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T-PROST: A Transdisciplinary Process Oriented Framework to Support the Product Design Phase in Systems Concurrent Engineering

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Abstract. The objective of this work is to present and to discuss the potentialities of a transdisciplinary process modeling methodology, which has been named T-PROST Framework, to support the product design phase processes (production and management) in the systems concurrent engineering lifecycle. The methodology consists in creating a conceptual reference model of the systems concurrent engineering lifecycle processes and to transform it into specialised models of the areas of (Model Based) Systems Engineering, Project Management, Business Process Management and Simulation Modeling. The main benefits generated by the approach are derived from: The systematisation of the model development, encompassing both the systems engineering processes and their management; The use of the T-ProST Framework for model implementation and analysis, based on the simultaneous use of diverse disciplines and their respective methodologies and tools; The joint assessment of the specialised models created to provide better solutions and to improve project development. The T-ProST Framework can be used for the implementation of generic environments, made by the ensemble of applications implemented with the specialised tools used in the diverse disciplines. These generic environments can be used to perform product lifecycle management by organisations conducting short lifecycle project developments, characterised by low and mid-level complexity scopes submitted to severe time and budgetary constraints, as an alternative to the use of complex, expensive and difficult to configure proprietary systems existing on the market.

Keywords. Systems Engineering, Project Management, Business Process Management, Simulation, Transdiciplinary Process Modeling, Product Lifecycle Management

Introduction

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

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The general goal of the research endeavors on T-ProST has a wide scope and very ambitious nature: to develop a mature and comprehensive transdisciplinary process modeling methodology and to design and implement its integrated supporting environment for conducting studies of a large category of complex discrete event process problems in order to achieve better and integrated solutions. The problem domain covered by T-ProST is essentially the same one covered by discrete event process modeling and simulation procedures based on modeling representations, such as Activity Cycle Diagrams (ACD) [8], Role Activity Diagrams (RAD) [11] and Workflow Diagrams (Workflows) [12].

The main difference and original contribution between the use of the T-ProST Framework and that of the traditional use of its component disciplines is the creation of a transdisciplinary process model and its use as a common basis for the development of their individual specialised process models. This is done by conducting a systematic modeling procedure designated as Conceptual or Reference Modeling and making use of a graphical notation denominated Unified Lifecycle Modeling Diagrams (ULMD), an innovative diagramming technique originated from a fusion of the aforementioned graphical representations [1,2].

This work presents the T-ProST approach as a totally integrated application of their individual methodologies and techniques, originated from their autonomous component disciplines, to the design phase of the SE lifecycle. The limitation of the scope to the design phase of the SE lifecycle in order to explain the T-ProST approach was made for demonstration purpose only. In fact, it can be applied to any category of complex discrete event process that can be dealt with the Unified Lifecycle Modeling Diagrams (ULMD) notation and it is intended to be scalable and capable of being used in a wider context, covering the whole organisation´s business process management.

The rest of this work is structured according to the following. Section 1 defines some fundamentals concepts used in T-ProST. Section 2 describes the methodology and its application. Section 3 identifies the problem and sets the overall scope of the research. Section 4 presents the conceptual modeling phase and the resulting reference meta-model. Section 5 refers to the use of the methodology to create basic or generic PLM environments, made by the ensemble of applications resulting from the implementation of the speciliased models, making use of the autonomous disciplines and their supporting tools. Section 6 makes some considerations on T-ProST´s domain of applicability and the benefits and limitations of the methodology. Finally, the Section 7 presents the conclusions.

1. Fundamentals of the Methodology

The most fundamental and distinctive concepts in T-ProST are those of the transdisciplinary reference process model and its specific notation, denominated ULMD [1,2]. The reference process model in ULMD describes the system´s lifecycle process in its essential structural and dynamical features, with the special purpose of serving as a common basis for the development of the additional specialised models to be implemented in each of the autonomous component disciplines ofT-PROST.

The format of the modeling notation resembles very much that of the basic set of BPMN [13] icons with a few extensions and one could question the need for “yet another type of process modeling notation or graphical diagrams”. In fact, BPMN is widely used and supported by large communities, becoming the “de facto” notation for creating models to be converted into specific proprietary notations and implemented in a variety of proprietary tools offered by different systems´ manufacturers.

