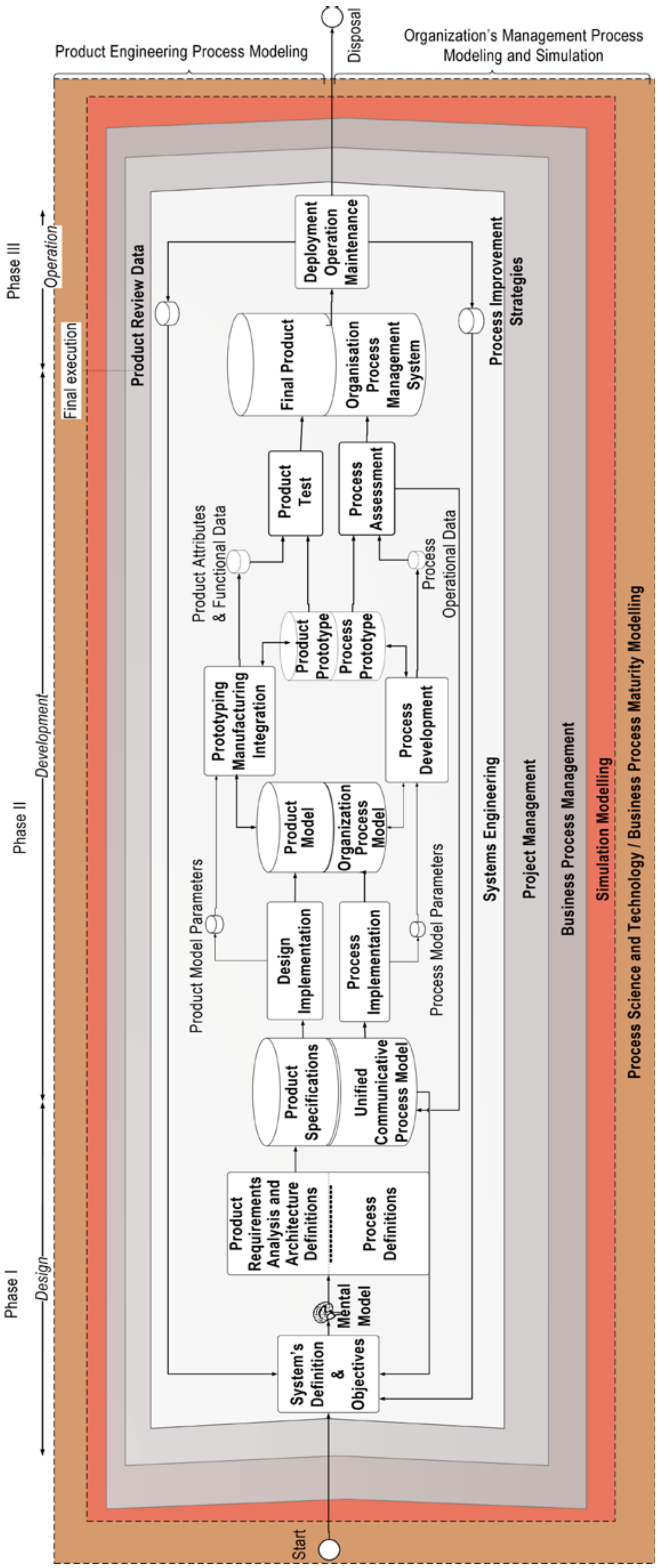

Figure 2 – The Process View of the Knowledge Structure in ProST

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. Successive iterations or round trips need to be performed, in order to reach the necessary degree of refinement and consistence of the reference model to be created and used by all interested parties.

The complete product lifecycle comprises the product development process and its corresponding organisation management process, both seen as parts of the enterprise business process, which comprises the phases of design, development and operation. These phases are further decomposed into the sub-phases of model building, model implementation, experimentation and analysis, and assessment. Successive iterations can be performed for the continuous improvement of the processes. This is the object of the so called implementation method to be described below.

1.5 The Implementation Method

The *Implementation Method* or *Unified Life Cycle Process Modelling* is created by the aggregation of the different process views originated from the disciplines or dimensions of (Model Based) Systems Engineering (Hardware or Software), Project Management, Business Process Management, Simulation Modelling and their applications to the System Concurrent Engineering processes.

Figure 3 shows *ProST´s Implementation Method,* named *Unified Life Cycle Process Modelling*, consisting in a method for application of the ProST Framework. The rounded rectangles are the transformation processes and the cylinders stand for the model knowledge content (model representation artefacts – various formats) at a specific point in time.

The *Unified Process Model Life Cycle* proposed by the approach includes all managerial procedures related with the organization´s management processes, as well as the core engineering activities related with the product´s development process, both seen as parts of the overall enterprise business process or *System´s Unified Process Life Cycle*.

The term *Conceptual Model* used in ProST is a concept associated with the mental logical content of the system's operation taking into account the study's objectives, i.e. the workflow of processes of the unified process life cycle. It can be defined as the extraction of the basic knowledge (logical) content about the product development process life cycle and the organisation management process life cycle executed in support of this development, be it a piece of hardware or software. This use of the term *Conceptual Model* is consistent with the one presented in Nance's conical methodology (Nance, 1994), who differentiates between the *Conceptual (Mental) Model* and the *Communicative Model*, this last concept used to designate any model representation in a communicative format.

The building of the *Conceptual Model* is done simultaneously with the creation of the *Reference Model* of the system. The Reference Model is created in two steps, by representing the logical content using two types of different diagramming techniques, namely IDEF0 and ULMD, as detailed in chapter 4. The creation and the use of the *Reference Model* is a corner stone of the methodology, in order to assure the cross consistence of the other specialised models to be created later using several kinds of notations and the integration and unification of the results they will produce. Each kind of model targets a different knowledge area and the benefits their use will bring to the model building and joint analysis of the problem.

The *Reference Model* summarises the results of the specification and representation of the essential aspects of all organisation managerial procedures, named "organization's management process", with the core product engineering activities, named "product development life cycle process", which together constitute the system´s unified life cycle process model. The *Conceptual and Reference Model Building* phase also defines the system's boundaries, the model control parameters and eventual additional premises and restraints, that is, the overall scope and objectives of the study.

The modelling of the *Organisation Management Process* is the identification of the essential aspects of the *architecture* and *operation* of the organisation to produce the product. By *architecture*, one refers to the organisational structure, the types of agents or participants, their interactions, the kind of resources used by them, as well as the overall system´s data regarding these entities and resources. The *operation* refers to the process executed by the organisation and its participants and their related model data.

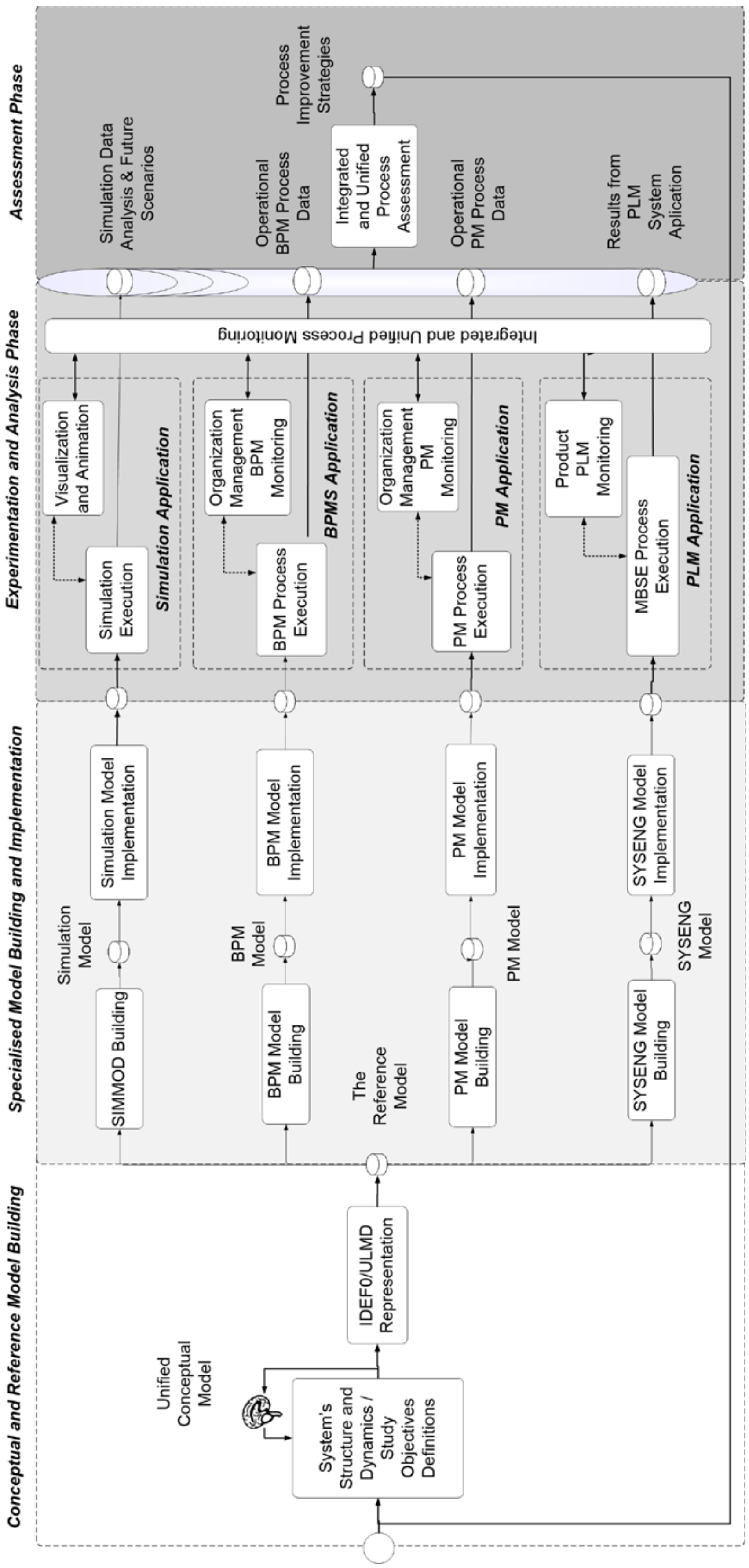

Figure 3 - The Unified Lifecycle Process Modelling (ProST´s Implementation Method)

The descriptions of the organisation management process and that of the product development process can be made in an iterative way, performed as if one would be drilling a tunnel starting from both extremities. The description of the organisation management process is performed in a top down way, starting with the system´s macro process and proceeding with its hierarchical decomposition, so that at the lowest level reached by the modelling procedure stay the core engineering activities related with the product development process. The description of the product development process is performed in a bottom up way, starting with the core engineering activities related with product development and progressing to include the management operations related with project management and business management processes.

The second phase is denominated *Specialised Model Building and Implementation*, divided into several branches, each one addressing a specialised technique and made of two macro activities (called *Specialised Model Building* and *Specialised Model Implementation)*. Each macro activity is depicted in Figure 3 with a single activity in its lowest level of decomposition, but it can be further hierarchically decomposed, if necessary.

This modelling phase produces a multi-layered description, in which the techniques used to build the model layers are disposed in the following order, from the outermost to the innermost: Simulation Modelling-Business Process Management-Project Management-Systems Engineering. The representations used in each of the modelling steps are those traditionally used by the respective discipline that is driving the correspondent modelling stage. Chapter 4 of this technical report makes a more detailed explanation and shows an example of the application of this modelling procedure to a case study of the commercial services provided by LIT (Laboratory for Integration and Testing) at INPE (National Space Research Institute).

The *Specialised Model Building* consists on the transformation of the Reference Model described in ULMD into different formats, such as Business Process Diagrams (BPD) and Simulation Modelling graphical representation formats, depending on the specific simulation system one is targeting for model implementation. Each kind of model targets a different knowledge area and the benefits they bring to the joint model building and analysis of the problem.

The *Specialised Model Building* step is performed with the support of model building tools, such as BPMS systems for BPMN modelling, and simulation systems´ GUI interfaces for the model graphical description in a specific representation format. Nevertheless, this phase of model transcription is the most difficult and time consuming to accomplish, since the modeller has himself to assure the consistence and equivalence of the models created in the different environments, if he does not have any automated support from these environments to verify this procedure.

In the second step of the *Specialised Model Building and Implementation* phase, the *Specialised Model Implementation*, one makes use of all functionalities of the BPMS and other supporting tools of the environments for model completion. Usually, these functionalities are provided as extension of the modelling mechanisms existing in the existing supporting environments for model building mentioned before. These additional functionalities allow the full implementation of the applications required, for example in case of the simulators and the BPMS tools used in support of the approach.

The various process models undergo a third phase of transformation, the *Experimentation and Analysis Phase*, with the addition of the project of experiment and the execution of the model's applications, which will be executed according to different threads. In some case studies these threads do not make use of all possible views mentioned in ProST´s definition, they may just contemplate two of these views. For example, a first one for process enactment in production mode, with business process functionalities, and a second one for simulation execution, with embedded functionalities comprising the design of experiments, the building of scenarios, the analysis and results displaying capabilities.

The joint application of the various modelling and analysis tools to the same unified life cycle process model aims at achieving the complementary benefits from each of the techniques involved. The BPMS systems allows the creation of applications to support the real system operation, the monitoring and the management of the process. The benefits from the use of advanced simulation tools come from the use of pre-built mechanisms, which allow the creation of projects of experiments and the analysis of different execution scenarios.

Data collected during real system's operation can be used as input data for simulation model execution, making validation easier and future scenarios projections more reliable. The important issue to keep in mind is the verification of the implementation of the different specialised models, to keep the consistency and validity regarding the unified system's specifications along the whole process.

The *Assessment Phase* carries out, in an integrated way according to the diverse views and disciplines, the evaluation of the results from the different threads of execution, for instance the BPM and simulation threads, and settles process model improvement strategies.

The implementation of the model improvement strategies and the introduction of changes to the system might make it necessary to restart the modelling procedure and to execute the complete model life cycle as many times as necessary.

1.6 The Supporting Environment

The integrated and unified techniques involved in a ProST study need support from computer aided hardware and software engineering tools, in order to assure consistency and compatibility across different model formats and the complete interoperability of its component tools. These tools range from computer aided design and manufacturing systems, software engineering environments, communication interfaces, verification mechanisms, and applications to perform automatic model transcriptions and implementations.

The use of the diverse disciplines with their different modelling capabilities and representation formats allow for a more thorough study and analysis covering the entire model life cycle, from model building, experimentation, analysis and continuous improvement of the processes. The study and analysis of the model is conducted in close link with the real system (the enterprise) operation. The real system operation might be orchestrated by some BPMS applications, for example, and the data generated by these applications can be used as the source for model input data, definition of control parameters and the validation of the simulation and of other project management supporting tools.

1.7 The Meaning and the Scope of the Disciplines used in ProST/BPMMM

SYSENG – Systems Engineering

Systems Engineering: The systems engineering´s modelling activities can be looked at making use of one of two different perspectives. The first one is named process view, which consists of the representation of the network of activities (process map) showing the core processes (with its inputs, outputs, control, and resources), as they are executed by the engineering team during the design, development, carrying out of AIT activities, and management of the production process throughout its entire life cycle. The second way to look at the engineering activities is named product descriptive view and it consists of the use of modelling techniques, such as Model Based Architecture, Model Based Engineering (MBE), and Model Based Systems Engineering (MBSE), to generate the artefacts related with the product design and specification. These two modelling perspectives are interconnected throughout the entire product´s engineering life cycle, but they need to be well differentiated and understood for the creation of the appropriate process model representation (process view) and of the multiple product design and specification artefacts typical of MBE and MBSE procedures.

PM – Project Management

Project Management is seen as application of the project management techniques and tools to extend the engineering model with the necessary activities related with the management of the product development throughout the complete life cycle. It represents the point of view of the project manager and the techniques and tools used to work out this type of model are those referred to in the specialised literature on the subject, generally designated as Project Management Body of Knowledge (PMBoK, 2012).

BPM – Business Process Management

Business Process Management (BPM): as a discipline, the view on BPM stresses the fact that it spans the whole life cycle of the models built using the technique, i.e., BPM is defined as an structured and systematic approach to the analysis, improvement, control, and management of processes to increase the quality of products and services *throughout their entire life cycle*. From a holistic perspective, BPM combines Total Quality Management (TQM), which is incremental, evolutionary and continuous in nature, and (Business) Process Re-Engineering (BPR), which is radical, revolutionary, and regarded as a one-time undertaking suitable in most circumstances for performance improvement. (Hung, R. Y., 2006).

SIMMOD – Simulation Modelling

Simulation Modelling follows the traditional definition of systems modelling for simulation purposes, with the remark that the model under consideration is a representation of an aggregate of the product development processes with those of the organisation management processes throughout their entire life cycles.

ProST/BPMMM – Process Science and Technology

Process Science and Technology / Business Process Maturity *Meta*Modelling are defined in this work as the aggregation and unification of these four models/modelling techniques as they are studied and applied by the disciplines above mentioned. It consists of a transdisciplinary process view describing the structure and evolution of the enterprise (product plus organization) business processes, comprising both the product development and the organisation management processes throughout their entire life cycles.

1.8 Analysis of Cross Effects of the Simultaneous Use of Disciplines

The disciplines considered for carrying out a complete ProST case study are, as stated above: (Model Based) Systems Engineering, Project Management, Business Process Management and Simulation Modelling. For each of these disciplines a team of specialists can be chosen to deal with that specific knowledge domain for application in the complete study. The interaction among these teams with their different views is the mechanism that drives the evolution of the reference model in successive iterations until it reaches the degree of confidence desired.

The main assumption is that there will be benefits from the simultaneous and integrated application of the diverse techniques to find a solution to the problem, making use of a common basis for system´s model building and analysis, represented by the reference model. The idea is to take advantage from the joint application of all or some of these modelling and analysis techniques in support of the complete life cycle of complex products´ and services´ development processes, in order to benefit from their complementariness, regarding the aspects for which each one of them is especially stronger.

