Modeling the "AS-IS" product development process: lessons learned from a practical experience in the aerospace industry

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Summary: In this article we summarize the experience of regional jet aircraft manufacturer Embraer AS in its recent effort to model its Integrated Product Development (IPD) process. Given the distinctive nature of Product Development in relation to well behaved processes such as manufacturing, finance, etc (where traditional modeling notations and techniques are largely applicable), a specific context based modeling approach had to be developed and implemented in this project, and form the scope of this article. Of special interest are the lessons learned, and insights gathered, during the project. This article is therefore placed as a practical contribution both to other industries involved in PD process modeling, as well as to researchers interested in the subject of PD process modeling.
Keywords: product development, process modeling, reengineering, engineering design, DIP, IPD, design, NPD, PD

1. Introduction

During the last decades, literally thousands of companies around the world have been engaged in efforts to model their core business processes (manufacturing, product development, finance, etc). The reasoning behind these improvement efforts is simple: Better processes (=more efficient) represent competitiveness and consequently increase the ability of the company to keep competitive in its sector. Many good books are available on this topic (under what has been generally called Business Process Reengineering (E.g. HUNT, 1996; GALLOWAY, 1994; MANGANELLI & KLEIN, 1996 e HARRINGTON, 1991).

One common step to any process improvement effort is the drafting of the current process model (the "as-is" model), where the focus is to generate a process model that represents the best description of the current practice (and not the desired, or the "to be" process). Various modeling methodologies and notations such as IDF0/SADT (See HILL, 1995 and MARCA & MCGOWAN, 1993) and the EPC (*Event Process Chain*) are currently available to support this stage. The applicability of these methods and notations to modeling the Product Development (PD) process, however, is questionable, given the particularities of PD practice.

Indeed, the practice of PD in industry is complex by nature, always involving different ranges of activities, such as definition, specification, design, detailing, analysis, testing, certification, which must always be conducted following requirements and restrictions of time, cost, quality, environment and certification authorities. In order to be carried out consistently, a "well-established" environment must also be set (simultaneous environment) and the right tools and working methods to support the execution of the process must be available to practitioners. All of these characteristics must be taken into consideration when choosing and establishing the methodology to be used to represent the process.

Another characteristic that is intrinsic to PD, which renders most of the common known modeling techniques inappropriate, is its research and innovation character. Furthermore, and contrary to well behaved processes (where activity A follows B, that follows C, etc), such as in manufacturing and finance processes, the practice of PD is strongly characterized by the abundance of inter-relationship and inter-dependencies among the activities that compose the process. All of these characteristics are typical in simultaneous product development situations, such as the one found at Embraer Aerospace, in Brazil.

In April 2000, a project was established at Embraer focused in modeling its PD process. A careful study preceded the implementation of the project and was focused in investigating, understanding and incorporating all of the lessons learned in the previous internal modeling efforts, in order to establish a modeling approach with a higher change of success than the previous adopted approaches. The project, which follows the derived approach, is currently (August 2001) being conducted, involving about 200 engineers (including Junior and Senior Engineers) from the Engineering Department. So far, the results have been very satisfactory, supporting the hypothesis that a customized approach for process modeling, in PD environments, is more effective than the adoption of common known, out of a book, modeling techniques and notations.

In this article we approach the topic of PD process modeling focusing in the practice, applicable methods and tools, as well as the lessons learned at Embraer during its PD process-modeling project. The work is thus placed as a contribution to authors and practitioners involved with PD process modeling.

2. Modeling approaches - Discussion

To model a process means no more than to get to know and make explicit the way that a given process is conducted in the practice. In a real life situation, however, this task can become quite complex. In some cases, this complexity is born out of the modeling depth that is aimed. In other situations, the complexity is a direct consequence of the degree of complexity that involves the process itself (as in the case of the PD process), or even the way that the process in currently conducted in the practice. Another fact that may render process modeling a complex venture is the non-existence of a macro, well-established process, to be used as a departing point in the modeling effort.