The use of the ULMD notation, however, is just a first step (the conceptual modeling phase) of a gradual modeling process and one can state that some semantic characteristics of ULMD are non-existent in any of the traditional graphical or textual process model representations, such as ACD, RAD, Workflows or even BPMN. These characteristics turn out to be essential for the type of logic and knowledge represented in the reference model.

The ULMD distinctive features start with its high level of abstraction and minimalism, comprising only a dozen of different symbols for expressing the complete structural and dynamics of the agents´ lifecycles as concurrent processes. The diagram logic expresses all-in-one: the hierarchical process decomposition, the variety of agents and messages and their process control flows, the agents´ lifecycles or roles and the interactions among them. The diagrams are created in the form of encapsulated modules, which can be displaced in frames or swimming lanes and pools, describing from a very simple process (task) to a very complex one (macroprocess).

Underlying all these characteristics, some of which could still be stated in regard to Business Process Management Notation (BPMN), there is an unequalled feature that differentiates ULMD from all other types of existing process modeling diagrams. They are not about pure logical operations and control flows (flowcharts), they are essentially about real time consuming transformation activities performed by real entities and messages (objects) exchanged between them.

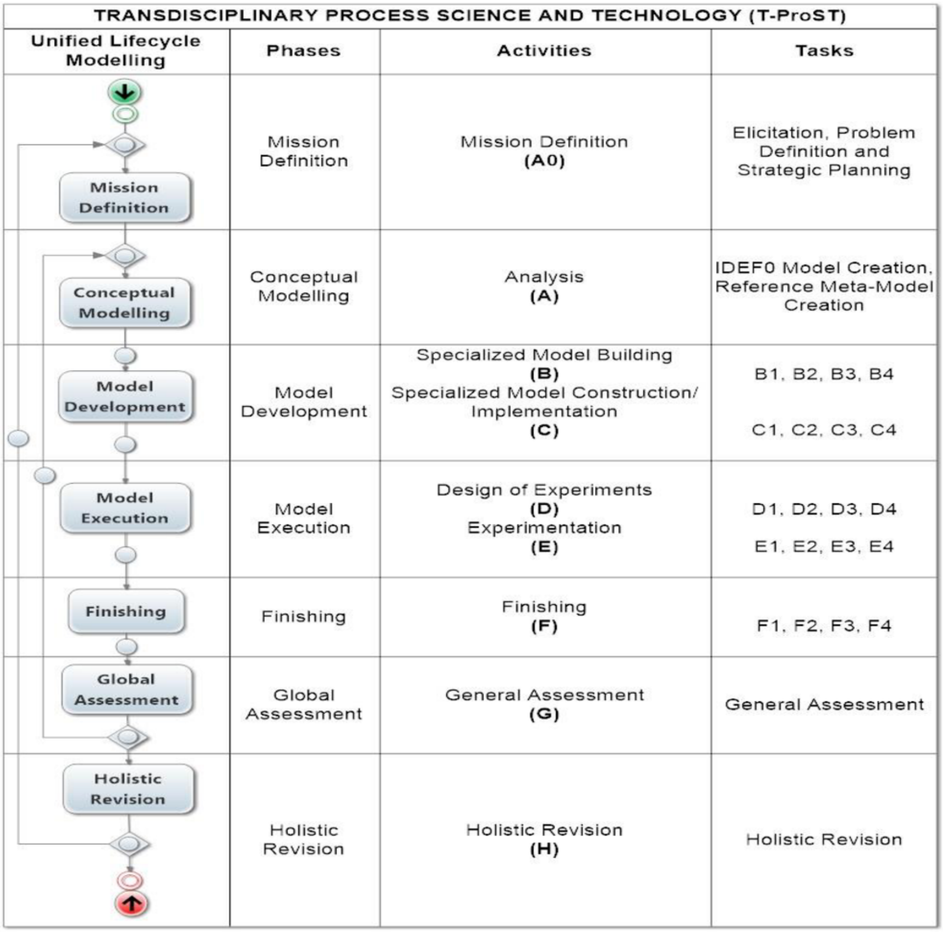
The links correspond to real entities flowing along their lifecycle (solid lines) or objects (dotted lines) exchanged between the activities, both used as inputs to other activities. Each class of entity has its specific process lifecycle, and they interact to perform their time consuming common activities, which get into a halt until all required inputs (entities and/or objects) are available and the additional internal initial conditions for their execution are satisfied. One special type of condition is external and it is depicted graphically, named triggering mechanism.