The techniques are seen as complementary since they have their modelling and analysis capabilities focussed on different views of the system´s architecture and behaviour, whilst sharing a common basis for the representation of the most important aspect of the system´s model logic (knowledge content), i.e., the specific components´ workflow of processes or the entire system´s process map.

The knowledge about the model extends far beyond the representation of the process reference model and of its evolution throughout the entire model life cycle. The diverse techniques can be used to progress separately with the system´s modelling and analysis in each one of the individual disciplines, making use of their best potentialities. To assure that the results are amenable for comparison, a reference model taking into account a specified decomposition level is kept as a baseline for comparison across all disciplines.

The advantages of the joint application of the disciplines derive exactly from the fact that their model results can be compared both locally (at each activity), as well as globally (taking into account the partial workflow of processes or entire process map), since they have a common basis (the reference model) to assure this type of comparison.

The expectation is that the joint application of the diverse techniques will produce better modelling and analysis capabilities for the study of the system than their isolated use would provide.

The different modelling views will also require a deeper reflection about the structure and dynamics of the system, leading to a better modelling and understanding of its operation, especially in cases one is dealing with systems that contain very complex process specifications.

Table 1 presents a matrix relating the name of the disciplines, as well as their expected cross effects (benefits and drawbacks) categorised by types, originated from the interaction of the teams who apply them in ProST/BPMMM case studies.

Some of these interactions are in no way new to their communities of users and/or researchers, who have published on them in the literature of the area. An example is the Type A cross effect – the natural interplay among engineers and project managers - or the Type C trend – the interplay among BPM and SIMMOD modellers - which enhance the BPM applications in complex business models by allowing the analysis using simulation for achieving better performance, model optimisation and/or continuous improvement. Nevertheless, the joint application of the disciplines in ProST/BPMMM studies presents some particularities, due to their roles in the unified process modelling.

TABLE 1 – DISCIPLINES AND THE TYPES OF CROSS EFFECTS YIELDED BY THEIR JOINT APPLICATION IN ProST

ALL-IN-ONE	BPMMM	BPMMM	BPMMM	BPMMM	BPMMM	BPMMM	BPMMM	ALL-IN-ONE
ProST	SIMMOD	C	F	E	F	C	SIMMOD	ProST
ProST	C	BPM	B	D	B	BPM	C	ProST
ProST	F	B	PM	A	PM	B	F	PorST
ProST	E	D	A	SYSENG	A	D	E	ProST
ProST	F	B	PM	A	PM	B	F	ProST
ProST	C	BPM	B	D	B	BPM	C	ProST
ProST	SIMMOD	C	F	E	F	C	SIMMOD	ProST
ALL-IN-ONE	BPMMM	BPMMM	BPMMM	BPMMM	BPMMM	BPMMM	BPMMM	ALL-IN-ONE

In the following only the main cross effects of the simultaneous application of some of these disciplines are discussed. The remarks are directed particularly towards those aspects that are considered to be derived from the special way they are used in ProST. Whenever applicable, remarks are also made on the existing results from equivalent simultaneous applications of these disciplines in the literature of the BPMM area.

PM X BPM – Type D

The joint application of PM and BPM will complement the benefits from the isolated application of the PM technique, because BPM applications can be built to automate and help the management process. This type of effect appears frequently in combination with the Type F – BPM X SIMMOD – since many BPMS systems already implement simulation functionalities to experiment with the models (Kienbaum et. al., 2013).

PM X SIMMOD – Type E

The joint application of PM and SIMMOD improves the assessment of results by a combination of the normal procedures used in PM with the addition of the simulation technique, with the aim of enhancing the understanding of the factors and strategies which significantly affect project execution (Travassos, P.R.N. and Kienbaum, G. S., 2009).

The analysis using simulation of multi-projects, when these multi-projects are made by several single projects of identical nature, will produce a better understanding of the characteristic of the single project or process. This allows the improvement of its descriptive process and of its resources allocation, as well as the reduction of the lifecycle times (Augusto Neto, A., Kienbaum, G. S., Guimarães, L.N.F., 2007).

The analysis and optimization of the execution time in a project management study can be obtained by the dissociation of the time delay incurred by the entities staying in the queues in front of each activity from the proper duration of these activities, what is treated as an aggregated estimation in the project management current studies, based on conservative estimative. The reduction of these waiting times by increasing the number of resources allocated, while keeping control of their relative costs, shall produce on its own a major gain of productivity in the execution of single projects.

The gain in productivity will be even greater when one considers the scaling factor, existing in systems in which real multi-projects or multi-processes need to be carried out, with their start time shifted only by a certain delay and their processes being executed in parallel, by big work teams divided in classes by their specialities.

The analysis currently performed in project management studies has no capabilities for experimentation of alternative forms of the modelling of their processes, for the animation of the passage of time, neither for the testing of the dynamical resources allocation, in the case of multi-projects. These are clear deficiencies of these systems, when they are compared to the existing simulation systems. These mechanisms will be an essential part of the hybrid PM and SIMMOD environment proposed.

SIMMOD will allow a better understanding of the dynamics of the process in PM studies, especially concerning the sequencing of activities and the cooperation among the entities and resources, as well as the building of the different execution scenarios for experimentation and analysis of results. Statistics will be analised, such as the waiting time in the queues in front of the activities, and the parameters can be changed, for example the allocation of the resources, which lead to the final recommendations regarding the way to improve systems operation.

SIMMOD studies performed with this hybrid environment will keep track of the complete map of dependences and sequencing of all activities, as well as of the resources allocated in the model. Experimentation and simulation model assessment will be improved and productivity will be enhanced in some segments or in the overall project´s lifecycle, through the optimization of resources allocation and the minimization of completion times, subject to costs constraints.

The above result can be achieved by creating pre-built mechanisms that are independent from the specific model under consideration, allowing model assessment for project enhanced productivity to become part of the normal objectives of simulation systems. These model independent mechanisms may be developed by using existing functionalities, or may be newly created if these functionalities are still not available, in an integrated PM, BPM and Simulation environment (Kienbaum, G. S.; 2008).

BPM X SIMMOD – Type F

The applications built using BPM support the implementation, the execution, the monitoring, the management, the assessment and the automation of the processes, whereas SIMMOD improves the performance analysis, by means of defining alternative scenarios for system´s operation, with the aim of improving the understanding of the factors and strategies which affect process execution.

The data generated by the BPMS application might be used to feed the simulation model of SIMMOD with input data about the real execution of the process, in substitution of the any database with historical data, what improves the quality of the data input to the simulation system. The BPMS tools have the required functionalities for this purpose, providing facilities for collecting and graphically displaying statistics about the status of the entities flowing in the system, as well as the searching mechanisms for consultation of the attributes of any resources and processes in the system.

ProST/BPMMM – All-in-One

The different modelling views require a deeper reflection about the structure and dynamics of the system, leading to a better modelling and understanding of its operation, especially in cases one is dealing with complex systems process definitions. The benefits come from their simultaneous and integrated application, making use of a common basis for modelling and analysing the system, represented by the reference model (Travassos et. al., 2006; Travassos et al., 2007).

The animation mechanisms and the displays with execution data provided by the different tools from different disciplines will either complement or validate each other, and together they will produce a detailed overview of the status of the process execution. The monitoring and assessment encompasses qualitative and quantitative aspects, such as quantity of orders in the system and their situation (ongoing, delayed or closed) and all sort of statistics about each activity or the process as a whole, such as number of orders in the queue in front, execution time, etc.

One difficulty faced by the modellers trying to use the existing software tools for conducting ProST case studies is their lack of interoperability, since they do not provide automatic mechanisms for the transcription of the models, nor their cross consistence checking during modelling. They also present no mechanism for data communication among them during model execution, which requires manual work for the creation of interfaces for their use by the modeller himself.

The verification of the models is an arduous and error prone process, pointing to the need of a full integration of these tools in the future. This interoperability of tools is under construction, for some them already in the market, for example those used by the author in the case study shown in chapter 4. One can see, nevertheless, that their use of XPDL representation for model import/export facilities is still not fully operational, neither regarding model portability nor the exchange of execution data, as tested and evaluated by the author.

1.9 Conclusions

The expected benefits from the application of the ProST approach to conduct advanced studies on BPMM applied to systems concurrent engineering are:

- Different and complementary views of the process model are created, for example the BPMN model in BPMS systems, showing the workflow of processes, together with its implementation using simulation tools, allowing the analysis of the dynamic behaviour and of the interaction between the system's entities and their use of resources for the accomplishment of the processes.

- The different modelling views require a deeper reflection about the structure and dynamics of the system, leading to a better modelling and understanding of its operation, especially in cases one is dealing with complex system´s process definitions;
- The use of a multifaceted modelling aids to a better visualization and communication of the model among the participants, as well as for the experimentation, analysis, assessment and the documentation of the model;
- The essentials aspects of the model are identified in the beginning of the modelling process, but these aspects need (and ought to) be enhanced during the next steps performed by the analyst, while he implements the models in the business process management and simulation systems.

As a consequence and a synthesis of the above mentioned, a better understanding of the problem may be achieved, leading to a better quality of the models developed and bringing benefits to the complete model development life cycle.

CHAPTER 2 − PROST! A TRANSDISCIPLINARY VIEW ON BUSINESS PROCESS MATURITY MODELS

Abstract

The general research area of Business Process Maturity Models (BPMM) and their specific fields, namely Business Process (BP) Modelling, Business Process Management (BPM) and Business Process Orientation (BPO), are characterised by the existence of a plethora of concepts, methods, techniques and tools to support the design, enactment, management and analysis of the core operational business processes of organisations. There have been many efforts to survey and structure the knowledge base from the main research area and its components and some of these works, considered as the most relevant and/or recently published, have been used as sources for the current review. Nevertheless, the majority of these works tackles the "what?" question, that is, what is the scope of the area. The "how?" question, i.e., how BPMM can be applied in a systematic way as a mature, replicable methodology, seems to be still widely open for contributions. The objective of this research work is to review the state-of-art in BPMM and to propose a systematic and innovative approach based on a transdisciplinary view for (re-)structuring the BPMM knowledge base, denominated a Framework for Process Science and Technology (ProST), which aims at the development of a mature, replicable methodology for conducting advanced studies in BPMM. The approach is envisioned for generic applications, but it is analysed in this work regarding particularly its potentialities for applications in the areas of Systems Engineering Project Management and Process-Oriented Organisation Management.

Keywords: Business Process, Business Process Modelling, Business Process Management, Business Process Orientation, Business Process Maturity Model/ling, Framework for Process Science and Technology.

2.1 Introduction

Business Process (BP) modelling, Business Process Management (BPM) and (Business) Process Orientation (PO) are key terms referring to closely related research fields, usually seen as components of a wider research area, designated as Business Process Maturity Model (BPMM[1]) (Van Looy et al., 2011).

The body of knowledge on BPMM is made not only of pieces of disjoint information originated in the fields of BP, BPM and PO, but it also appears scattered in the literature in a variety of other closely related disciplines, such as Systems Engineering (SYSENG), Project Management (PM) and Simulation Modelling (SIMMOD).

The main research area of BPMM and its correlated branches, as well as the other disciplines above mentioned, have their origin based on a common building block, namely the concept of discrete event (DEV) process. The DEV process is the common bond that gives rise to all other concepts, methods and tools used to study the modelling, analysis and enactment of processes executed by enterprises when performing their engineering and managerial operations, generically designated as business processes. It is nevertheless frequently treated as the "missing link", i.e., overlooked as such both by researchers and practitioners of these individual disciplines, because traditionally they have been developed and are usually applied in an autonomous way, without any effort to identify their commonalities, overlapping aspects and/or complementariness.

A myriad of original articles in the fields of BP modelling, BPM and BPO and on their main encompassing research area of BPMM have been written (list of references). Several authors have proposed a variety of Business Process Maturity Models (BPMMs), which describe the journey of the enterprises towards gradually improving their degree of process orientation and effective implementation, i.e., maturity and capability (list of references). Much has also be written about process classification frameworks, which describe attempts to create reference model for use by different types of enterprises for structuring and guiding the design of their business processes, such as the Zachman´s Framework (Zachman, J. A., 1987), APQC Framework and the MIT Process Handbook (MIT, 2003).

There have been also some literature surveys conducted in the area, which summarise the definitions of the concepts, of the implementation methods and of the positive (and sometimes negative) aspects of their use in the

[1] The acronym Business Process Maturity Models (BPMM) is used by these authors to designate both the artefacts created (the models), as well as the procedure executed for their development along the entire life cycle (the modelling process).

modelling, the management of business processes and the structuring of organisations according to a process-oriented view (Kohlbacher, M. 2010).

These literature surveys, nevertheless, seem not to fill two essential gaps perceived by the author. On the one hand, they usually cover the BPMM knowledge domain (the scope) with no previously organised structuring approach in mind, and they end up by reproducing an extensive list of encapsulated and non-concatenated topics. This fact raises a barrier to the users from different backgrounds, who need to make sense from this information chaos, in order to be able to interpret, organise and put in practice the techniques for carrying out advanced BPMM studies in a comprehensive way. On the other hand, little has been done regarding an attempt to describe BPMM as a mature discipline, one with a systematic approach on how to conduct the process modelling (evolve the models) throughout the entire model life cycle, in order to align the organisation management (managerial) with the product development (engineering) processes.

Comprehensive definitions of BPMM, as well as of maturity and capability, are still missing, according to Van Loy et al. (2001), who proposed their own. This work builds upon the concepts formulated by these authors – with its definition of BPMM as an aggregation of the generic definitions of BP, BPM and BPO – and extends it with the addition of some other components, originated from other disciplines closely related with the conduction of advanced BPMM studies. The additional disciplines included in the holistic view of BPMM presented in this work are disciplines of SYSENG, PM and SIMMOD. The BPMM research area is portrayed as an aggregate of complementary techniques with some overlapping aspects and the proposed approach makes use of a common basis or reference model to allow their joint application and the exploration of their complementary benefits, as well as avoiding their individual gaps.

The objective of the work is to contribute for a better understanding of the BPMM "what?", "how?" and "with which resources" questions, respectively its scope, its methodology and its techniques and supporting tools. The elements originated from various disciplines that deal with complex discreet event processes, seen as BPMM components, are defined and organised in the form of a multidiscipline, making use of a holistic view and a systematic modelling approach, in order to contribute to their unification and integration and their effective application in advanced BPMM studies.

The transdisciplinary view, systematic process modelling approach and the supporting tools to conduct BPMM studies described in this work are all together designated Framework for Process Science and Technology (ProST Framework). The ProST Framework consists of an organised knowledge base (**Knowledge Architecture**), a method to evolve the models along their life cycle (**Implementation Method**) and the methodology´s supporting tools (**Supporting Environment**). The ultimate goal of the ProST Framework is to structure the knowledge domain of BPMM and their components, in order to obtain the best benefits from the joint application of the various existing techniques mentioned and to avoid their individual gaps.

The rest of this article is organised as follows: Section 2 presents a survey of the BPMM Literature; Section 3 describes the ProST approach for BPMM; Section 4 the unified process modelling methodology; and Section 5 an analysis and assessment of results, regarding the potential for application of the ProST Framework in Systems (Concurrent) Engineering. Finally, Section 6 presents the results obtained so far and the guidelines for future developments of the research.

2.2 A Literature Survey on BPMM

The complete list with the definitions of the main concepts used in the ProST approach is introduced in the following, starting from the basic concepts of DEV and DEVP and progressing through the phases of BP design, modelling, engineering and management. The transdisciplinary view on BPMM starts with the most basic of their component elements, the Discrete Event (DEV) Process (DEVP) and creates upstream and downstream extensions of the definition of BPMM formulated by Van Looy et al. (2011), based on the concepts BP, BPM and BPO. The works adds some elements to their original set of concepts, such as DEV, DEVP, Product Lifecycle Management (PLM), SYSENG, Model Based Systems Engineering (MBSE) and PM. Finally, SIMMOD is included to form the complete knowledge domain of the ProST holistic view on BPMM as defined here.

Many of these concepts are not univocally formulated in the literature, as stated in Van Looy et al. (2011). The individual generic definitions of the concepts BP, BPM and BPO reproduced in this work were in fact extracted from this reference. The others might contain some degree of dissention and/or overlapping, depending on how they are used in different contexts by the different authors, who created them (for example in manufacturing, when compared with information exchange). The individual source of reference of each concept defined is carefully stated together with its definitions.

2.2.1 The Fundamental Concepts

Discrete Event (DEV) refers to changes in the states of a Discrete Event System (DES) that happen at specific points in time. *Discrete event process (DEVP) modelling* refer to the techniques used for modelling and analysing sequences of DEVs performed by the agents (participants) of a DES, especially for processes which can be modelled as networks of queues and activities. These processes are found in a large range of applications, generally related with industrial production and the services executed for organisation management purposes.

"*Business Process(BP)* is (1) a repeatable set of coherent activities, (2) triggered by a business event and (3) performed by people and/or machines, (4) within or among organisations, (5) for jointly realising business goals and (6) in favour of internal and/or external customers" (Van Looy et al., 2011). One should notice that the focus of this BP definition is on two components: *modelling* (i.e. predefining processes in textual or graphical descriptions) and *deployment* (i.e. performing or running processes accordingly).

In addition to the definitions, BPs are categorised according to their (1) functionality and (2) structure. First, the functional types are:

- core, operational, primary or value-adding processes: concerning the production and delivery of products or services, contributing to value creation and directly related to external customers;
- support or value-enabling processes: for supporting the core processes and facilitating organisational performance, characterised by internal customers, for instance, processes in information management or human resources;
- management processes: linked to the strategy and policy setting, serving the overall planning, and controlling all activities in the organisation.

(BP) Reference Model (RM) is a generic representation of a company's BP. A generic reference model is usually developed for individual industrial sectors. Companies within each sector can then create their standard process models by adapting the generic reference model to their own specificities. By means of a reference model, a single product-development-vision can be attained, bringing all the stakeholders participating in a specific development to the same level of knowledge (Rozenfeld, H. et al., 2009).