Various authors such as PUGH, 1991; CROSS, 1989; ULLMAN, 1992 e MCGRATH, 1996 have proposed, in the last decades, theoretical models of reference for product development. Most of these models are funded in the experience and perception of these authors, and are normally directed towards the prescription of models applicable to any kind of industry, developing any type of product. In some cases the proposed models includes the steps, activities, applicable tools, etc of a typical PD effort. An interesting fact is that very few companies are able to understand their own PD practice using the "lens" provided by these reference models (see for instance BARKAN, 1994). The result is that, whereas didactic, these models are rarely appropriated to be used as the basis for a modeling effort in the practice.

In the last few years, some research projects have been established directed towards the construction of reference models appropriate to specific industrial sectors (see for instance the work of ROZENFELD, 1997). The idea behind these efforts is the creation of models that are more concrete, and that can, therefore, be used as reference models to specific industrial sectors. This type of research, from the best of our knowledge, is still in the early stages of development and, even though some good results have been reported, the thesis of the appropriateness of industry specific PD reference models needs yet to be proved. For most of the industries involved in Product Development modeling, three approaches are generally employed:

1) Top-Down modeling approach: In this case, the model of the process is built from the top-down, until a degree of detailing that is satisfactory to the company's particular goals. This case is very common, especially when the company has an established macro model (top level model) of its process, from which the modeling effort can be initiated. The advantage is that this approach is less complex and generally catches the interest and early involvement of top management. The major problem is that it is generally very difficult to concatenate the daily reality of the company's PD practice to the macro process. Thus, the generated model, even though representing a good "general view" of the process, is generally too abstract to be understood and applied by those involved in the daily of the process practice (PD practitioners).

2) Botton-Up approach: This is the inverse way of modeling. In this case, the process practitioners (i.e., the people that actually execute the activities and tasks of the process) would be involved in the construction of the model, starting with the bottom level activities and tasks. The method has the strong advantage of catching up the interest and participation of the practitioners responsible for the process, and always will bring credibility to the generated model. Another advantage is that, having participated directly of the project, the intended people are more likely to see how their "contribution" fits into the PD model, being thus more likely to use the proposed model. The problem of this approach is that generated models are always created following (or based on) local perceptions of the process (functional or departmental). The consequence is that a holistic view of the process is difficult to be set, and also any cross-functional process improvement effort, basing on the derived model, is difficult to be accomplished. Considering that the interfaces between sectors and departments are the place where most of the improvement opportunities can be found, this is a major drawn back in this approach.

3) Mixed Approach – The case Embraer: In the middle of the two approaches discussed above it is possible to think of various mixed approaches. In the work discussed in this article, the applied approach initiates with the establishment and approval by top-management of a macro model of the process. From this point the attention moves towards the lower level of the PD process. Functional teams are assembled and trained with the goal of modeling their own "portion" of the general PD process. As soon as these local "partial processes" are written, we move to the stage of modeling the interfaces and connecting the local processes, until they are finally connected to the top-level process initially proposed. Even though this approach appears complex (specially in the stage of connecting the local processes), our experience in

Table 1 – Lessons learned and solutions implemented during the project (summary)

Lessons learned (Internal, external and literature) (Treats and risks in the project)	Proposal
• Project is initiated with lots of motivation and involvement from participants, but is soon placed as a secondary activity in order to give way to more urgent matters. All of the spent efforts are wasted and the project is abandoned (often to be born again years later!).	♦ Top management must be fully involved in the project and have a correct understanding of the nature of the project, its goals, the proposed solution and necessary involvement. ♦ The modeling project must be included in the Engineering Department's annual action plan (or similar document) that establishes the department's priorities for the specific year. ♦ Management must be ready to staff the project with the necessary human resources to conduct the project. ♦ Depending on the size of the organization, a 100% focused company based team (project's core team) must exist in order to coordinate and support the project.
• Process modeling is conducted by people from outside the organization (consultant, trainee, etc). The consequence is that the people responsible for the process (the ones the "live" the process) do not feel the "owners" of the derived information, are rarely able to understand the description of the process (employed terminology, underlying concepts, etc), and will, therefore, not use the results of the effort.	♦ The whole of the modeling project MUST be conducted with the full involvement of the process practitioners (specially the key engineers) and owners. They are not only the ones that know the process, but also the ones that will use the generated models later on.
• Generated process models become obsolete (and consequently useless) too soon.	♦ The computer-based tool used to store the information of the processes must be friendly. Maintenance of the processes (when necessary) shall be easy and quick to perform. ♦ The responsibility for the maintenance of the processes becomes part of the job description of the process owner. ♦ The maintenance of the processes must be regularly included in the annual action plan (or similar) of the company´s engineering department.
• The format (notation) of the process charts and description is too complicate for the typical engineer, rendering the whole effort useless.	♦ To involve the process owners and actors in the choice of the right format (notation) for the description of the processes. ♦ To involve the process owners and actors in the modeling effort, in order to guarantee that the described processes are in conformance to their interpretation and way of understanding the process.
• Project participants want to have access to a computer modeling tool too early in the project, and therefore lose the opportunity to discuss and settle an unified understanding of their own processes.	♦ Any software will be made available to participants only after a minimum number of round table discussions have been carried out involving all of the interested parties. This force discussion, understanding, and revel problems and opportunities.