The control flows are always associated with some type of entity, resource, object or triggering mechanism, and they reactivate the processes in a hold at a particular point in time and location, making it progress through its complete lifecycle.

2. The T-PROST Framework

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

Figure 1 presents the T-ProST approach described as macro-processes and their respective component activities. The first column shows the Implementation Method or Unified Lifecycle Modeling procedure used to create the specialised models and evolve them along their lifecycles.



TRANSDISCIPLINARY PROCESS SCIENCE AND TECHNOLOGY (T-ProST)			
Unified Lifecycle Modelling	Phases	Activities	Tasks
Mission Definition	Mission Definition	Mission Definition **(A0)**	Elicitation, Problem Definition and Strategic Planning
Conceptual Modelling	Conceptual Modelling	Analysis **(A)**	IDEF0 Model Creation, Reference Meta-Model Creation
Model Development	Model Development	Specialized Model Building **(B)** Specialized Model Construction/ Implementation **(C)**	B1, B2, B3, B4 C1, C2, C3, C4
Model Execution	Model Execution	Design of Experiments **(D)** Experimentation **(E)**	D1, D2, D3, D4 E1, E2, E3, E4
Finishing	Finishing	Finishing **(F)**	F1, F2, F3, F4
Global Assessment	Global Assessment	General Assessment **(G)**	General Assessment
Holistic Revision	Holistic Revision	Holistic Revision **(H)**	Holistic Revision

Figure 1. Transdisciplinary Process Science and Technology.

The Implementation Method or Unified Modeling of the System´s Lifecycle Process is created by the aggregation of the different worldviews used by the individual disciplines that are part of T-ProST. These disciplines are jointly applied making use of a reference model as a common basis for the uniformisation of the system´s description, representative of its essential structural and dynamical features. The implementation method comprehends the transformation of the reference model into the specialised models, their implementation, execution, analysis and assessment, initially as units, and later on as aggregate, yielding a complete multidimensional analysis of the system, based on a holistic view that encompasses all individual disciplines applied.

The mission Definition phase consists in the system or problem definition and the identification of the study´s objectives, which is performed in one activity divided into three tasks, denominated Elicitation, Problem Definition and Strategic Planning, for generality purposes.

The second phase is the Conceptual Modeling Phase, to build the hierarchical reference process meta-model in ULMD format, describing the operational processes, corresponding to the real transformations occurring in the system. This makes it easier for the different kinds of users and modelers to understand the system´s behavior, and later on to translate this model logic into their specific type of notations, in order to accomplish the specialised model building and construction phases.

The remaining phases are those shown in Figure 1 with their respective denomination and more detailed definition given by the decomposition of its respective macro-process into its components, consisting of composed or single activities, the last ones named tasks.

The four numbered types of Tasks B, C, D, E and F are those related with the four component disciplines of T-ProST (SE, PM, BPM, and SIM). They are treated separately during the phases of Model Development, Execution and Finishing (specialised modeling, execution and evaluation), and their results are integrated in the Global Assessment Phase, to yield a thorough assessment of the multifaceted model created making use of the transdisciplinary reference model.

3. Problem Definition

The Systems Engineering Body of Knowledge (SEBoK) [3] defines that the complete Systems Engineering´s Lifecycle (SE´s Lifecycle) comprises 4 (four) macro-processes, namely (Conceptual) Design Phase, Development Phase, Operation and Disposal. The problem domain of interest in this work is the design phase of the SE´s Lifecycle.

Figure 2 shows the SE´s Lifecycle design phase main processes, Conceps Definition and Systems Definition, and their decomposition, their sequencing and the feedbacks between these processes, obtained from SEBoK [3], with the addition of the processes Feasibility Analysis and Planning, in order to adequate it to project management and space sytems engineering standards.