Systems (Concurrent) Engineering or simply *Systems Engineering (SYSENG)* is an interdisciplinary approach to problem solving. SYSENG spans the whole system lifecycle from defining customer needs, capturing required functionality, undertaking design synthesis, system build and system validation while considering the complete problem domain. The aim is to produce a system that satisfies defined technical requirements within cost and timeframe constraints. Other important issues such as customer training, product maintenance/upgrade and product disposal are an integral part of the overall systems concurrent engineering process. Figure 1 shows the product lifecycle in SYSENG.

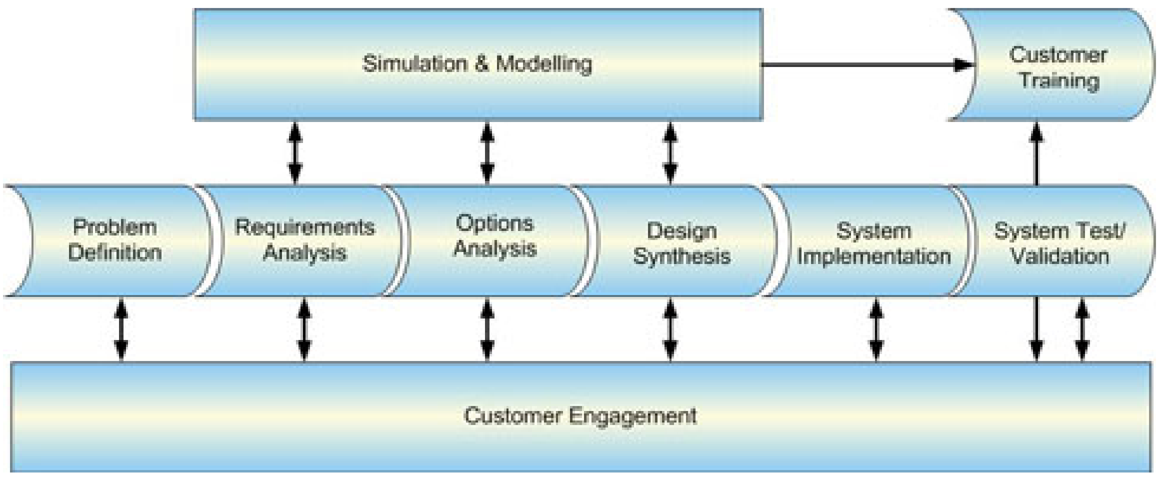

Figure 1: The Systems Engineering Lifecycle (Source: Loughborough´s Systems Engineering Webpage, 2012)

Product Life Cycle Management (PLM) is defined as a systematic concept for the integrated management of all product related information and processes through the entire lifecycle, from the initial idea to end-of-life. The aim of this integration is to overcome the existing organisational barriers and to streamline the value creation chain. The IT solution to support PLM results from the integration between Enterprise Resource Planning (ERP), Product Data Management (PDM) and other related systems, such as Computer Aided Design (CAD) and Costumer Relationship Management (CRM). (Schuh, G. et al., 2008).

"*Model Based Systems Engineering (MBSE)* is the formalized application of modelling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases." (INCOSE, 2011). More pragmatically, "MBSE is translating physics, functional and economics/social based (project) data into interrelated model representations" (Stoewer, H., 2012).

Business Process Management (BPM) is a structured and systematic approach to the analysis, improvement, control, and management of processes to increase the quality of products and services. From a holistic perspective, BPM combines Total Quality Management (TQM), which is incremental, evolutionary and continuous in nature, and (Business) Process Re-Engineering (BPR), which is radical, revolutionary, and regarded as a one-time undertaking suitable in most circumstances for performance improvement. (Hung, R. Y., 2006).

(Business) Process Orientation (PO) can be interpreted as the organisational effort required making business processes the platform for organisational structure and strategic planning. A process-oriented organisation is also often referred to as "horizontal organisation", "process-centered organisation", "process enterprise", "process-focused organisation" or simply "process organisation". A process-oriented organisation comprehensively applies the concept of BPM. (Kohlbacher, M., Reijers, H. A. 2013; Willaert, P. et. al., 2007).

A construct for Business Process Orientation is a set of attributes a company need to possess in order to be considered a process-oriented firm. PO is a construct which consists of several dimensions. Following the line of authors who did extensive research in the field of PO, Kohlbacher and Reijers (2013) identify the following 10 dimensions as components of a PO construct:

- process design and documentation
- managerial support
- the existence of process owners
- applying the concept of process performance measurement.
- information technology
- adaptation of organisational structure to process view
- presentation of appropriate knowledge on process issues (improvement, redesign, and change management)
- establishment of process-oriented Human Resource system
- existence of a formal instance called BPM office coordinating and integrating process projects
- organisational culture such as teamwork, readiness to change, flexibility, and customer orientation.

According to Van Looy et al. (2011), *Business Process Maturity Model/ling* can be defined as a model to assess some performance parameters and/or to guide the introduction of best practice and improvements in organisational process maturity and capability, expressed in lifecycle levels, by taking into account an evolutionary road map. The characteristics under scrutiny include: (1) process modelling, (2) process deployment, (3) process optimisation, (4) process management, (5) the organisational culture and/or (6) the organisational structure.

The six basic components above are grouped by the authors in a funnel structure, starting from the definitions of (1) a BP, which is a subset of (2) BPM, and which in turn is part of (3) BPO. The scope of BPMM thus involves a BP dynamical perspective (process life cycle) and a descriptive perspective (static, hierarchical structure).

The concepts of maturity and capability are relevant in the BPMM terminology. An increase in maturity gradually facilitates an increase in capability by prescribing continuous improvements. On the one hand, maturity indicates the extent to which an organisation has deployed its BPs explicitly and consistently, by taking into account the basic BPMM components. On the other hand, capability comprises the competencies to achieve the targeted process results, and thus relates to the expected performance of a BP. It is used to indicate a growth in an individual basic component, instead of an overall growth. As a result, it is more accurate to refer to 'organisational maturity' with regard to BP, BPM or BPO, and to 'process capability' when pinpointing a single process among the various categories which have to be performed for the completion of the organisation´s operations.

The provision of the assessment and improvement methods in BPMM is of paramount importance. The assessment method supports the practitioner in identifying an organisation's AS-IS level in maturity and capability, and in indicating the gap with the TO-BE situation. The improvement method assists the practitioner with prioritising the necessary improvements, and best practices. It also defines the components to assess among the six listed, whether to assess maturity and/or capability, and which are their predefined levels.

The multitude of Maturity Models illustrates the difficulties among practitioners to choose a model that best fits their organisational strategy and objectives. Examples for the four main tracks in the literature on BPMM are Capability Maturity Model Integration (CMMI) (SEI, 2009), ISO/IEC 15504 (ISO/IEC, 2003, 2008), FAA-iCMM (FAA, 2001) and OMG-BPMM (OMG, 2008).

The *BPMM degree of maturity* achieved by organisations in their journey to process orientation can be assessed using one of the BPMM proposed by different sources, such as the one developed by the Object Management Group (OMG). To make this concept easier to understand in the OMG definition, the model has been limited to four levels of maturity:

- Organisations at level 1 are considered to be able understand the need for continuous improvement and have a general awareness of BPM.
- Organisations at level 2 have moved on from level 1 and are able to identify and address a few individual topics within BPM.
- Organisations at level 3 must have applied substantial elements of BPM as part of their continuous improvement programme.
- Organisations at level 4 have established policies and procedures for continuous improvement through the application of BPM.

Finally, the concept of *Simulation Modelling (SIMMOD)* closes the list of definitions required to build the ProST transdisciplinary view on BPMM proposed in this work. It is described "as the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behaviour of the system and/or evaluating various strategies for the operation of the system" (Shannon, R. E., 1998). The scope of SIMMOD is very encompassing, however, and it extends far beyond its use for BPMM applications, whose role is to act as a valuable tool for model analysis and continuous improvement in general, independently of the scope of the actual area under consideration.

The fact that the list starts with the DEV concept as its atomic element and closes with Simulation Modelling as its most generic component (external boundary) reinforces the idea that the scope of *Business Process Maturity Modelling (BPMM)* comprises the complete body of knowledge on discrete event processes, whose common link is represented by the DEV component. The interchangeable use of the terms BPMM and *Process Science and Technology (ProST*) in this work is deliberate. Both are seen as equivalent, and they are indistinctly used to designate the research area that encompasses the complete model life cycle of complex discrete event systems, regarding the engineering and managerial problems faced by organisations, related with their product development and the management of their business processes.

2.2.2 **Holistic Views in BPMM**

Holistic views in the BPMM literature is not about the description of BPMM as a potential discipline (its scope and methodology), whose objective would be to improve the alignment of the production and management processes of an organisation.

The term Holistic View in the BPMM literature commonly refers to a general process-oriented portray of an organisation describing its internal structure and dynamic (Rosemann, M. & de Bruin, T., 2005; Rosemann et al., 2006; Harmon, P., 2004). The focus is on the artefacts which need to be created (models) to describe the process oriented character of an organisation and to measure the degree of maturity it has already achieved on its road to process orientation excellency.

The designation of holistic view minimally contemplates the use by the organisations of the BPMM concept as the main drive of their process-oriented management philosophy (Willaert et al., 2007). A process-oriented organisation, therefore, applies the techniques and tools designated as BP, BPM and BPO - such as workflow modelling, business process modelling, business process management, business process-oriented constructs of various kinds – to the modelling/structuring of their core processes and they provide mechanisms for assessment and improvement of their degree of business process orientation.

Some authors go even beyond this definition and include other aspects of interest in the model to form this complete process-oriented portray of the organisation, such as the company's environment, strategy, values & beliefs, information technology, and the "resistance to changes" from their employees (Willaert et al., 2007).

2.2.3 **Frameworks for BPMM**

BPMMs have been designed from which organisations gradually benefit in their journey towards excellence. BPMMs present a sequence of maturity levels and a step-by-step roadmap with goals and best practices to reach each consecutive maturity level (Van Looy et al. 2011). However, a BPMM proliferation exists (Sheard 2001, Paulk 2004), which makes it necessary to consider the different BPMM designs. Models like OMG (2008) have labelled their levels by focussing on business process optimisation, e.g. 'initial', 'managed', 'standardised, 'predictable' and 'innovating'. Other BPMMs, like the one of the Rummler-Brache Group (2004), express maturity levels as advancements in business process management, e.g. 'BPM initiation', 'BPM evolution' and 'BPM mastery'. Thirdly, there are BPMMs which prefer to emphasise the degree of business process integration , e.g. McCormack and Johnson's levels of 'ad hoc', 'defined', 'linked' and 'integrated' (McCormack and Johnson 2001). Although their primary focus differs, BPMMs take into account similar capability areas. The latter are collections of related capabilities that need to be assessed and improved in order to reach business (process) excellence.

2.2.4 Process Classification Mechanisms

2.3 ProST/BPMMM: A Transdisciplinary View on BPMM

Process Science and Technology (ProST) is a neologism to designate an innovative and multidisciplinary view on BPMM, consisting of the integration and unification of concepts, methods and tools used in the whole product engineering and organisation management life cycle processes, namely the modelling, simulation, building, execution, automation, management and continuous improvement of complex products and services development processes in general. The denomination appeared for the first time in Silva et al (2011) as an alternative interpretation of the content and meaning of the term *Design and Process Science* (SDPS 2011). It may however be seen as the equivalent of a holistic process modelling view on BPMM, with the main focus of its application directed to the area of *Systems Concurrent Engineering* (INCOSE, 2011).

2.3.1 Definition of Process Science and Technology

Process Science and Technology (ProST) 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, Business Process Management, and Simulation Modelling. The scope of the disciplines underlying ProST, i.e., the meaning of their models/artefacts and of their systematic modelling approaches in regard to their inclusion in the definition of ProST, are briefly described in the following:

- *(Model Based) Systems Engineering*: The systems engineering´s modelling activities consists of the workflow of process (or complete process map) showing the core processes (with its inputs, outputs, control, and resources) performed by the engineering team in their overall efforts to develop the product throughout its entire life cycle. The techniques and tools commonly used to work out these kinds of models include DEV, BP Modelling and Workflow Modelling for the basic description of the process workflow (process view). A holistic view of the product life cycle makes use also of Model Based Systems Engineering (MBSE), Model Based Engineering (MBE), and Product Life Cycle Management (PLM) for product design and the description of the related production management activities.
- *Project Management*: it is seen as application of the project management techniques following a process-oriented view supported by software tools for extending the engineering model with the necessary activities related with the management of the product or service development throughout the complete life cycle. It represents the point of view of the project manager and the techniques and tools used to work out this type of model are those referred to in the specialised literature on the subject, generally designated as Project Management Body of Knowledge (PMBoK, 2012).

- *Business Process Management (BPM)*: as a discipline, the view on BPM stresses the fact that it spans the whole life cycle of the models built using the technique, i.e., BPM is defined as an structured and systematic approach to the analysis, improvement, control, and management of processes to increase the quality of products and services *throughout their entire life cycle*. From a holistic perspective, BPM combines Total Quality Management (TQM), which is incremental, evolutionary and continuous in nature, and (Business) Process Re-Engineering (BPR), which is radical, revolutionary, and regarded as a one-time undertaking suitable in most circumstances for performance improvement. (Hung, R. Y., 2006).
- *Simulation (Modelling)*: it follows the traditional definition of systems modelling for simulation purposes, with the remark that the model under consideration is a representation of an aggregate of the product development processes with those of the organisation management processes throughout their entire life cycles.
- *Process Science and Technology / Systems Concurrent Engineering*: it is the aggregation and unification of the four models/modelling techniques (disciplines) above mentioned to build a holistic and transdisciplinary process modelling view of the enterprise, comprising both the product development and the organisation management processes throughout its entire life cycles.

Aiming at: Modelling, 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 BPMM/ProST study is an exercise of directly building and applying theoretical and practical knowledge and techniques, in an integrated and unified (transdisciplinary) way, to solve a complex discrete event process problem. The main goal is the development of a unified communicative model of the system (reference model) for carrying out multidimensional analysis, according to the various disciplines mentioned, throughout the entire model life cycle.

The key difference of the approach is 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. 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.

A *ProST Framework* is a systematic modelling approach to conduct ProST studies, made of: (1) A *Knowledge Architecture*; (2) An *Implementation Method*, covering the product´s development and the organisation management life cycle processes; (3) A *Supporting Environment*.

2.3.2 The Knowledge Architecture - Descriptive View

The fundamental concepts previously defined as components of the knowledge domain of the original BPMM definition are put together with the addition of the disciplines of SYSENG, PM and SIMMOD, in order to create a transdisciplinary view on all disciplines dealing with discrete event processes, denominated ProST/BPMMM. The aim is the creation of an innovative framework to conduct advanced studies in BPMM and to apply it in Systems Engineering.

The knowledge domain is formed by a layered hierarchical structure, starting from the most specific to the most generic, each component depicting a part of the knowledge base and extending its predecessor, until they form the complete image of the scope of the ProST/BPMMM research area. Figure 1 below depicts the elements and their funnel structure representative of the complete knowledge base involved in the ProST/BPMMM research area.

Figure 1 shows a "descriptive view" - a hierarchical structure of the fields - depicted as layered components. This descriptive view conveys not only the notion of hierarchy – from the simplest, most specific, to the most general or complex element - but also a precedence in the way one should progress in the understanding and application of the various techniques presented in the literature.

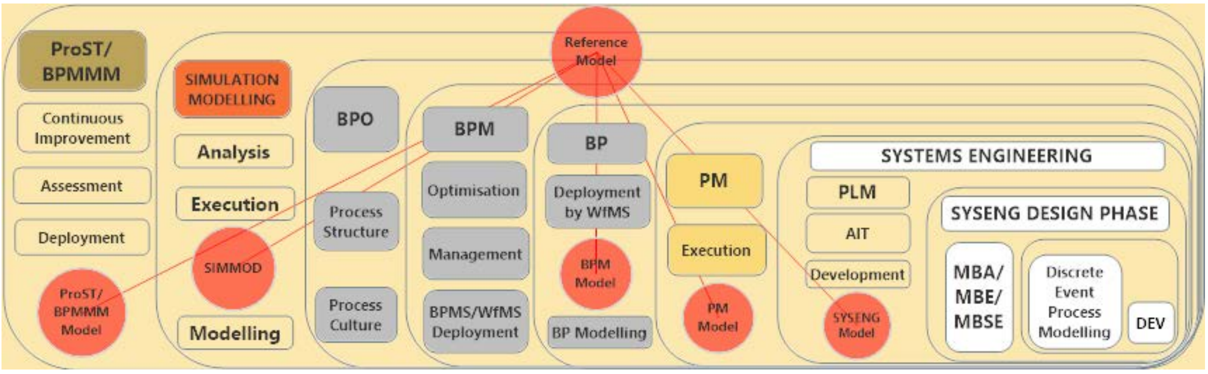

Figure 1 – **The Knowledge Archictecture** – Process Science and Technology and Business Process Maturity *Meta*Modelling

Another relevant aspect of the graphical representation in Figure 1 is that the "life cycle process" of the various modelling techniques being described, that is the evolution of the models along their life cycle, is represented by the vertical display of some concepts, showing the phases of design, building, deployment, execution and analysis existing in each of them.

2.3.3 The Knowledge Architecture - Process View

In a ProST study, the systematic modelling approach makes simultaneous use of various modelling techniques in an integrated way and on a real time basis along the complete model development life cycle. One should think of this modelling approach as the orchestration of different services, each one related to a specific model view, corresponding to the type of technique involved in the complete real system development processes.

Figure 2 shows the systematic modelling procedure resulting from the integration of the distinct knowledge domains and model views associated with the different disciplines and their responsible actors involved in a ProST 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 (Kienbaum et al, 2012).