this project have shown that the approach triggered participation and involvement of both top-level management and functional people (engineers, etc), which is absolutely essential for the success of this type of project.

2.1. The depth of the model: How dep should we go?

The expected level of detail (process depth) must be intrinsically connected to the goals of the project. The more detailed one expects the model to be, the longer the time consumed and the larger are the odds that the process model with soon become obsolete. In some of the companies that we investigated, the PD process-modeling project took more than 5 years. In some other cases, it took no more that a few months. It all depends on the level of detail targeted, the complexity of the PD practice and the availability and level of involvement of people to carry out the project internally.

2.1. Executed/supported by consultants or internal personnel?

This is a typical question asked by companies when they first get involved in modeling efforts. It is very tempting the idea that, for a certain amount of money, a consultancy company will not only model 100% of your process, but also identify your problems and propose steps to improve your process. Many companies choose this way, only to find out that the results are generally bellow the promised by the consultants.

At Embraer this approach was also experienced in the past, with less than satisfactory results. It must be clear to the people involved in modeling the company's PD process, since the beginning of the project, that the only people that really know the company's PD process, and therefore that are able to describe it, are the ones that "live" the process, that is, the PD practitioners. The conclusion is that all of the modeling activities must be executed by the PD practitioners, and not by "outsiders" (consultants, trainers, researchers, etc). It is also fundamental to get the PD practitioners to have the real sense of ownership for the modeled information. Without this, the language used to describe the process is likely to be "strange" to the owner of the process, very often not corresponding to the way that the process owners perceive their process.

To the consultants (either internal or external), if applicable, is left the rule of providing methodology, guidelines and support to the project.

2.3. Based on computer (software supported) or not?

Regarding computer-based tools to support modeling, dozens of options are available. Some are simple flow-building tools (e.g., *FlowCharter*Ò, *Visio*Ò, and many more). Others are a lot more sophisticated, including the utilization of specific modeling methods and notations, and, in some cases, the need for specific apparatus (e.g. *Aris Toolset*Ò). More recently we have seen companies advertising tools that propose not only to support the modeling process, but also to support the implementation and the daily operation of the generated models (work flow like software). One example of such class of modeling tools is the software *KPM*Ò, from a company called KTI. The real applicability and advantage of the later type of tool has yet to be proved, as very few companies have already tried it.

We must notice that it is very comfortable the idea that any modeling effort must start with the choice of a modeling tool. Although tempting, Embraer´s experience shows that there must exist an initial stage in the modeling effort where meetings are held, with the employment of "Post-It" and paper based forms, where the goal is to achieve a minimum level of common understanding among the process practitioners of the nature of their own processes. It is surprising to see that even people working together in the same process, for 10 or 15 years, can still have very different perceptions and interpretations of their processes. Such leveling of understanding is not possible to be achieved if a computer tool is given to the teams too early in the project.

3. Modeling Embraer´s IPD Process – Past experiences and lessons learned

As mentioned above, in the last decade various modeling efforts have been carried out at Embraer, as well as in thousands of other companies, with various degrees of success. Modeling efforts often consume a lot of time, patience and resources from all of the involved parties. It is therefore important that the adopted approach in any new modeling effort is able to take maximum advantage from the lessons learned in the past experiences, increasing, thus, the chances of success.

At the beginning of the modeling effort described in this article, a careful investigation was conducted focused in identifying all of the good and bad experiences from past modeling attempts, both internally and externally (from certain selected companies in the Aerospace sector). These lessons (See summary in the Table 1) provided the fundamentals for the decisions taken during the project, regarding approach, methodology and way to go. Taking these lessons into concern along the project has been considered by the project core team as key for the success of this effort.