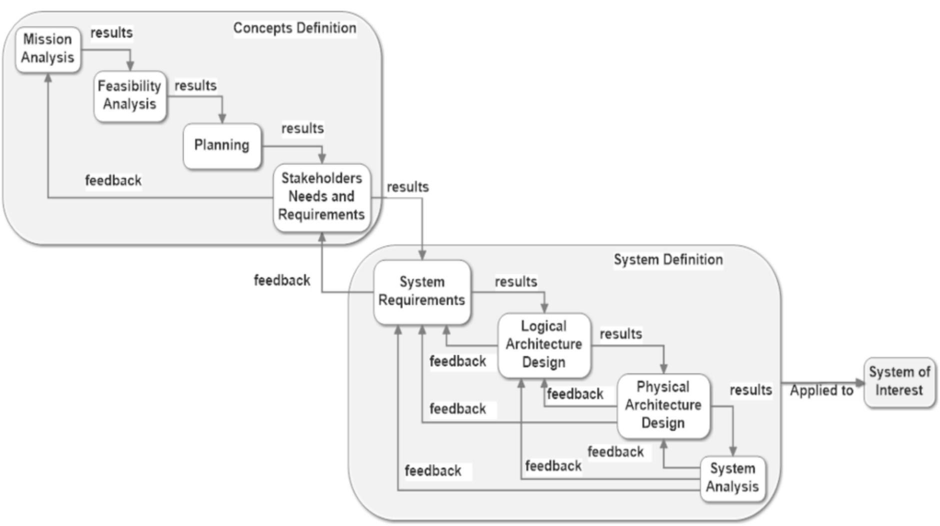


Figure 2. SEBoK [3] SE´s design phase processes, modified by the authors.

Any enterprise that has (Model Based) Systems Engineering (MBSE) as the main driver of its production processes may well make use of the concepts and definitions given in SEBoK to describe their product´s design phase according this structure.

During model execution several successive iterations and/or feedbacks are performed, until the final result is achieved, that is, the complete definition and specification of the System of Interest (SoI) is reached.

4. Conceptual Modeling

The Conceptual Modeling procedure consists in the formal description of the model through the realisation of two activities, namely The IDEF0 Model creation and the Reference Meta-Model Creation.

4.1. The IDEF0 Model Creation

Integrated computer aided manufacturing DEFinition for function modeling (IDEF0) [14] is a method designed to model the decisions, actions, and activities of an organisation or system. Effective IDEF0 models help to organise the analysis of a system and to promote good communication between the analyst and the customer.

IDEF0 models are often created as one of the first tasks of a system´s development effort. As a communication tool, IDEF0 enhances domain expert involvement and consensus decision-making through simplified graphical devices. As an analysis tool, IDEF0 assists the modeler in identifying what functions are performed, what is needed to perform those functions, what the current system does right, and what the current system does wrong.

Each activity or function in the IDEF0 model may be decomposed in several layers or levels. The subsequent levels follow the same conventions as the previous ones, therefore a complete IDEF0 model is a hierarchical representation of the component processes described by their internal decomposition in activities or functions in whatever number of levels necessary to reach the desired level of granularity for a complete and detailed model description.

In the creation of the IDEF0 model one makes the hierarchical decomposition of lifecycle descriptive macroprocesses without the concern of the processes sequencing. The objective of the creation of the IDEF0 model is to identify the hierarchical processes themselves and their parameters of interest such as: inputs, outputs, resources or mechanisms used in their execution. The inputs and outputs may represent objects (raw materials or finished products, respectively) and the controls are usually associated with the standards and rules to which the processes are submitted.

4.2. The Reference Meta-Model Creation

The second task of the Conceptual Modeling Phase is the creation of the Reference Meta-Model, a process model based on the descriptive model and the addition of the sequence of execution or workflow of processes. The workflow for process execution is added at this stage of the unified model development lifecycle, making use of the ULMD notation

The generic reference model of the systems lifecycle process describes the complete process map with their time sequencing, the main actors or agents and their respective process lifecycle, separated in pools and lanes for which these actors or agents are responsible, the routing mechanisms and the flow of control for process execution, the diverse types of feedback loops, to perform some kind of rework or revision of products and objects that should have been previously accomplished.