In Figure 2 Systems Engineering, Project Management, Business Process Management and Simulation Modelling are represented as complementary techniques that can be integrated for the description and the evolution of the unified product engineering and the organisation management models along their complete life cycles. They are disposed in layers, meaning that they present some precedence while they are being built, although iterations is the main drive of the whole development process. All process models make use of the same reference model and they evolve gradually, making use of a systematic approach for the development of the progressively detailed hierarchical layers by means of repeated iterations for model evolution throughout its life cycle.

The upper and lower parts of the picture show the complete enterprise process lifecycle, comprising the product engineering processes and the organisation management processes necessary to accomplish the product. The enterprise´s business process lifecycle is further divided into the phases of design, development and operation.

The processes described are those related with the manufacturing enterprise: the design and the engineering of the product, i.e., the workflow of production processes (technical processes), the project management processes, as well as the additional business process management processes to complete the model of the organisation management processes. This last one takes also into account the interfaces to third party support (supply chain and maintenance). The outermost layer is the created as a simulation model, the equivalent of the organisation management process model ready for simulation and experimentation.

The important point to be remarked here is that a reference model is created and used right from the start to build the multi-layered model made of the specialised representations, which are kept consistent across all disciplines. A round-tripping modelling procedure is executed, the bottom up pathway starting with the systems engineering workflow of processes (process map) and the top down approach starting with the organisation business process management model in macro components, which are hierarchically decomposed until they show the core production processes or systems engineering workflow of processes.

This multi-layered process structure and modelling methodology mirrors that described in De Backer and Nuffel (2011)[2] for multi abstraction layered process modelling, with the difference that the layers here are associated with specific disciplines, which impacts on choice of the model representation technique used in it. In other words, it is not just the fine-grading of the overall process model decomposition, which is being considered, but the discipline associated with each layer, ranging from the engineering view in the innermost layer, passing by the project management and the business process management views in the intermediary layers and finally reaching the simulation view in the outermost layer.

The shadowed areas associated with the disciplines 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 design and 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 business process managers and the simulation modellers.

2 Manu De Backer, Dieter Van Nuffel. Multi-abstraction layered business process modelling. Computers in Industry. Vol 63, Issue 2, pp. 131-147.

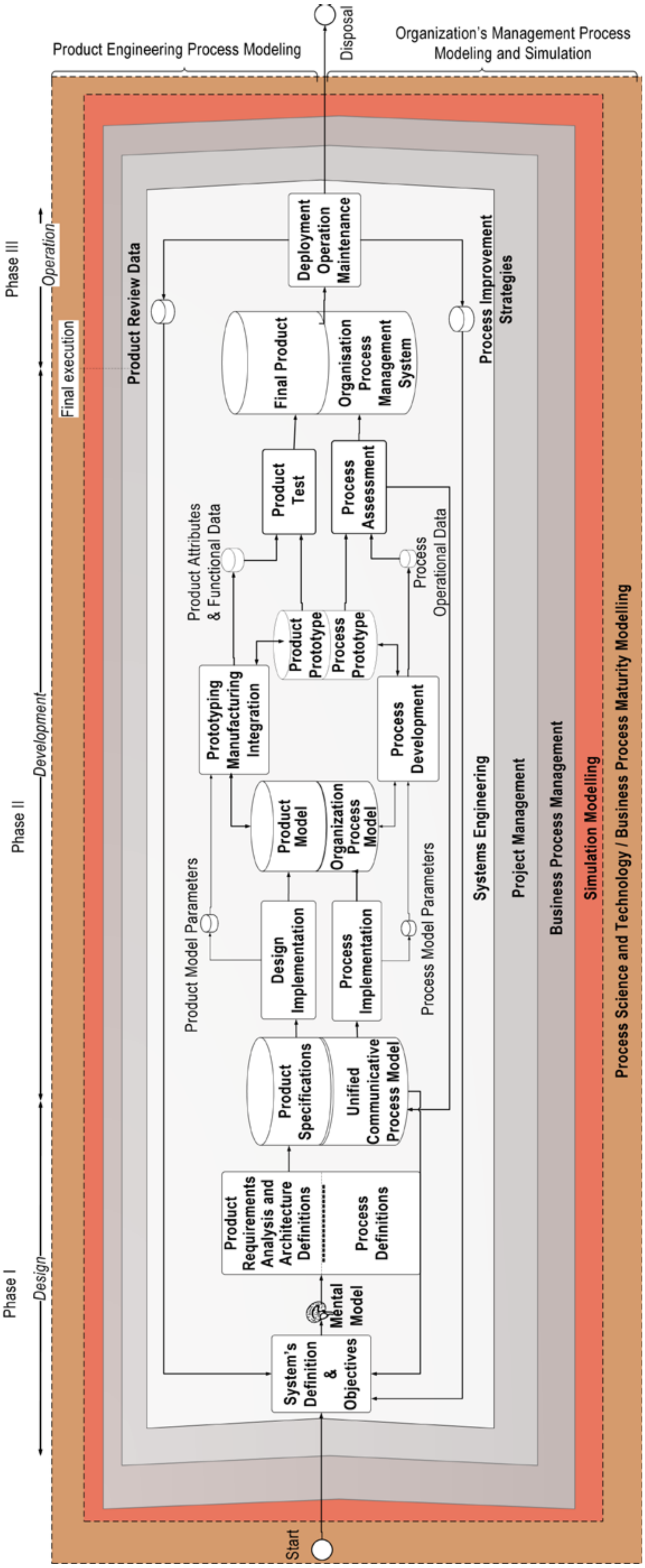

Figure 2 – The Knowledge Structure as seen from a process view perspective

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. Successive iterations or round trips might be needed, in order to reach the necessary degree of refinement and consistence of the reference model to be created and used by all interested parties.

2.4 The Unified Process Modelling Methodology

The *Implementation Method* or *Unified Life Cycle Process Modelling* is created by the aggregation of the different process views originated from the disciplines or dimensions of (Model Based) Systems Engineering (Hardware or Software), Project Management, Business Process Management, Simulation and their applications to the System Concurrent Engineering processes.

The unified life cycle process model created by the approach includes the managerial procedures related with the organization´s management processes, as well as the engineering core activities of the product´s development process. The simultaneous use of diverse representations techniques to build specialised process models of the enterprise or complete real system (product plus organization) based on a unified reference model is the cornerstone of the approach, thereby allowing the exploration of the complementariness and the strengths of the various disciplines when simultaneously applied for the solution of complex business problems.

Figure 3 shows *ProST´s Implementation Method,* named *Unified Life Cycle Process Modelling*, consisting of a method for gradual implementation of the ProST Framework. The rounded rectangles are the transformation processes and the cylinders stand for the model knowledge content (model representation artefacts – various formats) at a specific point in time.

The first phase of the unified life cycle modelling procedure is denominated *Conceptual and Reference Model Building*. This apparently duplicated designation is on purpose, in order to define the meanings and emphasise the difference between the terms *Conceptual Model* and *Reference Model*.

The term *Conceptual Model* used in ProST is a concept associated with the extraction of the logical content descriptive of the system's behaviour taking into account the study's objectives, i.e. the extraction of the knowledge about the complete process map (workflow of processes) describing the system´s manufacturing activities. The emphasis on the meaning of "Conceptual" is consistent with the one presented in Nance's conical methodology (Nance, 1994), who differentiates between the conceptual (mental) model and the communicative model, this last concept used to designate all other types of model representations in communicative format.

It shall be remarked that there are other more popular and different uses of the term conceptual modelling in the literature, as for example one associated with the architectural and functional requirements of the products themselves, when one is making use of model based system engineering (Embley and Tahlheim, 2011). Another use of the term conceptual modelling is related to the initial phase of the simulation modelling procedure, which deals with the extraction and representation of the essential characteristics of a system (its configuration and behaviour) for the purpose of conducting a simulation study of the system (Robinson et al., 2011).

In common all these definitions have the fact that they refer to the idea of extracting the basic knowledge (the essentials) about a system´s specification. The differences are that in the traditional literature the term conceptual model refers to the system´s configuration and/or the dynamics of its operation, be it a piece of hardware or software, and the authors include the representation of the model as part of these specifications. In ProST the conceptual model refers to the process map with the workflow of processes performed in the system only (logical or mental content) and the representation of the conceptual model is termed communicative model. The artefacts produced by the manufacturing process can be models of many different types, including for example SysML descriptions, architectural, functional and physical specifications, and graphics of many types. The artefacts are inputs and outputs of the activities components of the workflow of processes.

The conceptual model and the reference model summarise the results of the specification and representation of the essential aspects of all organisation managerial procedures, named "organization's management process", and of all product engineering core activities, named "product development life cycle process", which together constitute the system´s unified life cycle process model. The conceptual model building activity also defines the system's boundaries, the model control parameters and eventual additional premises and restraints, that is, the overall scope and objectives of the study.

The modelling of the organisation management process is the identification of the essential aspects of the architecture and operation of the organisation to produce the product. By architecture, one refers to the organisational structure, the types of agents or participants, their interactions, the kind of resources used by them, as well as the overall system´s data regarding these entities and resources. The operation refers to the process executed by the organisation and its participants and their related model data.

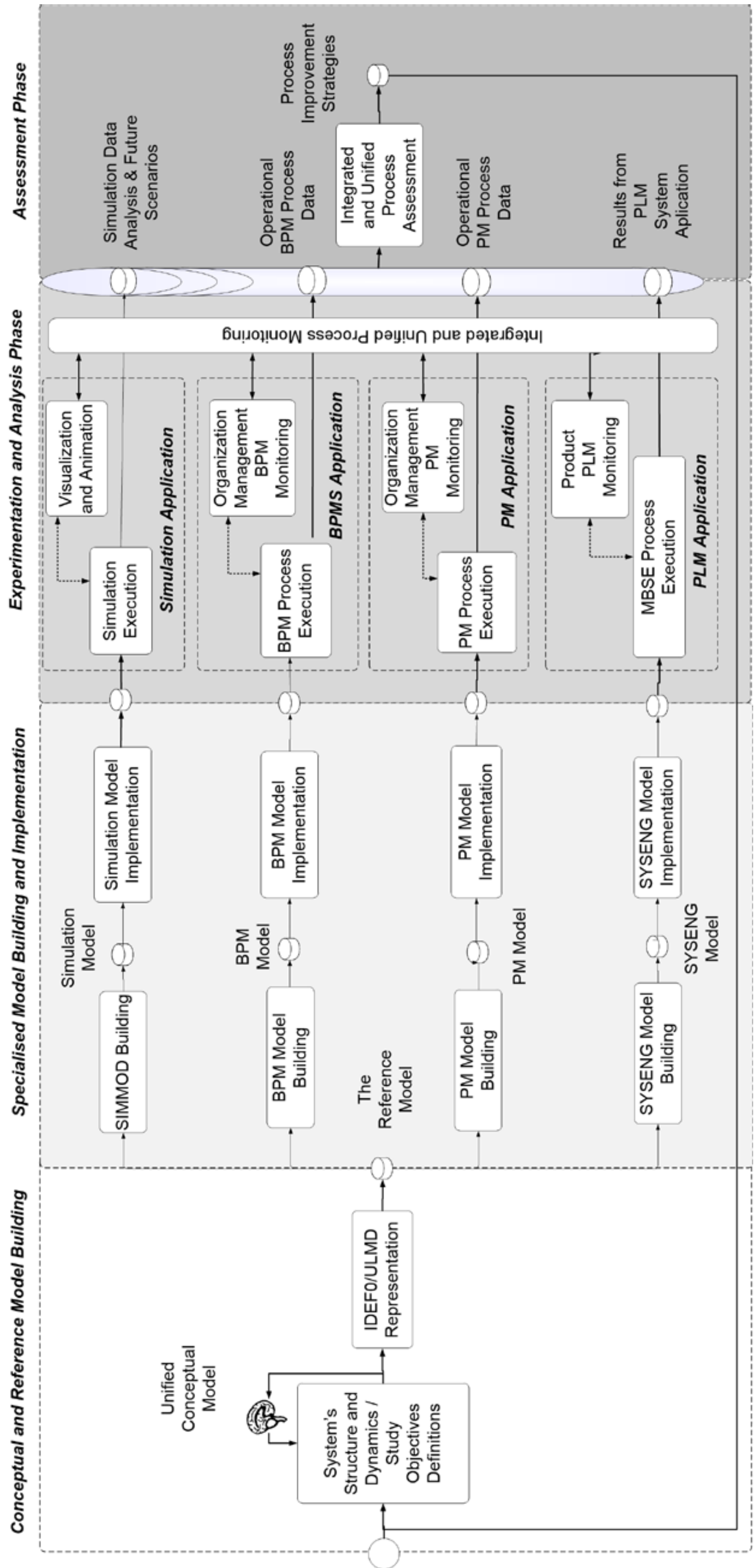

Figure 3 - The Unified Lifecycle Process Modelling (ProST´s Implementation Method)

The description of the organisation management process precedes that of the product development process in a top down approach and is preceded by the product development process in a bottom up approach. If one is performing the modelling in a top down way, one starts with the system´s macro process designated as the “organization’s management process” and proceeds with its hierarchical decomposition, so that at the lowest level reached by the modelling procedure stays the core engineering activities related with the product development process. In a bottom up approach, the modelling process is performed in a reverse way, but both procedures can be conducted iteratively, or even simultaneously, as if one would be drilling a tunnel from both ends, in order to speed up the modelling and achieving better consistence during the complete model building procedure.

The system is modelled using an agent/role type of description, with each agent responsible for its own life cycle of activities, depicted as a process map or workflow of parallel and concurrent activities, which together describe the complete operation performed by the system to accomplish its objective or final product.

The reference model is created making use of two steps, the first one making use of the IDEF0 notation and the second one the creation of the Unified Lifecycle Model, making use of Unified Lifecycle Diagrams (ULMD). This last notation is a type of Role Activity Diagram (RAD), which has been created based on an extension of Activity Cycle Diagrams (ACD) and Project Evaluation and Review Technique (PERT) diagrams, originally proposed in (Travassos, 2007) with the denomination of Unified Simulation Modelling Diagrams (USMD).

The creation and the use of the reference model is a corner stone of the methodology, in order to assure the cross consistence of the other communicative models to be created later using several kinds of notations and the integration and unification of the results they will produce. The reference model is the common link for the development of the additional specialised communicative models, for later implementation of the simulation and of the additional operational models, such as the BPM model, allowing for the carrying out of the joint analysis based on a multidimensional process view.

The second phase is denominated *Specialised Model Building and Implementation* and it comprises two macro activities, called *Specialised Model Building* and *Specialised Model Implementation*, each one containing a single activity in its lowest level of decomposition for the purpose of this illustration, but which can be further hierarchically decomposed, if necessary.

The *Specialised Model Building* is the initial step of the *Specialised Building and Implementation Phase* of the system´s diversified communicative processes models, by transforming the reference model described in ULMD into different formats, such as Business Process Diagrams (BPD) and Simulation Modelling graphical representation formats, depending on the specific simulation system one is targeting for model implementation. Each kind of model targets a different knowledge area and the benefits they bring to the joint model building and analysis of the problem.

The *Specialised Model Building* step is performed with the support of model building tools, such as BPMS systems for BPMN modelling, and simulation systems´ GUI interfaces for the model graphical description in a specific representation format. Nevertheless, this phase of model transcription is the most difficult and time consuming to accomplish, since the modeller has himself to assure the consistence and equivalence of the models created in the different environments, if he does not have any automated support from these environments to verify this procedure.

In the second step of the *Specialised Model Building and Implementation* phase, the *Specialised Model Implementation*, one makes use of all functionalities of the BPMS and other supporting tools of the environments for model completion. Usually, these functionalities are provided as extension of the modelling mechanisms existing in the existing supporting environments for model building mentioned before. These additional functionalities allow the full implementation of the applications required, for example in case of the simulators and the BPMS tools used in support of the approach.

The process models undergo a third phase of transformation, the *Experimentation and Analysis Phase*, with the addition of the project of experiment and the execution of the model’s applications, which will be executed according to different threads. In some case studies these threads do not make use of all possible views mentioned in ProST´s definition, they may just contemplate two of these views. For example, a first one for process enactment in production mode, with business process functionalities, and a second one for simulation execution, with embedded functionalities comprising the design of experiments, the building of scenarios, the analysis and results displaying capabilities.

The joint application of the various modelling and analysis tools to the same unified life cycle process model aims at achieving the complementary benefits from each of the techniques involved. The BPMS systems provide for the creation of applications to support the real system operation, the monitoring and the management of the process. The benefits from the use of advanced simulation tools come from the use of pre-built mechanisms, which allow the creation of projects of experiments by designing scenarios and performing their analysis.

Data collected during real system’s operation can be used as input data for simulation model execution, making validation easier and future scenarios projections more reliable and vice-versa, results from the simulation can be used for improving the overall process model. The important issue to keep in mind is the verification of the implementation of the different communicative models, to keep cross consistency between the disciplines and their validity regarding the unified system's specifications along the whole process.

The results from the different threads of execution, for instance the BPM and simulation threads, provide information for the fourth and last phase of the unified process life cycle, the *Assessment Phase*, which is also carried out according to the diverse views and disciplines in an integrated way. This last phase carries out a system´s performance evaluation and settles the strategies for continuous process model improvement.

The implementation of model improvement strategies and the introduction of changes to the system might make it necessary to restart the modelling procedure and to execute the complete model life cycle as many times as necessary.

2.5 ProST/BPMMM Application in Systems Engineering

2.6 Conclusions

CHAPTER 3 – THE COMMERCIAL SERVICES PROCESSES AT LIT/INPE

Abstract

ProST (Process Science and Technology) designates an innovative and transdisciplinary study and research branch that consists of the integration of concepts, methods and tools used for modelling, analysis, automation and management of processes, originated from different disciplines usually applied as autonomous techniques, and of their joint application to enhance the solution of business process problems in general. This work describes a case study of the application of a Framework for ProST - a systematic modelling procedure based on a unified process modelling approach for the use of Systems Engineering, Project Management, Business Process Management and Simulation techniques and their supporting tools - to conduct an advanced study of a complex business process systems. The case study is performed on a real system, namely the Laboratory for Integration and Testing (LIT) of the National Space Research Institute (INPE/Brazil) and the commercial services processes it provides for the aerospace industrial sector.