4. Goals for modeling Embraer´s IPD

A sharp understanding of the objectives of the modeling project must be set before embarking in the effort. Hundred of companies have learned at a very expensive price that no modeling project can be started before the goals are established. To model just for the sake of having the process modeled is definitely not a clever approach. For the project discussed in this article, the following goals (ranked by order of importance) were discussed and agreed by all of the Engineering managers:

1. To provide raw-material for being used in the elaboration of training and adaptation programs to engineers.

2. To explicit the "*know-how*" of the organization.

3. To improve planning in the new programs.

4. As a basis to choose and develop new computer systems to support the PD process.

5. To improve Embraer´s PD process (Generation of a "To-be" model).

6. Generate material to support AS9100 implementation.

7. Generate internal procedures, when needed.

8. Identify problems and promote improvement.

The established goals drove, among other things, the modeling approach to be applied in the project, the degree of involvement request from functional personnel and, mainly, the final format of the modeled processes.

The final version of the proposed approach, summarized in the next sections, represents our best efforts to concatenate the best process modeling practices currently available in the literature to the goals and specific context of Embraer, always taking into consideration the lessons learned described in Table 1.

5. Concepts and Adopted Terminology

The term "process" allows for all sorts of definitions and interpretations. Indeed, any organized set of steps, tasks, activities, operations or decisions, involved in the execution of a certain effort, can be regarded as a "process". On this respect, many books have been written presenting all sorts of definitions for this term, and related ("activity", "task", etc). However, less important than to find the "right" definitions for these terms, is to have them consistently defined, and mainly, understood and agreed by all of the modeling project participants.

Some PD processes can be rather simple, and entirely executed by one person (e.g., rivet dimensioning, specification of a connector, etc). In other cases it can involve entire organizations, with dozens of people being gathered to carry out the various activities involved in the process (e.g., the development of the fueling system of a new aircraft). It is therefore necessary the selection and the definition of terms to differentiate the levels of a process according to their scope, lead time and number of involved people.

5.1. Terminology employed in the project

At Embraer the following terms were used to describe the company processes in their different levels:

- Business Process
- Process
- Sub-process
- Activity
- Task

The first level is known as the Business Process level. At Embraer, 10 Business Process have been defined (manufacturing, financing, etc). Integrated Product Development process (internally called DIP – from the Portuguese "*Desenvolvimento Integrado de Produtos*") is one of these business processes.

In some cases, and with the goal of facilitating the modeling of a business process into the lower levels, it is possible to split the business process into a number of parallel processes. We can, for instance, think of a new aircraft development process as a collection of parallel processes being carried out simultaneously such as the development of the wing, the development of the fuselage, the development of the tail, tooling development, ground support equipment development and so on (See Figure 1, levels 1 and 2).

Each of these parallel processes can, by their turn, be sub-divided into SUB-PROCESSES, which are no more than sets of activities grouped by affinity. In the case being discussed, the following sub-processes are generally applicable to any object, part or system being developed:

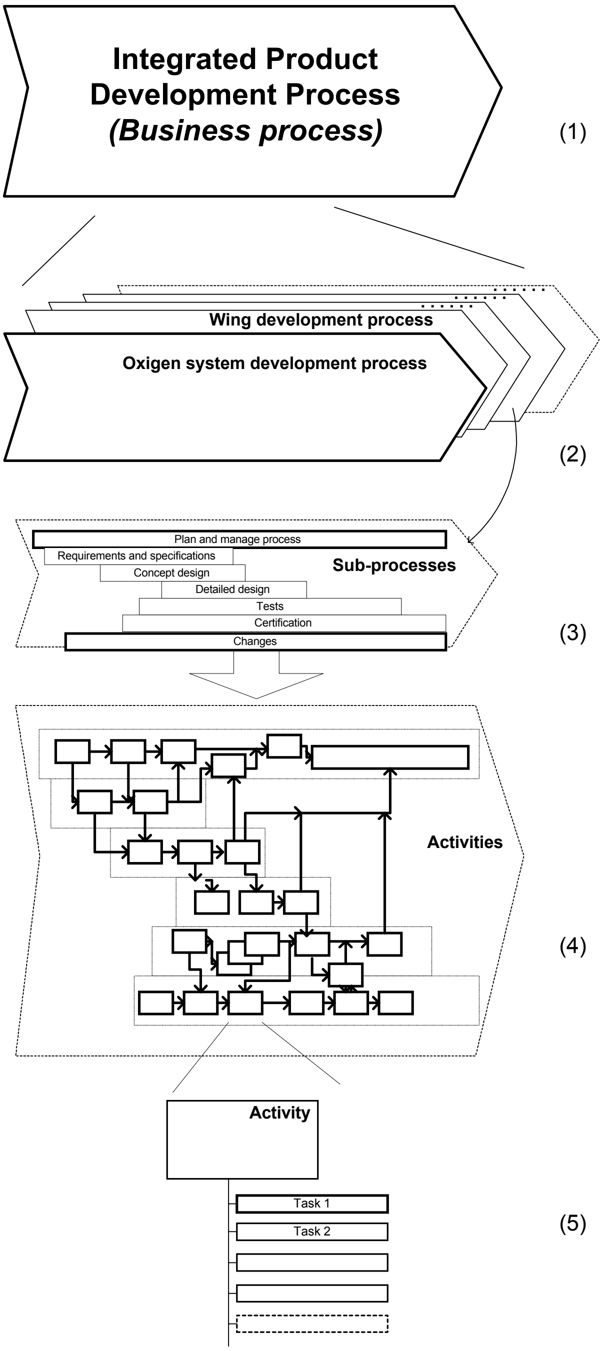

Figure 1. IPD process levels at Embraer

- Plan and manage development activities
- Establish requirements and specifications
- Conceptual design and definitions
- Detailed design
- Tests
- Certification
- Execution of product changes

Bellow the sub-process level we have the ACTIVITY level. Activities are often executed by one cell of work (team or individual) and have well defined inputs and outputs (See Figure 1, level 4). As an example of activity, in the scope of this project, we can imagine of (a) *Generate plan of work,* (b) *Execute fatigue analysis of a part,* (c) *Elaborate an engineering change order* and so on. Most of the efforts in this modeling project were focused in identifying and modeling the activities that composes Embraer PD process.

Bellow the level ACTIVITY we have the level TASK (Figure 1, level 5). This is the lowest defined level at Embraer, and involves operations (steps) of short duration, most of which entirely executed by one person. Example of tasks includes *(a) Entry data into a system's screen, (b) draw a small part of a system, (c) execute fatigue analysis of one structural component,* etc.

6. Describing processes and activities

In order to be capable of executing product development, a company must not only have technological domain of what is involved in the product. Indeed, they also need to have capable human resources (with the necessary skills, knowledge, abilities, etc), financial resources, infra-structure, information, leadership, appropriate tools, computers, testing equipment and many more constituent factors, all of them equally important in order to a company to be able do conduct PD properly.

To model processes and activities, in the scope of this project, means identify ALL OF the constituent factors that compose Embraer´s PD practice scenario, understand their inter-relationship, precedence, contexts and so on. It is therefore about identifying and describing the contents of the process, and not only to draw flows describing the process (which is normally the case of most process modeling projects that we observed in the practice of other companies).

6.1. What must be described

The exact content of the models depends, again, on where we want to go, that is, the objectives for the effort.

For the project discussed herein we have established the concept of "minimum", which tells us what are the attributes that are essential for any model to have (both the processes and the activities in the process):

1. Title and short description of the process/activity.

2. Functional area responsible for the process/activity (Notice that even though most processes are cross functional, one specific area is always identified as the owner of the entire process)

3. Skills need to carry out the process/activity.

4. Inputs (these are the set of information which must be supplied to the process/activity)

5. Who provides the information (person, functional area, or process that generate the needed information, including format and media)

6. Outputs (information that are generated by the process, and are used in other processes/activities)

7. Who uses the output information (person, functional area, or process that use the generated information, including format and media)

8. List of the activities that composes the process/activity

9. Key systems (Nastran, CATIA, SAP, etc) and documents (manuals, procedures, norms, etc) that specify how the process/activity must be executed.