The ULMD reference meta-model of the SE´s design phase is shown in Figure 3. The complete reference meta-model comprises: hierarchically displayed component processes; their main actors or agents designated as entities; their respective individual process lifecycles with their time sequencing; the complete description of the inputs and outputs (objects and messages consumed or generated by the processes); the control rules and norms used for the transformations; the human and material resources or mechanisms used by the processes; the interactions and connections links displayed inside the lanes or crossing over their borders. All of that is used as a baseline model to evolve to the next phase of model representation, known as the Specialised Models Development.

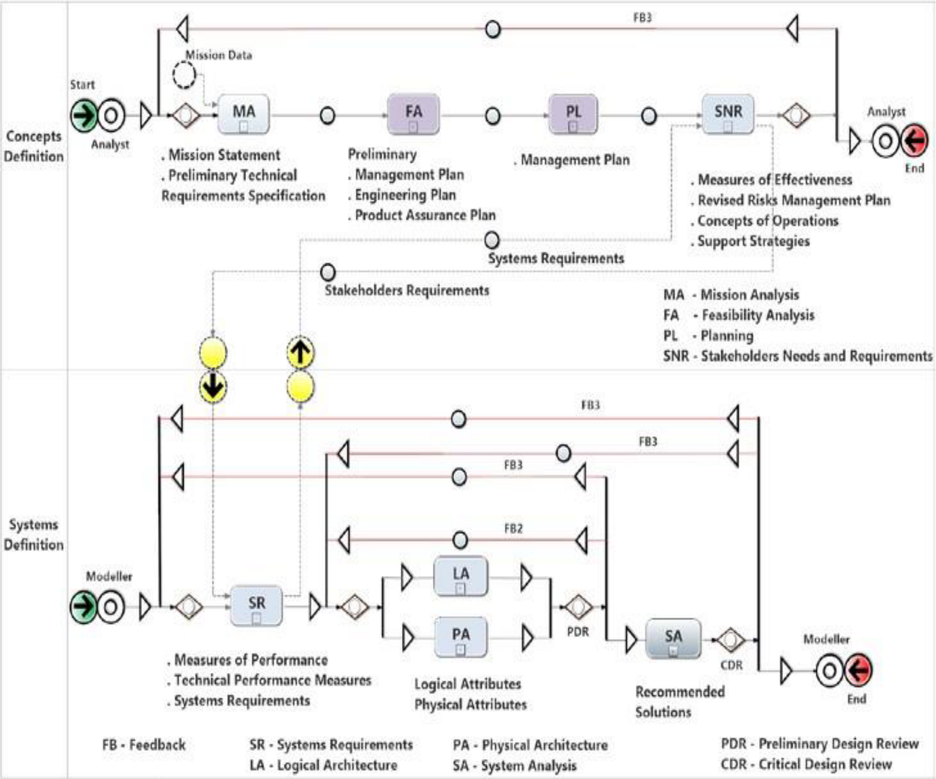


Figure 3. SE design phase – concepts definition and system definition – in ULMD.

4.3. Specialised Model Building

The specialised models are created gradually in the form of layers, the most internal one being the SE model, representing the systems engineering activities previously depicted in the generic reference model, equivalent to the core processes or real time transformation activities carried out for product development along its lifecycle, from its initial conception to its final stage.

The SE model expands the reference model and it represents the most complete description of the way the system is developed, acting as a configuration control system. This type of model is a descriptive model, that is, it is not intended to be executed as a process, it is intended to document the evolution of the system with all important information along the entire product development lifecycle, similar to a "recipe" on "how to produce the system", under an engineering point of view.

The PM model extends the SE model with additional PM processes, that is, it encompasses the activities needed for PM throughout the entire product development lifecycle. The PM model creation is considered as the application of PM techniques using a process-oriented view [5] supported by software tools.

The BPM model on its turn is built on the top of the PM model and extends it any additional processes required by the organisation for the complete management of its business processes, for example, with the ones related to the coordination of a portfolio of projects.

This gradual modeling and implementation procedure proceeds until the outermost layer is built, the SIM model, which encompasses all internal layers, made by the SE model with its core product development processes, the PM model with the additional PM processes and, finally, the BPM model, with the complementary business management processes carried out by the organisation during the complete product development lifecycle.