Keywords: Discrete Event Processes, Systems Engineering, Concurrent Engineering, Project Management, Simulation, Business Process Modelling, Simulation Modelling.

3.1 Introduction

This work describes a research project that has two main goals. The first one is of a scientific and general nature, targeting at the extension and organisation of a body of knowledge about concepts, methods and techniques, named Process Science and Technology (ProST) Framework, capable of producing enhanced Business Process Management (BPM) studies in general. The second one is of an applied nature, targeting at the application of the ProST Framework to perform a complete study of the process model life cycle of the commercial services provided by LIT/INPE to the Brazilian space systems industrial sector.

The first and general objective aims at making a contribution to the extension and consolidation of the ProST Framework itself, towards transforming it into a mature and formal methodology, involving both conceptual and technological aspects, this last one related with the development of its supporting tools.

The second and more specific objective seeks to demonstrate the practical application of the ProST Framework for the creation of an operational environment - made of PM, BPM and simulation tools - to support the commercial services processes provided by LIT. This operational environment shall support decision taking about the real system, regarding its execution, its automation, its performance assessment and monitoring capabilities, as well as its continuous process improvement.

This article has been structured as follows. Section 2 describes the context of the research, presenting some of its fundamental concepts and related work. Section 3 describes the Laboratory for Integration and Testing (LIT) of the National Space Research Institute (INPE/Brazil) and the commercial services it provides for the external aerospace industrial sector - the problem definition. Section 4 describes the unified lifecycle modelling procedure used in ProST applications, to be exemplified in the case study. Sections 5 and 6 present the actual model building. Section 7 discusses the procedure used for model data collection. Section 8 describes the execution and experimentation conducted with the model. Section 9 presents its analysis and assessment of results. Section 10 draws some conclusions and, finally, Section 11 points out some topics for future research.

3.2 Fundamental Concepts and Related Work

Basic Concepts

Process Science and Technology (ProST) 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 process model life cycle of complex products and services development and organisation management processes in general (Silva, 2013). The complete process model life cycle comprises the modelling, the building, the execution, the automation, the monitoring, the management and the continuous process model improvement.

A *ProST Framework* is a systematic approach to conduct ProST studies, made of: (1) A *Knowledge Architecture*; (2) An *Implementation Method*, covering the product´s development and the organisation management life cycle processes; (3) A *Supporting Environment*.

The Knowledge Architecture

The *Knowledge Architecture* presents a holistic view on the distinct knowledge domains associated with the study of complete product development and organisation management processes, usually treated in the literature under the umbrella designation of Business Process Maturity Models (BPMM).

The model domain in a ProST study contemplates different disciplines and the techniques they apply for modelling the systems engineering process and the organisation management process in a unified and integrated way. The concepts and techniques are those originated in diverse autonomous process study and research branches, such as (Model Based) Systems Engineering, Project Management (PM), Business Process Management (BPM) and Simulation Modelling.

Systems Engineering and Project Management are considered 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. Simulation and Business Process Management are also considered to be two complementary techniques that can be integrated and used for the description of a unified organisation 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 Implementation Method

The *Unified Life Cycle Process Modelling* procedure proposed in ProST makes use of different process views originated from the disciplines or dimensions of (Model Based) Systems Engineering (Hardware or Software), Process Simulation Modelling, Project Management, Business Process Management and their applications to the System Concurrent Engineering processes.

The approach encompasses all managerial procedures related with the organization´s management processes, as well as the core engineering activities related with the product´s development process, both seen as parts of the overall enterprise business process or *System´s Unified Life Cycle Process*. The complete *Unified Process Model Lifecycle* is further divided into the phases of Reference Model Development, Model Building and Implementation, Experimentation and Analysis and Assessment of Results.

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 modelling and the additional BPM operations. This complete set of processes are then submitted to a simulation modelling and experimentation study, completing the range of techniques used for conducting advanced BPMM studies, which have been denominated ProST studies, when they are conducted making use of the proposed approach. One should think of this unified process modelling procedure as the orchestration of different services, each one related to a specific model view or discipline, corresponding to the type of technique involved in the complete model lifecycle process used to study the real system.

The disciplines are named *dimensions* and they are related with the type of knowledge of the agent involved in the complete product lifecycle. The domain areas of each agent are depicted by 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 simultaneous use of diverse representations techniques to build transdisciplinary integrated process models of the enterprise or complete real system (organization plus product), making use of a common Conceptual Model or Reference Model, is the cornerstone of the approach and allows for the exploration of the complementariness and of the strengths of the various disciplines when performing their joint application.

The creation and the use of the *Reference Model* is a corner stone of the methodology, in order to assure the cross consistence of the other specific models to be created later using several kinds of notations and the integration and unification of the results they will produce. Each kind of model targets a different knowledge area and the benefits they bring to the model building and joint analysis of the problem.

The Reference Model is the common link for the development of the additional specific models, for later implementation of the simulation and of the additional operational models, such as the BPM model, allowing for the carrying out of the joint analysis based on a multidimensional process view.

The Supporting Environment

The integrated and unified techniques involved in a ProST study need support from computer aided hardware and software engineering tools, in order to assure consistency and compatibility across different model formats and the complete interoperability of its component tools. These tools range from computer aided design and manufacturing systems, software engineering environments, communication interfaces, verification mechanisms, and applications to perform automatic model transcriptions and implementations.

The approach envisages the simultaneous use of PLM (Product Lifecycle Management), PM, BPMS and Simulation tools in support of the modelling, simulation, automated execution and management of the processes, in the form of an integrated environment directly connected to the real system operations (constituted by the enterprise with its production and management processes). The integrated environment becomes an operational system that is used to orchestrate, monitor and manage the real system. The data generated by this operational system is used as the source for model input data, definition of control parameters, execution, experimentation, performance analysis and continuous improvement of the simulation model and vice-versa.

3.3 The LIT Complex and its Lab Units

The Laboratory for Integration and Testing (LIT) is a complex composed of several small laboratory units located in the same building, conceived for assembling, integrating and testing spatial devices for the Brazilian Space Program (INPE/LIT, 2011). The main Brazilian satellites and some satellites developed in cooperation with foreign partners have been built and tested in this plant, such as the ones developed in cooperation with China, Argentina and USA.

LIT's staff finds it hard to assure an efficient management of the services processes performed by the laboratory, especially when the activities related with the space missions occur simultaneously with those related with the accomplishment of external clients commercial service orders.

This happens because there is a great diversity and quantity of resources allocated to LIT's services processes, such as: human resources, constituted by its engineers and technicians; material resources, constituted by its climatic chambers, thermo-vacuum chambers, vibrators, anechoic chambers, warehousing sites, offices, meeting rooms, among others.

Additionally, there is the fact that the quantity of the services provided, as a sum of the activities originated from the space missions and those from the commercial services orders, has been growing steadily (INPE/LIT, 2009), which leads to even greater problem forecasts for the future of the organisation. These issues have motivated the present research work.

3.3.1 LIT´s Structure

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 the commercial service orders from the external aerospace industrial sector. The main labs comprised by LIT are:

- Antennae Laboratory
- EMI/EMC Electromagnetic Interference and Compatibility Measurements Laboratory
- Mass Properties Measurements Laboratory
- Metrological Laboratory
- Components Qualification Laboratory
- Thermal Vacuum Laboratory
- Vibration and Shock/Vibroacoustic Laboratory

3.3.2 The Commercial Services Processes at LIT

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

Besides carrying out the internal activities related with the space systems program, LIT provides additional services to the neighbouring high technology industrial sector, generally made of partners themselves of the Brazilian aerospace program. These additional services are provided simultaneously with those directly related with the space missions, 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.

The commercial services processes (INPE/LIT, 2005) are the focus of this article and they are described below grouped in three phases, each one addressing a part of the model life cycle of the system: the proposal elaboration phase, the execution of the service order, and the final phase of invoice issuing and reception of payment for the services provided.

The Proposal Elaboration Phase

The client sends some sort of service request – by telephone, e-mail or fax – to LIT's Commercial Sector. A member of the staff decomposes and register the service request in an online form, in which every kind of service provided by LIT is listed.

After the form is completed it generates a number, called process number, to be used as reference for following up purposes of the progress of the service order through the system.

Each service order needs to be assessed by the technical staff and a record is generated, containing the start date, the number of working hours necessary for service execution, and its conclusion date.

The system helps the data input and to elaboration of the answers from the individual labs, by maintaining a database with all scheduled activities (a chronogram) of each lab, by suggesting the number of hours needed for execution of the service and by making a forecast of its conclusion's date. The answers from the individual labs are further reviewed and aggregated by the system and they are made available to the Commercial Sector for preparation of the commercial proposal to be sent to the customer.

The Technical Area is notified about the requests generated by the Commercial Sector in order to be able to answer them and the Commercial Sector is notified about the answers given by the technical sector to these requests. The system warns both the Commercial Sector as the Technical Area if a certain request is not answered within a predefined time duration.

The Commercial Sector elaborates the commercial proposal and sends it for approval by the management.

Once approved by the management, the Commercial Sector sends the proposal to the client via mail, fax or e-mail, and registers this information in the system.

If the finish date of the proposal's validity is approaching, the Commercial Sector is notified by the system in order to contact the customer and to request an answer whether the proposal was accepted or rejected. The acceptation or rejection of the proposal is registered in the system.

If there is a confirmation of acceptation from the client, the Technical Area is notified by the system. If no confirmation is received from the client until the proposal expires, both the Commercial Sector and the Technical Area are notified by the system.

The Execution Phase

When the services involve the testing of devices, the Warehousing Sector receives the external client's device in the Storage Room and, in case of service orders from internal clients, the device is sent directly to the lab, where it is filed and registered in the system. The commercial proposal associated with the equipment received is located in the system using its reference number.

If the device arrived without any formal service request, or this happens previously to the issuing and/or acceptation of a commercial proposal by the client, the storage sector notifies the Commercial Sector for it to take the necessary measures to deal with that exception.

When the arrival of an equipment is registered, the system notifies the Technical and the Commercial Areas. Once in possession of the equipment, the area opens a service order and this service order is updated constantly during service execution. Even services that do not involve equipment need to have a service order issued for them.

After service is completed, the area registers in the system its conclusion, by closing the service order. When applicable, the equipment is sent to the storage room, to be picked up by the external customer. The internal customers withdraw the equipment directly from the lab.

The documents generated (certificates, reports and others) are sent to the Commercial Sector, where they are registered and a copy is sent to the customers. Another copy is sent to the Documentation Sector, which is responsible to complete the registering data, such as storage location, for example.

The digitalized data are input to the system by each area and the Commercial Sector is notified by the system in order to register them and to send them to the clients. After registering by the Commercial Sector, the Documentation Sector is notified about them as well.

When a service is not finished by its due date according to its service order, the system warns the Technical Area.

When the equipment arrives at the Storage Sector the delivery term (partial or complete) is issued via the system. The Storage Sector awaits until the client withdraws the equipment, holding it in the Storage Room (external clients) or in the lab (internal clients). Once the equipment is withdrawn, the information is registered in the system.

The Invoice Issuing Phase

The Commercial Sector, using IT systems specially developed for this purpose (INPE/LIT, 2005), generates the necessary data for the elaboration of the tax invoice and receipt and send them to the Foundation responsible for issuing these documents and for receiving the payment from the client. The Foundation sends the tax invoice and receipt back to the Commercial Sector, who register the data and send them forward to the client. The Commercial Sector awaits the client's payment and, once it is done, updates the system with this information.

3.4 LIT´s Commercial Services Unified Life Cycle Process Modelling

This Section describes the application of ProST´s Framework to the real system used for the case study, the Commercial Services Processes executed by LIT to INPE´s external industrial partners. All specialised process models are built and implemented making use of a systematic procedure throughout its complete life cycle, from model building, implementation, execution and analysis, trying to assure consistency and equivalence across the different disciplines and their characteristic representation formats.

In the Process Science and Technology case study presented in this work, the three different knowledge areas and techniques identified and the way they are used in the solution of the problem are:

- Project Management: the service orders originated by the space missions, as well as those resulting from the accepted proposals from clients of the commercial services, are scheduled using Gantt graphics, created by software tools such as MSProject (Microsoft, 2013).
- Business Process Management: BPMS systems are used in support of the modelling, execution and management of the processes. The data generated by the real system is recorded by the embedded BPMS application and it is further used for input to the simulation, extending from the definition of the model control parameters to the project of experiment, analysis and the validation of the model. The opposite is also true, data from the simulation may be used to help analysing and improving the process model to be used by the BPMS system.

• Simulation: The simulation process model is created making use of the Reference Model, then it is implemented, executed and analysed with an appropriate discrete event simulation system.

Figure 3 shows the Unified Life Cycle Process Modelling approach for joint applications of the different disciplines or dimensions of PM, BPM and Simulation in ProST, as applied in the current case study. The rounded rectangles are the transformation processes and the cylinders stand for the model knowledge content (model representation artefacts – various formats) at a specific point in time.

The first phase of model lifecycle process is denominated Conceptual and Reference Model Building and it comprises two parallel activities. The *Conceptual Model* and the *Reference Model* are concepts associated with the specification of the workflow of processes executed by the organisation management and the product design and development process. One important remark that shall be made is that in ProST the term Conceptual Model is a word reserved for the logical content, that is, the mental model, whereas all different types of representation, including the Reference Model and the other specialised models created making use of the specific techniques used in each discipline, are generically designated Communicative Models.

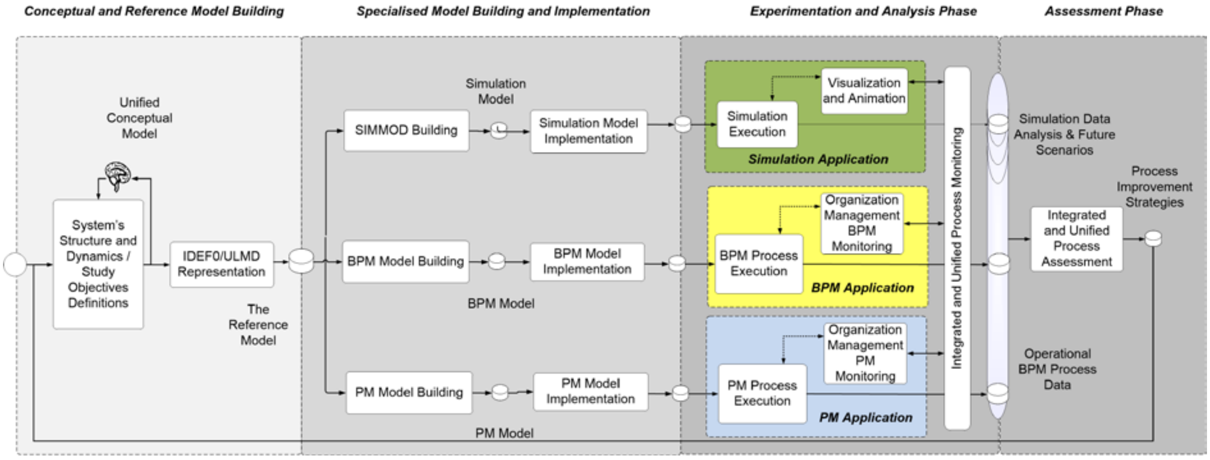

Figure 1 – LIT´s Commercial Services Unified Life Cycle Process Modelling.

In this case study, there is no "actual product" being developed. This is the reason why a systems engineering model has not be shown and is not considered as part of the unified life cycle process model, as usual (vide chapter 2). Nevertheless, the services being executed can be seen as part of a general process "product integration, testing and organisation management processes", related with the accomplishment of the service orders placed by the companies of the external space industrial sector, who request the testing of their own devices.

The cycle starts with the specification of the system and of the objectives of the study, which defines the scope of the model to be built. The specification of the workflow of processes, descriptive of the organization management and of the product engineering processes is one of the main product of this phase (conceptual or mental model). The other final product of this phase is the representation of the conceptual model into a communicative model named reference model, making use of two steps, performed using the notations IDEF0 and ULMD. The reference model will be used throughout the remaining of the modelling process as a baseline model for the creation of the specialised models belonging to the various techniques, namely PM, BPM and simulation. The reference model encompasses the definitions of the system's boundaries, the model control parameters and eventual additional premises and restraints, that is, the overall scope and objectives of the study, in the current case study designated as "LIT´s Commercial Services Processes".

The next phase of model development is the building and the implementation of the specialised process models, for representation of the reference model making use of different formats, such as the BPMN notation and the proprietary simulation graphical model representation formats. This phase is divided into two single activities, the first one called Specialised Model Building and the second one Specialised Model Implementation, each one containing a single activity for the purpose of this illustration, but which can be hierarchically decomposed, if necessary.

The Specialised Model Building consists in the creation of the system´s diversified specialised processes models, by transforming the Reference Model described in ULMD into different formats, such as Business Process Diagrams (BPD) and Simulation Modelling graphical representation formats, depending on the specific simulation system one is targeting for model implementation. Each kind of model targets a different knowledge area and the benefits their use will bring to the model building and joint analysis of the problem.

The Specialised Model Building step is done with the support of model building tools, such as BPMS systems for BPMN modelling, and simulation systems´ GUI interfaces for the model graphical description in a specific representation format. Nevertheless, this phase of model transcription is the most difficult and time consuming to accomplish, since the modeller has to assure himself the consistence and equivalence of the models created in the different environments, if he does not have any automated support from these environments to verify this procedure.

In the Specialised Model Implementation step, one makes use of all functionalities of the BPMS and other supporting tools of the environments for model completion. Usually, these functionalities are provided as extension of the modelling mechanisms existing in the supporting environments for model building mentioned above. These additional functionalities allow the full implementation of the applications required, for example in case of the simulators and the tools needed for BPM support.