10. New technologies and tools that should be investigated, and that are related to this process/activity.

11. Main problems faced by the people responsible for the execution of the process/activity.

12. Suggestions of improvement.

13. Tips.

7. How to conduct the modeling effort?

The way to implement a certain approach is strongly dependent of certain key context-specific variables, including (a) past experience in process modeling and the results achieved from these experiences – positive or negative results, (b) prevailing attitude of the involved personnel in relation to this type of project (somehow a consequence of the item 'a'), (c) availability of specialists (the ones that really know the process, and are therefore capable of describing it), (d) involvement of top management and (e) priority given by top management to the project. Analyzing each of these variables in relation to the context of Embraer´s Engineering Department in the year 2000, a proposal was presented composed of the following 4 (four) phases:

Phase 1: Identify the processes and activities that compose Embraer´s IPD and detail the project plan (considering priorities, interests, etc).

Phase 2: Carry-out modeling project (all of the processes and activities).

Phase 3: Enter process derived information into a corporative modeling system (software).

Phase 4: Translate (derive) process model information into specific applications (according to specific interests, expectations and objectives of the functional area and programs involved).

7.1. Phase 1: Identify Embraer´s PD processes and activities and set priorities

The following steps were conducted during this initial phase (See Figure 2):

1. Organize the modeling project (organization of the effort, core team, modeling teams, etc).

2. Equalize understanding of Embraer IPD (Araujo & Cruz, 1999) among team members.

3. Train all of participants on the proposed modeling approach (steps, method, plans, priorities, etc).

4. Identify the IPD processes and validate with the functional areas (Step must be conducted with the participation of all of the involved managers and the key members from the functional areas).

5. Identify core technologies and technological domains involved in the process.

6. Detail the project plan (considering priorities, interests, etc) and validate with top management.

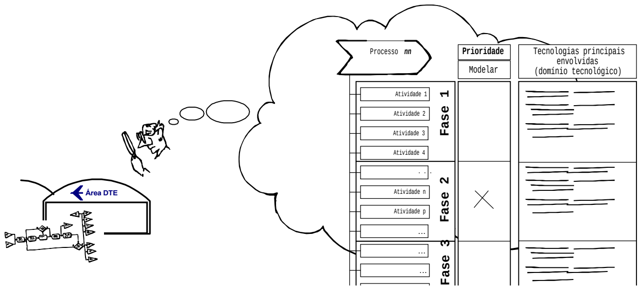

Figure 2. Phase 1 of project: Identify process and activities and generate project detail planning

7.2. Phase 2: Carry-out the modeling project (all of the processes and activities)

In this phase the various teams in the functional areas, were responsible for:

1. Constructing the process charts and describing all of the processes.

2. Detailing all of the activities in the processes.

3. Validating the modeled processes and activities with the owners of the processes.

For the project in question, this phase consumed a total of 11 months, with the participation of more than 200 engineers (some of them working full-time in the project). During this long phase we made extensive use of various techniques and tools from project management, always with one foot on the lessons learned at Embraer in the past. The most difficult aspect was to keep alive a long–term project that was, although important, not considered a priority for the department.

7.3. Phase 3: Transport of the process and activities models to a computer based modeling system

In this phase, all of the modeled processes and activities will be entered into a corporate wide computer based process-modeling tool. This step is important, allowing the teams to work on the troublesome process interfaces.

The proposal is that all of the processes will be maintained, once the project is finished, directly into this unified process data-base. For that aim the Engineering Department is now (2001) working in the establishment of the figure of the Technical Responsible Engineer, who will have, as one element in his/her job attributions, the maintenance of the IPD processes and their dissemination and implementation into the various programs.

7.4. Phase 4: Translate (derive) process model information into specific applications

Once the processes and activities that compose the IPD have been described, agreed and made available to all of the PD practitioners, the next step is to generate specific "applications" out of the generated raw-material, that is, the process information (See Figure 3).

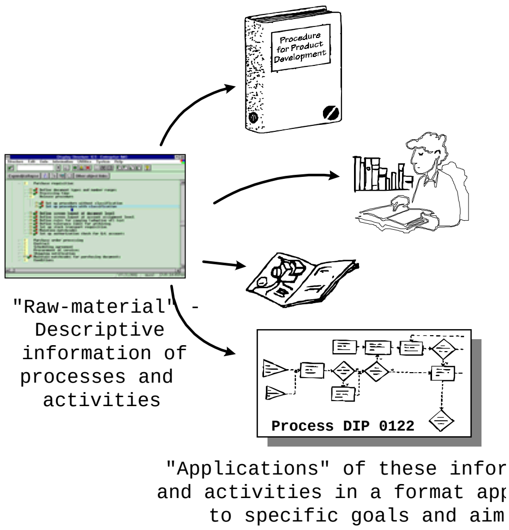

Figure 3. Generating applications out of process descriptions.