Any of the intermediary single layers can be treated separately and used for analysis purposes, in the traditional way their studies are performed. Simulation as a tool can also be used in association with any of the individual layers across the whole modeling procedure. The denomination of SIM model, however, is reserved for the fourth layer with the additional features necessary to conduct a complete simulation study of the SoI.

5. Implementation of Generic PLM Supporting Environments using T-PROST

PLM means Product Lifecycle Management, and its value is increasing, especially for manufacturing, high technology, and service industries. In fact, today PLM is widely recognised as a business necessity for companies to become more innovative in order to meet current challenges such as product customisation and traceability, growing competition, shorter product development and delivery times, globalisation, tighter regulations, and legislation.

The application of existing software tools originated from each of the individual study areas mentioned and the analysis of their integrated results in T-PROST can contribute to create a type of generic PLM modeling methodology and to build a general supporting environment, capable of performing systems engineering and management process modeling and analysis in a general context, and to significantly improve to the execution and management of the complete PM lifecycle activities.

The use of T-PROST for the implementation of a prototype of a generic PLM supporting environment has been the subject of a pilot project, which is explained in more details in a separate article submitted to TE 2016 [15].

These generic PLM can be used as an alternative to the use of complex, expensive and difficult to configure proprietary systems existing on the market. Their main potential users are designated transdisciplinary process-oriented Small and Medium Enterprises (T-SME organisations), who conduct highly advanced technological systems project developments, yet characterised by low to mid-level complexity technical processes, short concurrent engineering lifecycles, and severe budgetary constraints.

6. T-ProST´s Benefits and Limitations

T-ProST presents an interesting alternative way to improve the solution of problems involving complex business processes. T-PROSTS´s innovative holistic view addresses both the restructuring of the knowledge content (descriptive view) and the creation of a general systematic modeling procedure (unified process view), making use of reference models to base the individual or combined use of the diverse modeling techniques to create transdisciplinary multifaceted models.

The disciplines SE, PM, BPM and SIM incorporated in T-PROST are long established disciplines, with mature methodologies and supporting tools and large communities of users, therefore they encompass a wide range of methods and techniques used to deal with discreve event process problems in general. Their different types of worldviews, techniques and supporting tools are well known to their respective communities of users, although there is a lack of communication between them.

The T-PROST´s holistic view strives to unify the concepts, methods and tools from these diverse techniques and to jointly apply them in an easy and consistent way, integrating the work of multidisciplinary teams, reaching 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 proposed methodology can be applied to a large problem class dealing with complex discrete event process systems in general. This holistic approach could consolidate all the scattered knowledge on complex process under a single umbrella, capable of covering the entire problem domain and covering the complete process model lifecycle.

There is an expected overhead in this attempt to apply a transdisciplinary approach based on existing autonomous tools, represented by the expensive procedure in regard to maintaining model consistency and compatibility across the whole model development lifecycle.

The overhead resulting from the application of a unified approach right from the start of the modeling process is seen rather as an anticipation of future problems, which might remain unsolved if the traditional way, based on independent application of the techniques and the gathering and interpretation of their results to build a global solution thereafter, is applied.

This drawback can be reduced in future studies of this kind by the development of supporting environments made of an assembly of interoperable tools [15] and the use of formal verification procedures and of software mechanisms to improve process model consistency and compatibility.

7. Conclusions

The methodology has been applied in a real scenario of a small satellite project development conducted by the students of the postgraduate Course on Systems Engineering and Management (CSE- 331/ETE/INPE).

The application of the T-PROST Framework for small satellites project development is documented in [15], and it was performed as a class project, making use of Simprocess as its main software component, used as GUI for the reference model building, and some Commercial Off-The-Shelf (COTS) systems with open license or low cost academic versions as the additional tools for specialised model building.

The full benefits of T-PROST shall be achieved in the long run by the design and implementation of hybrid PLM supporting environments capable to deal simultaneously with all the issues involved in the individual study areas. Different complete generic PLM supporting environments of this type can be built to allow the modeling and analysis of a production process as the application of basic SE, PM, BPM and SIM tools, in substitution of complex PLM systems [15], which are costly and difficult to customize.

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