The specialised models building and implementation yield 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 of the branches describes the BPM model, which is used for process enactment in production mode, with management facilities, another one is used for the simulation of the process with project of experiments, scenarios´ visualisations and animations facilities embedded. The third thread corresponds to the execution of the project management application, meaning the use of an appropriate PM tool to monitor the carrying out of all actions associated with project management. Each thread makes use of its specific kind of process model representation, which are derived from the unified reference model, verified to assess their consistence, and validated in regard to system's specifications.

The implemented process models undergo a third phase of transformation, the experimentation and analysis phase, with the addition of the project of experiment and the execution of the model's applications, which will be executed according to different threads. The BPMS systems provide for the creation of applications to support the real system operation, the monitoring and the management of the process. The project management tool provides the following up of the activities with their actors and resources. The benefits from the use of advanced simulation tools come from the use of pre-built mechanisms, which allow the creation of projects of experiments, by designing scenarios and performing their analysis. Data collected during real system's operation assisted by the BPM and PM tools are used as input data for the simulation model execution as well. This way the process simulation is more faithful to reality and future scenarios projections are more reliable.

The results from the different threads of execution from the various threads - the PM, BPM and simulation threads - provide information for the fourth and last phase of the unified process life cycle, the Assessment of Results Phase, which is also carried out according to the diverse views and disciplines in an integrated way, for system´s performance evaluation.

The implementation of model improvement strategies or the introduction of changes to the system of "LIT´s Commercial Services Processes" might make it necessary to restart the modelling process and execute new cycles, allowing for the implementation of continuous improvement of the model.

3.5 System and Study Objective Definitions

To keep the model simple and gain the necessary skill with the modelling and the application of the ProST Framework, the LIT´s model of the commercial services processes was created initially containing only a limited set of processes. The problem has been restricted to the proposal elaboration phase, which was simplified in the form a few macro component processes and a reduced number of laboratory units and resources.

In future versions of the model, the complete set of services provided and their interface with the spatial mission processes will be added, as well as the complete set of laboratory units and a more detailed representation of the process model components involved, what can be done by hierarchically decomposing the macro processes shown in this case study.

3.6 The Reference Model Development

The Reference Model building phase extracts the essentials of the architecture and operation of the complete system (product plus organisation). By architecture, one refers to the organisational structure, the types of agents or participants, that is, the entities and resources of the system (LIT´s Complex of Lab Units). The operation (workflow of processes) refers to the processes (LIT´s Commercial Services) executed by the organisation and its participants, the interaction among these agents, as well as the overall system´s model related data.

3.6.1 The Systems Engineering IDEF0 Model

The systems engineering IDEF0 model is the first representation of the system created in ProST systematic modelling procedure and this stepwise model building way is an important aspect to assure that the model will be complete and consistent after some iterations.

The IDEF0 diagrams are used to help extracting the knowledge content about the specific activities that are performed in the overall service processes, as well as the inputs, outputs, types of resources and control mechanisms involved in these individual activities.

An important remark must be made about the IDEF0 diagramming technique. The systems engineering IDEF0 model described here shows exclusively the types and the description of the main attributes of the processes involved in the commercial services. In fact, IDEF0 diagrams do not even care about the sequencing of the activities, this aspect is left open for additional modelling steps. In the case of ProST modelling procedure, this is the object of a second step of the reference model building, to be detailed in Section 3.6.1.

In complete systems engineering case studies, though, one would expect to make use of other forms of graphical representations, such as UML and SYSML for example, to document systems requirement specifications, as well as of additional types of descriptions containing the the description of the functional and physical architectures of the product.

These additional representation formats and model types are not addressed in the case study presented here, because there is no actual "single product" being developed, the outcome of the services are the accomplished orders regarding different pieces of equipment being tested. If these additional representations are necessary, nevertheless, they can be added independently in the specialised model building phase (systems engineering model) and they will not change the description of the process life cycle done with the IDEF0 diagrams, they will simply add information to this type of representation.

The simplified systems engineering IDEF0 model of the LIT´s commercial services processes is shown in Figures 3, 4 and 5.

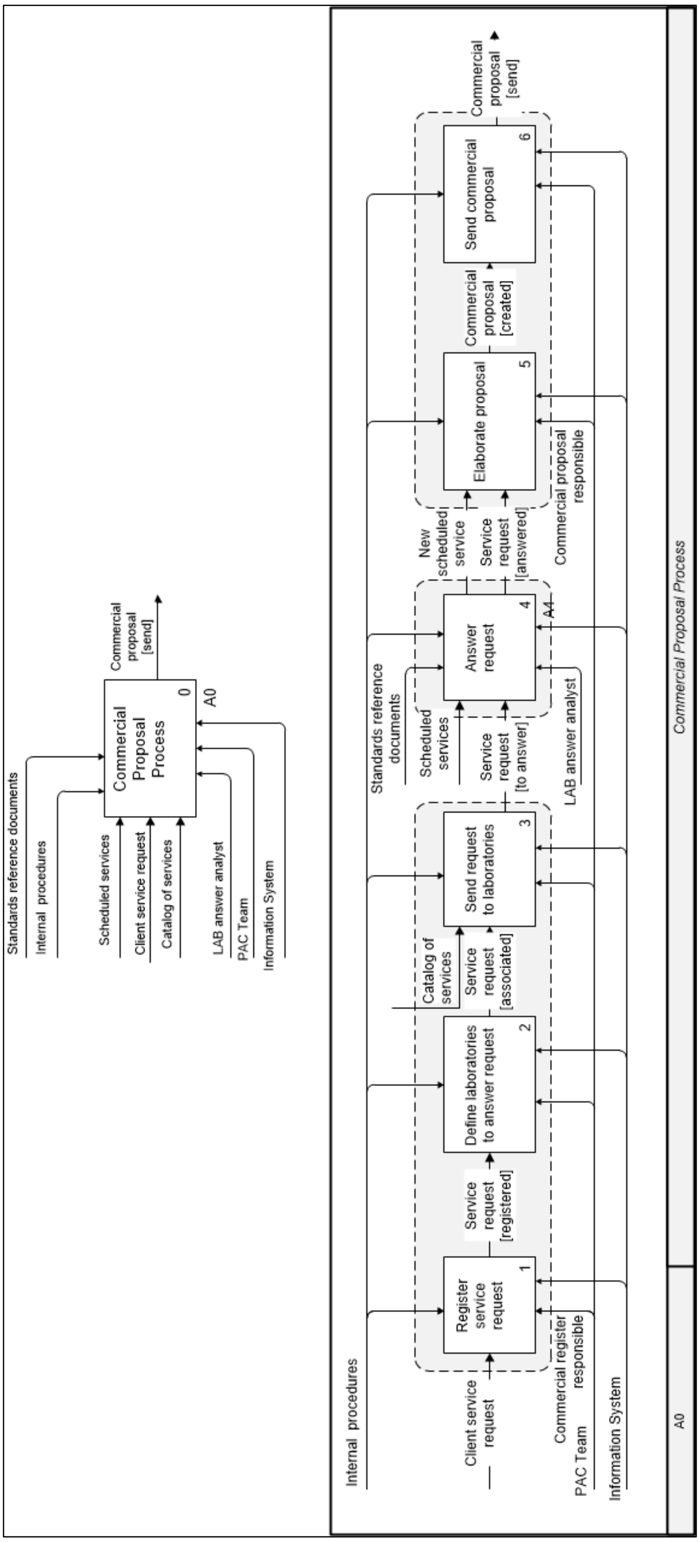

Figure 3 – The LIT´s Commercial Services Processes in IDEF0

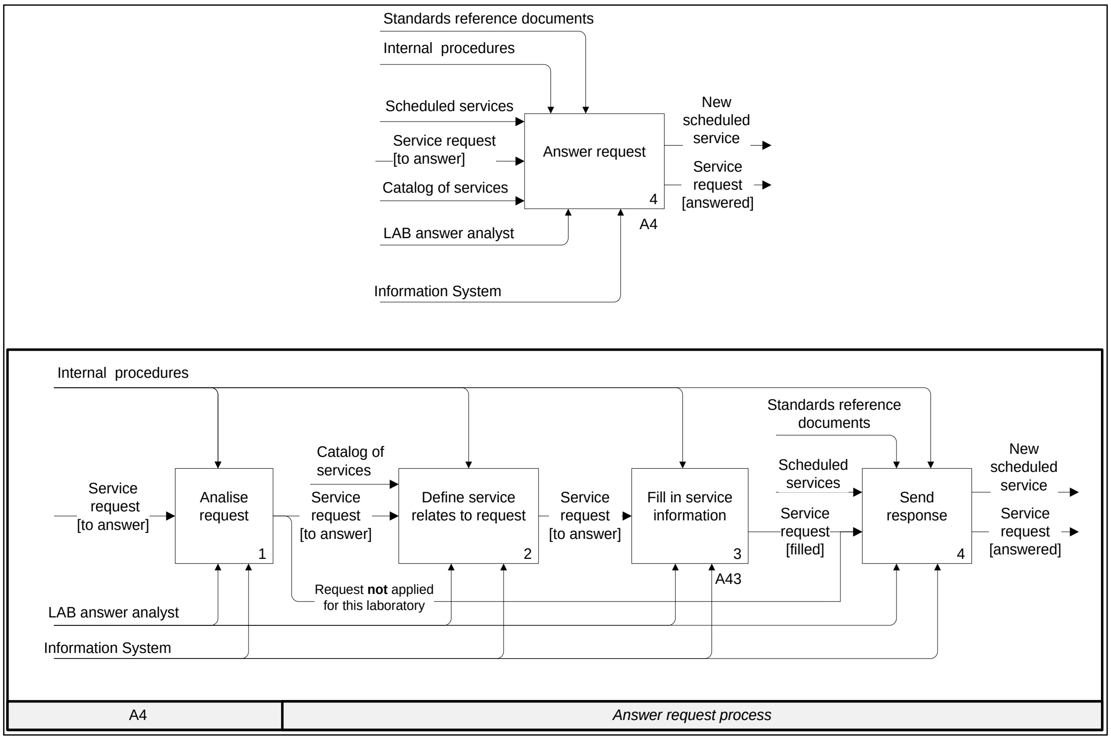

Figure 4 – IDEF0 Model of *Answer Request* Subprocess

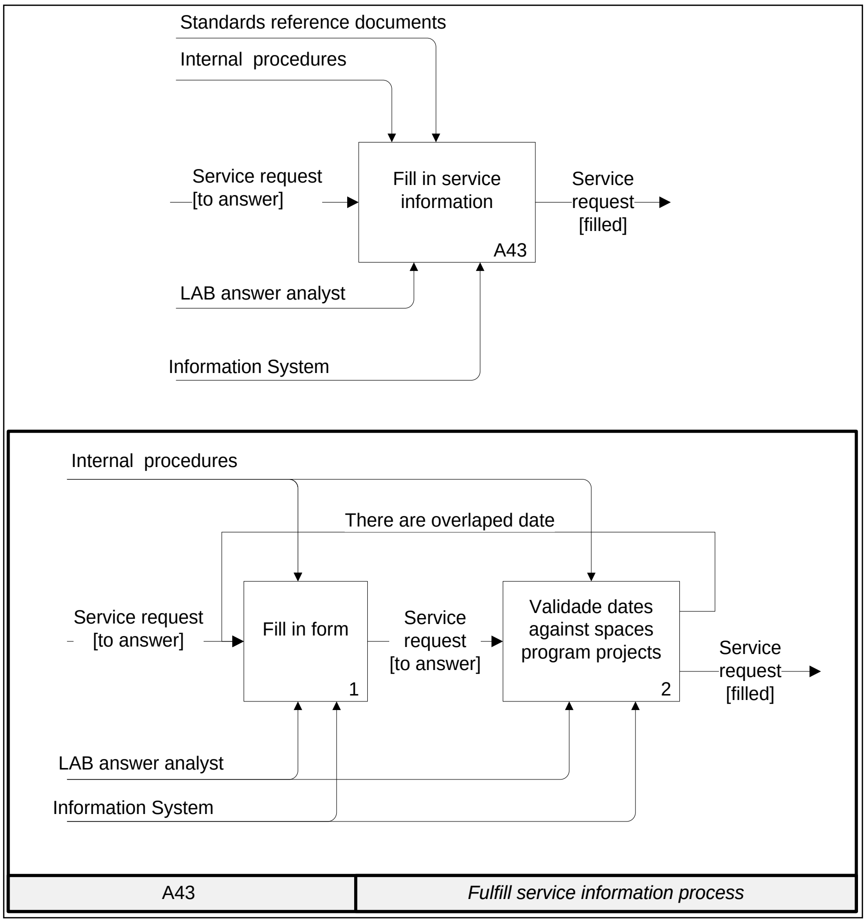

Figure 5 – IDEF0 Model of *Fill in Service Information* Subprocess.

3.6.1 The Reference Model

The Reference model is represented in a modelling notation designated ULMD (Unified Lifecycle Modelling Diagrams), derived from a graphical representation form proposed in (Travassos, 2007), originally denominated USMD (Unified Simulation Modelling Diagrams). USMD and ULMD were devised for unifying model descriptions of the workflow of processes in discrete event systems, such as these created to describe process models in the disciplines of Project Management (PERT/CPM), Systems Simulation (ACD) (Pidd, 1992) and Business Process Management.

The ULMD diagrams are used to complement the knowledge content extracted with the IDEF0 diagrams, adding the sequencing of the activities involved in the systems operation and determining the agents responsible for them, i.e., describing the workflow of processes performed by each agent to accomplish its respective part of the complete service process.

Figure 4 shows the ULMD (Unified Life Cycle Modelling Diagrams) model of the complete LIT´s Commercial Service Processes represented as macro activities.

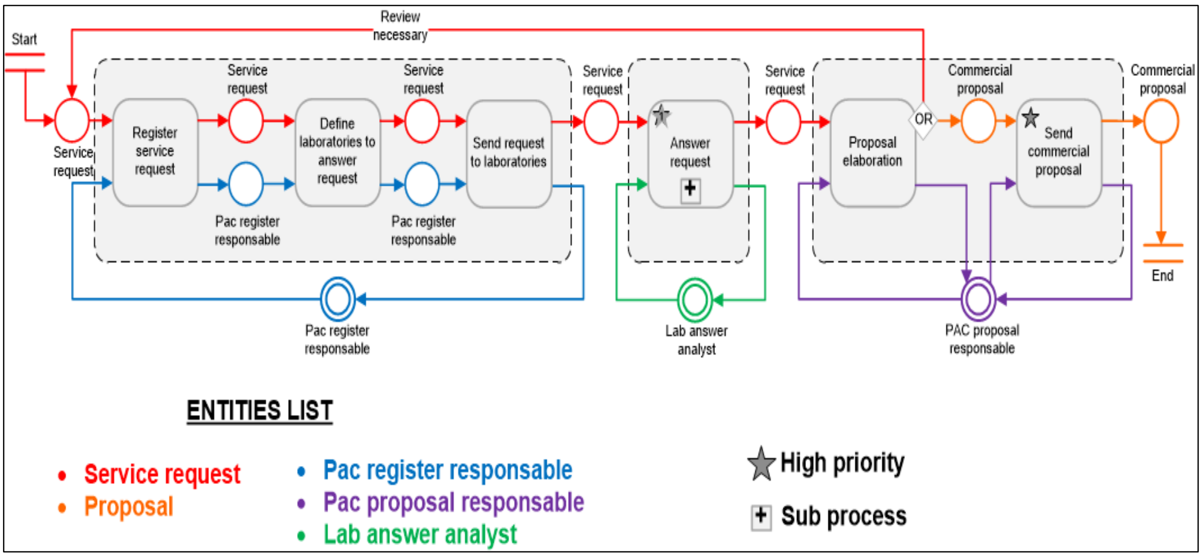

Figure 4 – The Reference Model of LIT´s Commercial Services Processes in ULMD (Macro)

The decomposition of the macro activities “Answer Request” and “Fill in Form” is shown in Figures 5 and 6.

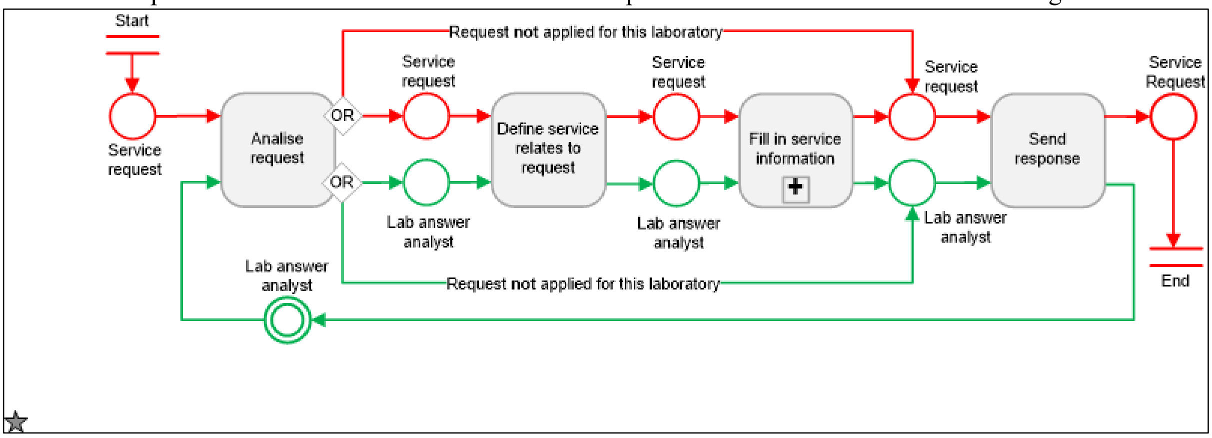

Figure 5 – The Answer Request Process Model in ULMD

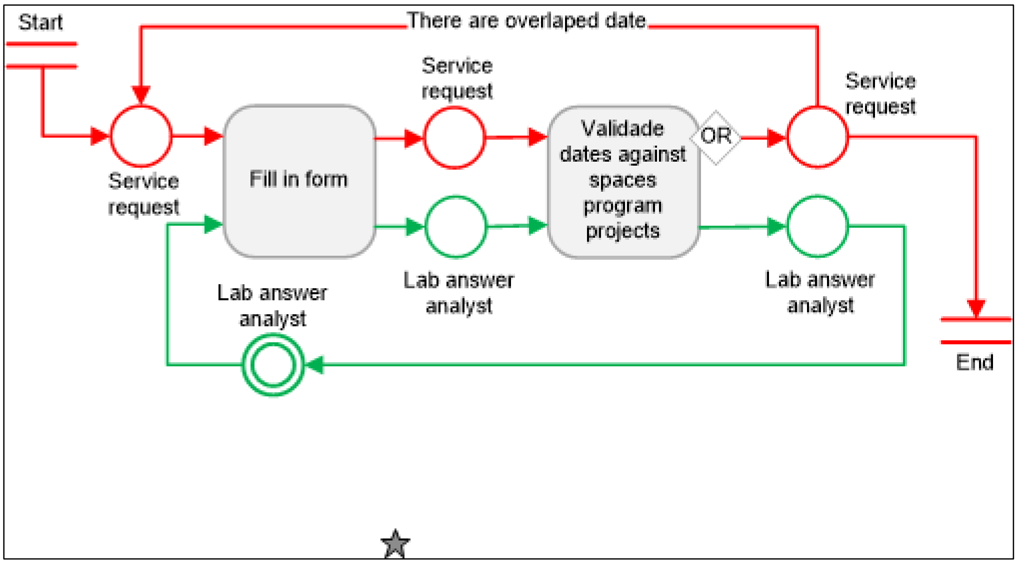

Figure 6 – The Fill in Service Information Model in ULMD

3.6.2 **The BPM Model**

The model with the BPMN description of the system was performed by making use of Bizagi Process Modeller (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 Modeller, but the original BPMN model had to be altered and complemented for this to be accomplished.