Most of the failed modeling projects that we investigated (internally and externally) had as their goal merely the description and delivery of the processes models (which corresponds to the Phase 3 of our case). Information of a process (forms and flows) is rarely an appropriate format to prompt application and utilization of the delivered process models. Further work is ABSOLUTELY necessary in order to transform this "information" into something that PD engineers and managers can use in their daily work, always considering specific interests and expectations of the various functional areas and programs.

For instance, if the goal is to train new engineers, an idea would be the creation of nice booklets and charts describing the process in a didactic format. The content is the same, but the format is appropriate to the aim. If the goal is to explain our processes to our international partners, a translation of the process into English would be requested. If the goal is to automate some activity in the process, a system (intranet, work flow, etc) should be built using the process information, and so on.

8. Final Considerations

Integrated Product Development (IPD) process is a complex phenomenon, with a strong technical and creative nature. This renders most of the currently available modeling notations, tools and methods not applicable to model this type of process. A context based modeling approach was built as part of a PD modeling initiative at Embraer Aerospace, and is summarized in this article. Some of the key lessons learned during this project and past modeling projects at Embraer were also disclosed, as well as some insights gathered during the project.

The thesis for the project, that an specific modeling approach, strongly focused on the context, and with strict observation of the lessons learned internally from other similar projects, is the most appropriate way to conduct this project is claimed to be valid, based on the good results achieved so far in the project, in confrontation to the poor results reported by companies applying traditional modeling approaches to model PD. Some final considerations, believed to be relevant to other companies involved in PD effort or investigation, include:

♦ Process modeling is not an exact science! There is never a unique, or final solution. Dozens of ways to understand any process are always possible, and equally correct. The important is to involve the process practitioners in the modeling effort, in order to derive a valid and agreed description.

♦ Process modeling is a learning experience. The more we get involved in the modeling effort, the more we learn about the process being modeled, and therefore, the more inclined we are to change the initial description of the model. To accept this fact is key for a successful modeling initiative. Keep the focus on the project goals. Two or three reviews of the models are always enough.

♦ Avoid falling in love with modeling software tools too early in the project. The major challenger in process modeling is not to get a model done, but get it agreed by all of the involved parties. Getting agreement from the involved parties is always easier if we involve these people during the project, and not afterwards.

♦ Make your best efforts to involve everyone (process owners and users) in the project. The more we involve this people, the closer we are from generating something that they will feel the "owners" of, and therefore will be more inclined to use.

♦ Be flexible with your modeling strategy and planning (in order to accommodate the emergencies and priorities of a real PD situation) but NEVER give-up the fundamental premises and assumptions established to the project (concepts, terminology, format, etc).

♦ Be creative to keep the project alive by keeping participants motivated. Frame the whole project as a unique opportunity for them to improve their work.

Finally, it is important to remember that process and activities, especially in PD environments, are intrinsically dynamic entities, always changing in order to conform to the new contexts, new organization forms, new paradigms, new tools and technologies and new projects. It is therefore essential that a mechanism be created in the organization in order to assure that the described processes are always a real representation of the current process practice. Too much money is spent yearly in modeling efforts that are already obsolete even before the project is completed.

9. Project Status

As we write this article (August 2001) the project is entering in its Phase 3 (see description above). Phase 2 was completed, with 96% of all of the IPD processes and activities being fully described (146 processes and 657 activities were identified and described).

Supporting the Phase 3, a computer-based system has already been selected, and the project participants will be soon trained on how to enter the processes and activities into the system. Negotiations are also under way with functional and program managers in order to establish desires, needs and opportunities for the Phase 4 of the project.

As soon as Phase 3 and 4 are completed we shall publish another paper to this Journal summarizing the experiences and results from these phases. Meanwhile, feel free to contact the authors for enquires about the project.

10. Acknowledgments

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