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Figure 7 shows the BPD (Business Process Diagram) model of the complete LIT´s Proposal Elaboration phase represented as macro activities. The decomposition of the macro activities “Answer Request” and “Fill in Form” is presented in Figures 8 and 9.

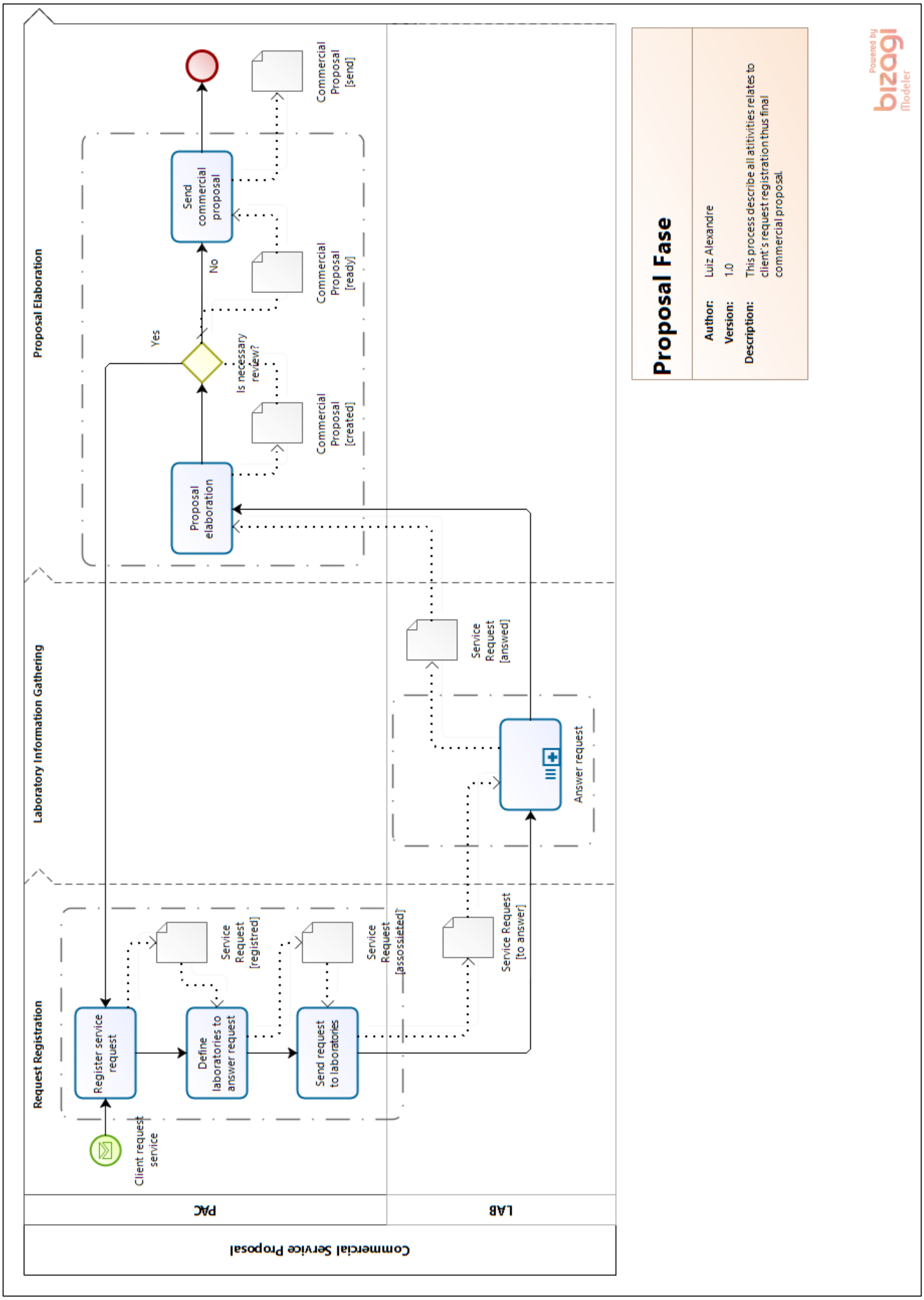

Figure 7 – The BPM Model of LIT´s Proposal Elaboration phase in BPMN (Macro)

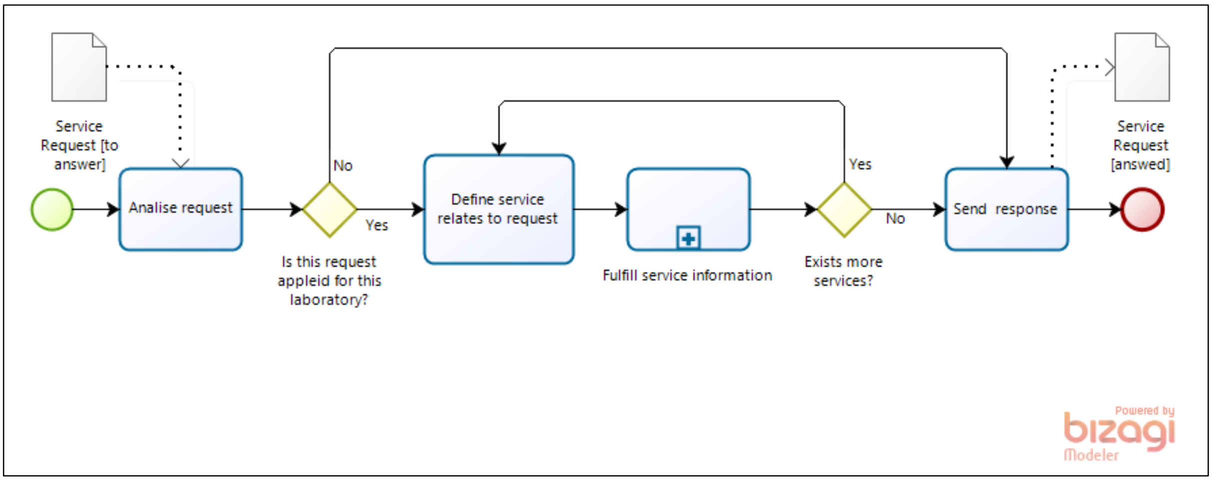

Figure 8 – The BPM Model of the Answer Request Process in BPMN

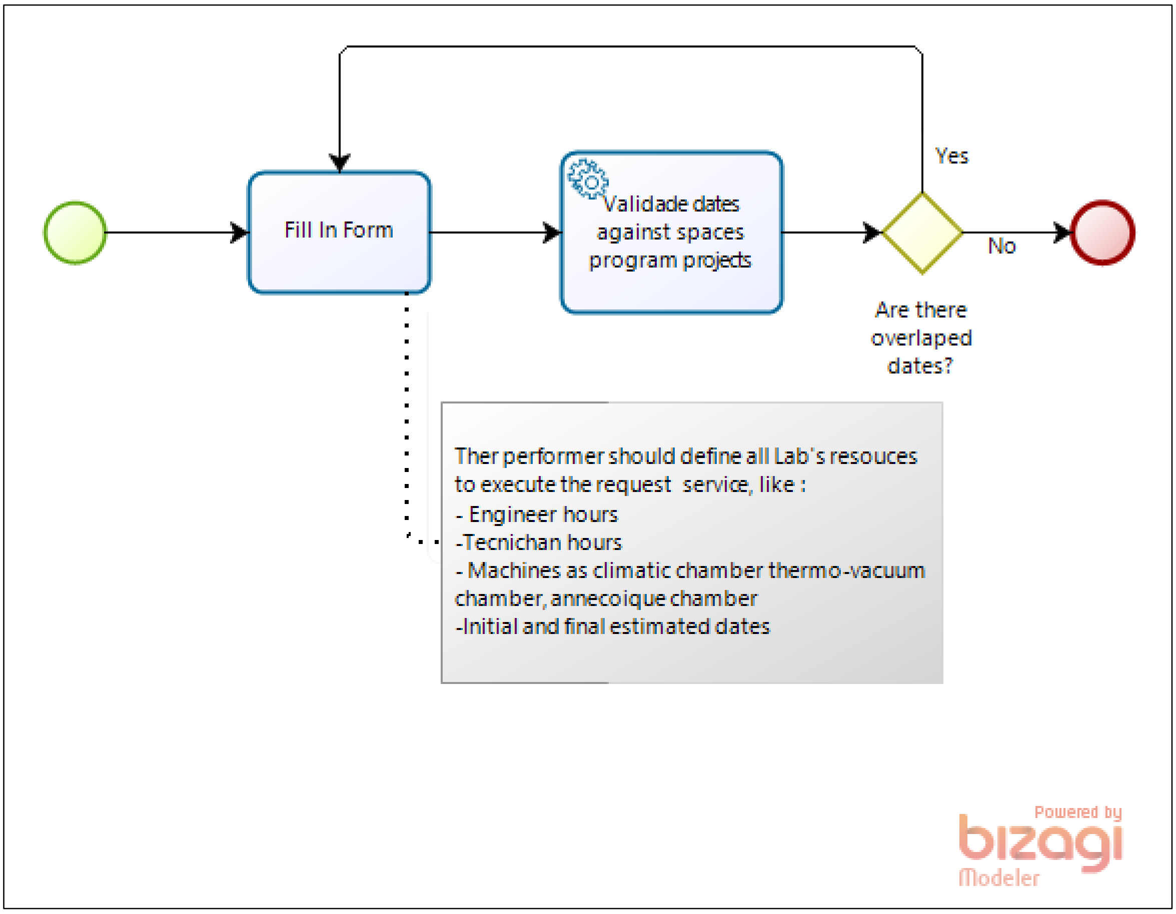

Figure 9 – The BPM Model of the Fill In Form Process in BPMN

3.6.3 The Simulation Model

In parallel, the Reference Model made using the ULMD representation was used to guide the elaboration of the simulation model and its implementation in the Simprocess simulation system (Simprocess, 2011). This simulation model is created using proprietary software and its specific type of representation, according to the simulation tool chosen by the user. Simulation models allow for complex descriptions of the structure and dynamic of the system and the experimentation and analysis of alternative scenarios for assessment of performance of the commercial services provided by LIT.

The model building using SIMPROCESS Graphical User Interface has benefited from the fact that the same icons used in the description of the commercial services, as shown in Appendix A, could be imported into the simulation system. They also could be used in the description of the hierarchical structure of the system, making the model more familiar and easy to understand to all participants of the project. Figure 10 below shows the first level of implementation of the LIT´s Commercial Services Model using SIMPROCESS GUI. The macro process Services Execution is depicted in more detail in Figure 11. This model was built for the assessment of the performance of the services provided and the equivalent of the proposal elaboration phase is not shown in the model, but it gives the idea of the type of hierarchical representation used in the simulation system, and of its potential as a tool for analysis of complex business process problems.

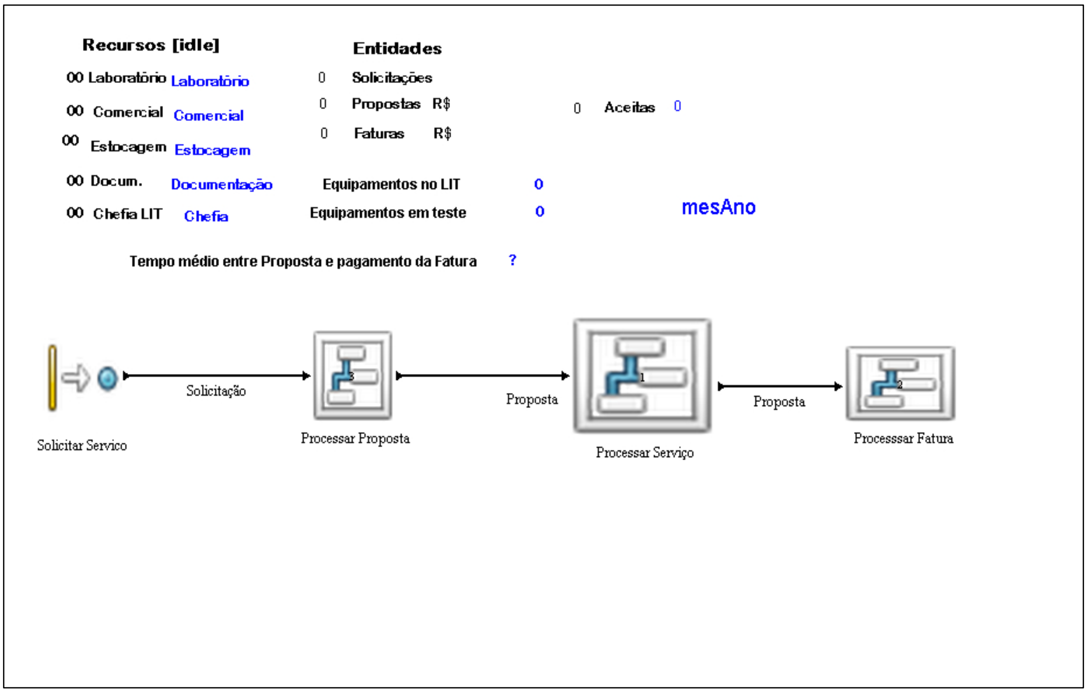

Figure 10 – Simprocess Model of the Complete LIT´s Commercial Services Processes.

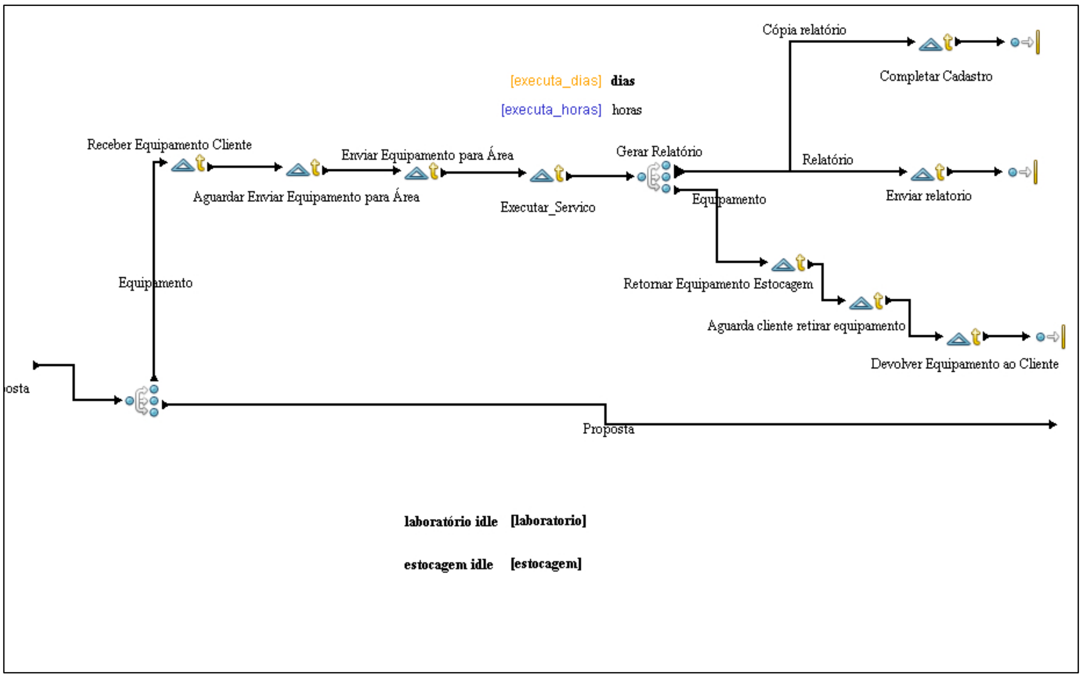

Figure 11 – Simprocess Model of the macro process component “Services Execution”.

3.7 The Collection of Data for the Models

After building the model, the next step was to determine the statistical distributions to be used to represent the duration of each activity. Data from the operation of the real system, extracted from LIT's information system (eLIT), were used to find the best distribution which fits each activity duration. This task has benefited from the use of the application ExpertFit, a tool that comes together with the SIMPROCESS simulation system.

Another important aspect was to correctly dimension the available resources for use by LIT for attending the industrial aerospace sector, that is, determining the total capacity of the various laboratories to attend commercial services, based on their total working capacity and its rate of occupancy related with the space program. For this purpose the CBERS-3 program was used to generate an agenda of resources utilisation by the several laboratories.

The information on the demand generated from the external sector in regard to the kinds of services provided by the various laboratories were also obtained from the system eLIT[3], which discriminates the services provided by each lab unit.

This model collection activity produced the following artefacts: the statistical distributions, to be used for the duration of all activities in the simulation; a full list of services provided by the lab units, their capacity and resources available and a simulated agenda with the demand for the diverse types of commercial services provided by each laboratory.

After performing the model data collection, the preparation for model execution was complemented by setting up a project of experiments (control parameters and possible scenarios) and populating it with the input data collected.

3.8 Execution and experimentation

Once the integrated environment has been implemented, it was necessary to set it up with all the information available, the majority of them obtained from the real system operation, then to execute it and assess its results.

The data produced by the eLIT information system has been used as the initial data source for input of data to the BPMS and Simulation System, to start their operation as an integrated software environment.

In a production / operational modus, the BPMS would naturally be fed by the staff personnel belonging to LIT´s commercial sector´s and lab units´, making use of real data produced by the execution of the daily services. Therefore, when this integrated environment becomes fully operational, and able to execute according to plan, it will take control of (automatise and monitor) all operations and the use of the eLIT system will be no longer necessary. Since this is still not the case, the trial BPMS system was fed manually with estimated data of the services orders (there was no recorded data available). These data are provided by three different types of users, namely: the *PAC register responsible* (staff member who attends the incoming orders to the PAC (Planning, Analysis and Cost sector); the *PAC proposal responsible* (staff member in charge of the elaboration of the PAC´s proposal); and the *LAB answer analyst* (staff member belonging to the lab units).

During the trial phase of a BPMS system one could anticipate that it would cause some difficulty to the staff personnel, who would have to input manually the data in both systems, the BPMS and the eLIT systems, creating a duplicate procedure and extra workload in their daily activities.

The agendas with the services provided for the space missions and that of the commercial services were overlapped by the analysis tool, a component of the integrated environment created, and it was easy to establish, using coloured graphical displays, where the conflicts arise related to the use of LIT´s resources.

The integrated environment created, as mentioned before, was not devised to be a definitive substitution of the eLIT system, neither the final solution to the problem of shared resources at LIT. Nevertheless, it played a significative role towards a better understanding of the system operation and the improvement of the services processes provided by LIT through the application of ProST.

The experimentation with the simulated agenda showed some unexpected results, such as the utilisation of the resources close to, or sometimes even above, 100% of their availability. The origin of these inconsistences was not detected, if they were caused by the use of inadequate statistical distributions, or from the data obtained from the eLIT system or even if it could be explained by the input from the real system´s data. This could also be a

[3] The eLIT system does not accurately match the process map used in the BPD´s diagrams. The data acquired by the eLIT system are sometime aggregate results of sequential activities, therefore the model data collection for the simulation was not always precise.

consequence of the actual services orders proposals received and scheduled, because they are kept waiting until a confirmation or cancellation is received from the client.

Another remark that shall be made is that, as a way to simplify the treatment of the resources throughout the whole of the integrated environment, one has assumed the rough approximation for their maximum utilisation time of eight hours a day. This is actually not true because climate chambers resources, for example, can remain turned on and be used for much longer time spans.

3.9 Analysis and Assessment of Results

Two objectives have been set up for development of the study case and assessment of its results in this research work, as stated in the following:

- The first one deals with the theoretical component, regarding the advances and the benefits of the application of the ProST Framework to the study case.
- The second one encompasses all other practical aspects, covering the quality of the tools developed and the assessment of the environment used in support of the approach.

A synthesis of how and to what extent each of these two objectives has been reached in this case study is presented in the following.

3.9.1 About the ProST Framework and its Application

The conduction of an advanced BPM study using Process Science and Technology in this work was based on two methodological fundamentals, each one related to a part of the unified life cycle process model:

- The building of a unique model (Reference Model) and its implementation using two different techniques, one the simulation model and the other for the operational models (PM and BPM) of the system.
- The use of an integrated approach for conducting the experimentation, analysis and assessment of results of these models.

The development of a Process Science and Technology study was an exercise of directly building and applying integrated and unified concepts, techniques and tools (transdisciplinary knowledge) to the solution of a complex process problem. The alternative would have been to having treated the same problem making use of n different (and supposedly independent) knowledge areas and techniques (multidisciplinary knowledge) for achieving a variety of insights and results. Thereafter, these solutions could had been put together and, since they would had been considered as independent coordinates, they would be used to build the full n-dimensional picture of the supposed complete solution of the problem.

Nevertheless, the two techniques used proved to be complementary to a certain extent, because they focus their modelling powers on different aspects of the system´s architecture and behaviour, but they take in account the process network as their main aspect of their model logic. Therefore, the benefits arise from their simultaneous and integrated application, based on the use of a common basis for modelling and analysing the system, represented by the reference model.

The conclusion is as follows: *Neither are the techniques independent nor the results they produced could had been put together at the end of the study, if they would not had been based on a single common basis right from the start of the study. The joint application of the techniques in the study of the system produced better modelling and analysis capabilities than their isolated use, **because they were based on a single reference model**.*

The application of a unified modelling approach right from the start of the model lifecycle resulted to some extent in an overhead, though, represented by the procedures needed to maintain model consistency and compatibility across the whole model development life cycle. This is a consequence of the actual multidisciplinary reality of the achieved solution, as opposed to the initial transdisciplinary promise of the proposed approach.

The above is a drawback of the transdisciplinary approach proposed when it is applied based on autonomous, already existing software tools. Rather than constituting an additional problem, this is seen as the result of the anticipation and of the attempt to solve future problems. These problems might arise in the process model life cycle if one follows the traditional way, which is the separate application of these techniques with independent models and the gathering and interpretation of the results to build a global solution thereafter.

A more encompassing and definitive solution for this problem shall be achieved only through the development of a mature unified life cycle process modelling methodology and its supporting environment, as a result of the improvement of the ProST Framework, to be obtained by its application to new study cases. The authors advocate that this methodology needs to be an evolution of the systematic approach presented in this work, which demonstrated its potential through its application to a specific problem and the use of two existing tools as its supporting environment.

3.9.2 About the Case Study and the Software Tools Used

The applications created in support of the management of the system were implemented using the BPMS Bizagi® (BizAgi 2011) and the SIMPROCESS® (SIMPROCESS 2011) simulation systems, chosen among other COTS systems due to their diversity of functionalities, friendliness of use and the existence of academic licenses.

The tools developed and the supporting environment used for their development are listed and reviewed briefly in the following:

- A simplified process model of the commercial services provided by LIT (industrial sector supporting activities), modelled in ULMD, BPMN and Simprocess simulation modelling notations
- The corresponding simplified 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
- A technical report written summarizing all analysis and conclusions about the problem drawn until now.

The Simulation Tool Simprocess ® and its Application

SIMPROCESS is a tool for hierarchical modelling which combines the power of Process Mapping, Discrete Event Simulation and Activity Based Costing (ABC) in one friendly Graphical User Interface.

The main characteristics of SIMPROCESS are: hierarchical Process Mapping; Object Oriented Methodology; Activity-Based Costing; animation; reports and graphical analysis through interfacing with MS-Access®; development by drag-and-drop procedures; reusable process models; realistic activities estimates; resources and consumable goods costs evaluation; dynamic visualization of the process and its bottlenecks; customizable reports, future scenarios and what-if analysis.

SIMPROCESS comes with a library of predefined components for the rapid creation of dynamic business process models, while an incorporated script language allows experienced programmers to add logic to the more complicated business process. SIMPROCESS is indicated for organizations which want to reduce the risks associated with dramatic changes in their processes. The tool allows the users, in a fast and easy way, to analyze different what-if scenarios and to make use of Java and XML technologies to attend the needs of their organizations for developing powerful and flexible process models.

SIMPROCESS and its applications can be used equivalently to a Decision Support System for analysis and decision taking about complex process systems, centered on the use of Modelling and Simulation techniques for process model building, execution and control, analysis, monitoring, and continuous model improvement.

SIMPROCESS and the applications developed with it turn out to be very versatile tools, offering a diversity of functionalities and resources. Among them, one shall remark:

- Customizable icons, which allowed the creation of a more communicative and familiar model to the team of developers;
- The creation of scripts, which allowed the customization of the tool and the introduction of specific logical aspects of the model;
- The plotting of graphical results during model execution, which enhances model understanding and analysis;
- The ExpertFit tool, which allowed the use of formal statistical distributions to represent essential characteristics of the model, exploiting to the best the use of the data collected from the operation of the real system.

The BPMS Tool BizAgi ® and its Application

BizAgi ® is a BPMS, an environment used to support the building of applications to automate complex business processes in a rapid and flexible way. It helps the users throughout all the development phases of the model life cycle, shortening system's development and deployment times and leading up to the continuous improvement of the organization's critical processes.

Bizagi applications are built progressively, starting with a process model of a workflow type, built in BPMN notation using a process modeler, and finishing with a Web application that executes as an embedded software component of the real system, automating, integrating and orchestrating all activities and resources involved in its operation.

BizAgi applications assure the efficient and adequate execution of all sequence of activities involved in the Business Process, by the correct person or resource, according to the enterprises' objectives and rules, allowing for the monitoring and the control of the process to be performed in real time.

BizAgi applications are capable of extracting the information related with process performance automatically and presents it to the right organization's personnel, helping improving the processes and increasing their efficiency. It offers and incomparable level of flexibility for modifying the Business Process in a simple, intuitive and consistent manner.

The Assessment of Application Tools as an Integrated Supporting Environment for ProST

The non-existence of a completely integrated and unified environment for simulation and BPM was overcome by the independent modelling using BPMN and process simulation modelling, as well as their independent implementation with the BIZAGI and SIMPROCESS systems. This resulted in an overhead in the effort for model development. This handicap will be treated in more detail in the continuation of this work, which will target the development of new study cases for the improvement of the models and the creation of formal verification mechanisms and software tools to support these studies.

The use of existing environments shows that a ProST supporting environment might be built by choosing among existing tools, with additional interfaces built for their integration. Alternatively, one could endeavour the development of an original integrated and unified environment composed by a set of tools designed from scratch to support the conduction of studies of Process Science and Technology in general.

The unified methodology and its supporting environment shall be based, in any of these cases, on the integrated use of consecrated pattern(s), verification mechanisms, communication interfaces, and applications to perform model transcriptions, in order to assure consistency and compatibility across different model formats and the complete interoperability of its component tools.

Despite of the drawbacks mentioned above, the tools used in this study case demonstrated good potentialities for their use as a supporting environment for the application of the ProST approach. These potentialities are:

- Different views of the model are created: the BPMN model in Bizagi Process Modeller shows its logical structural aspects and the representation of the simulation model in the Simprocess graphical interface describes in detail its dynamic behaviour and the interaction between the system's resources for the accomplishment of the processes;
- The different modelling views requires also a deeper reflection about the structure and dynamics of the system, leading to a better modelling and understanding of its operation, especially in cases one is dealing with complex system´s process definitions;
- The use of a multifaceted modelling aids to a better visualization and communication of the model among the participants, as well as for the experimentation, analysis, assessment and the documentation of the model;
- The essentials aspects of the model are identified in the beginning of the modelling process, but these aspects need (and ought to) be enhanced during the next steps performed by the analyst, while he implements the models in the business process management and simulation systems.

As a consequence, and a synthesis of the above mentioned, a better understanding of the problem was achieved, leading to a better quality of the models developed and its associated benefits to the complete model development life cycle.

3.10 Conclusions

The study conducted resulted in an enhanced BPM study, in comparison to the one that would have been produced by the application of the BPMS Bizagi or by the Simprocess systems in an isolated or, even if joint, not orchestrated way.

The case study presented has focussed on the organisation management processes and showed little of the potential of the method to deal with product development´s engineering processes, because no "single product" can be identified in this case, since the service orders are unrelated, made from an aggregate of separate demands from distinct clients. This resulted in the approach being applied in a simplified way, in which the systems engineering branch of the modelling procedure was not fulfilled. In conventional cases, in which the systems engineering branch is required, it is complemented by a full modelling of the design phase, equivalent to the V part of the systems engineering complete lifecycle.

The modelling of the design phase of product development would still find an application in this case study, but only with the goal of describing, specifying and dimensioning the "production line", in case it did not exist at all. Since LIT is a complex of existing lab units, already fully equipped with material and human resources, there is no need to carry out such kind of analysis for assessing its capacity to attend the commercial services demands. The full capacity of LIT´s infrastructure is well known from the beginning, the only consideration that has to be made is related with the restrictions posed by the spatial missions, which has priority and limits the availability of the resources for other utilisation purposes. These considerations must be taken into account when scheduling the commercial services orders, which should not interfere with the activities generated by the space missions and carried out in their behalf.

In future uses of ProST, when considering the development of satellites belonging to the space missions, one has to consider the complete cycle of the product AIT (Assembling, Integration and Testing) processes. It would be necessary to take into consideration the needs for modelling and analysing these product development processes, as well as those for (re)dimensioning LIT´s production line, if it becomes necessary.

The hurdles of the unexpected behaviour of the simulated agenda, the simplifications that had to be introduced to the model, as well as the duplication of the data input to feed both the BPMS and the eLIT systems required additional effort from the modeller for their overcoming. Nevertheless, one can state that, at the end, the development and the use of the integrated environment contributed to unveil or clarify many aspects of the system´s operation and helped to identify the sources of conflicts created by the use of shared resources at LIT.

3.11 Future Research

The joint application of simulation and BPM techniques in an orchestrated way to perform an enhanced BPM study of LIT´s commercial services processes produced a series of preliminary results, which helped identifying some of its deficiencies.

A list of suggestions is made in (Silva, 2012) for the improvements of the models and of the applications developed, in order to conduct a better analysis of the system, although one shall be aware that some of them might have considerable impact on the model structure and complexity, and therefore require a large amount of work.

Additionally, it would be advisable to consider the activities related with the space systems missions at LIT in a proper study of a similar nature conducted in this work. The inclusion of the space missions processes (mounting, integration and testing of spatial systems) would be an interesting subject for further research and the building of a complete model of LIT´s Services Processes.

In regard to the simulation application

The main characteristics that could be improved in the model are listed below:

- Discrimination of resources used in the Laboratory, classifying them into Engineers and Technicians;
- Discrimination of resources used in the Commercial Sector, classifying them into Administrative Assistant, Commercial Manager and Responsible for Invoicing;
- Discrimination of the types of Services provided (there are approximately 50 different types);
- Identification of exceptions and devising mechanisms for handling them.

In regard to the BPM application

A business process model might be seen simply as the evolution of the workflow model of a process, i.e., a structured set of activities to be executed consecutively or in parallel by individuals, machines or applications, in order to reach a given objective. A business process model, nevertheless, extends far beyond this simple definition of the dynamic behaviour and the interaction of the process resources. It encompasses:

- The organizations business rules, the strategic guidelines and politics of the enterprise
- The exceptions handling mechanisms
- Information databases and other kinds of elements

These elements might undergo continuous modification. Therefore, it is necessary to revise periodically the model and to keep it updated in relation to the aspects above.

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CHAPTER 4 − ONGOING AND FUTURE RESEARCH

Abstract

A summary of the ongoing researches and future research endeavours.

Keywords: Systems Concurrent Engineering, Project Management, Process Modelling for Simulation, Business Process Management, Process Science and Technology.

4.1 Ongoing Research

The results of the research project *A Framework for Process Science and Technology and its Application to Systems Engineering*, presented in this technical report, will be the subject of a co-edited book, entitled *Handbook on Process Science and Technology*. The book will document the continuation of the research work, which will be submitted for funding by research sponsoring agencies as a collaborative research project, to be continued between INPE/Brazil (National Space Research Institute) and the departments SEESE (School of Electronic, Electrical and Systems Engineering (SEESE) and SBE (School of Business and Economics), at Loughborough University (LU).

The ProST Handbook will contain a chapter with a literature review on the state-of-art of business process modelling techniques and the fundamentals of the ULMD (Unified Life Cycle Modelling Diagrams), notation used to create the reference model with the essential logical content of process models for future derivation of the specialised multidisciplinary modelling views.

The ProST Handbook will also contain several case studies, as listed below:

1. A complete study of the organisation´s management process of a stereotype organisation consisting of a generic Business Process Management Office.
2. The modelling and analysis of the design phase of the product engineering process.
3. The creation and analysis of a multifaceted process model to support the management of the service processes related with the product quality assurance in space missions. The model will describe a real system, corresponding to a section of the Services for Quality Assurance Division of the Department of Space Engineering and Technology at the National Space Research Institute.
4. The creation and analysis of a multifaceted process model to support the engineering and management services processes related with the space missions at the Laboratory for Integration and Testing of the National Space Research Institute.

4.2 Future Research Work

In order to progress with future researches in a long time basis, the project needs to have its original objectives decomposed in the following specific goals:

- Carry on identifying/classifying the BPMM and its branches BP/BPM/BPO concepts and techniques for assessment/comparison of their commonalities and complementariness to improve the understanding/restructuring/integration of their knowledge scope (ProST´s structural or descriptive view);
- Continue to unify/integrate the main modelling methodologies and analysis techniques from the above areas aiming at a continuous improvement of the unified process modelling approach for application in Systems Engineering (ProST´s dynamic view or BPMMM);
- Study the diverse existing process classification mechanisms (such as Zachman´s Framework, APQC, MIT Process Handbook), in order to choose one and/or to adapt their specialised reference models for use in specific case studies in the Systems Engineering area;
- Develop a complete case study of the systems engineering and organisation business management processes related with the design phase of product engineering applied to a real problem;
- Evolve the overall ProST/BPMMM approach with the application of the ProST framework in several other case studies.

These specific goals will be the subject of future research work to be proposed to master and doctoral research students of the course on space system engineering and management (CSE), part of the pos-graduation program of the Space Systems Engineering and Technology Department (ETE) at the National Space Research Institute (INPE).

APPENDIX A − REFERENCES

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