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ENGINEERING DESIGN PROCESS MODELLING IN ACTION - EMBRAER'S APPROACH – INSIGHTS AND LESSONS LEARNED

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Abstract

In this paper we summarize the experience of regional jet aircraft manufacturer Embraer AS in its recent effort to model its Engineering Design (ED) process. Given the distinctive nature of the design process, and the specific situation that the process modelling project took place, a context based customised modelling approach had to be developed and implemented in this project, forming the scope for the paper. 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 ED process modelling, as well as to researchers interested in the subject of ED process modelling.

Keywords: design process, process modelling, Reengineering, engineering design

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) lead to improved business competitiveness. Many good books are available on this topic, under the topic called Business Process Reengineering [7], [8], [9], [10].

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 modelling methodologies and notations such as IDEF0/SADT [11] and the EPC (*Event Process Chain*) are currently available to support this stage. The applicability of these methods and notations to modelling the Engineering Design (ED) process, however, is questionable, given the particularities of ED practice.

Indeed, the practice of ED 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 ED, which renders most of the common known modelling 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 ED is strongly characterized by the abundance of inter-relationship and inter-dependencies among the activities that compose the process [14]. 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 modelling its ED 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 modelling efforts, in order to establish a modelling approach with a higher change of success than the previous adopted approaches. The project, which follows the derived approach, is currently (February 2003) in its final phase, and involved about 300 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 modelling, in ED environments, is more effective than the adoption of common known, out of a book, modelling techniques and notations.

2. Modelling approaches

2.1 Discussion

To model a process means no more than to get to know and to 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 modelling 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 ED process of the company where the project took place), or even the way that the process in currently conducted in the practice (management complexity). Another fact that may render process modelling a complex venture is the non-existence of a macro, well-established process, to be used as a departing point in the modelling effort.

Various authors such as PUGH [3], CROSS [6], ULLMAN [4] and MCGRATH [2] 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 ED effort. An interesting fact is that very few companies are able to understand their own ED practice using the "lens" provided by these reference models [1]. The result is that, in inspite of their good intentions, these models are rarely appropriated to be used as the basis for a modelling 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 [12]. 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 ED reference models needs yet to be proved. For most of the industries involved in Engineering Design modelling, three approaches are generally employed:

2.2 Top-Down modelling 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 well established macro model (top level model) of its process, from which the modelling 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 ED practice to this 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 (ED practitioners).

2.3 Botton-Up modelling aproach

This is the inverse way of modelling. In this case, the process practitioners (i.e., the people that actually execute the activities and tasks of the process) are 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 ED 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.

2.4 Mixed Approach – The case Embraer

In the middle of the two extreme approaches discussed above it is possible to think of various mixed approaches. In the project discussed in this paper, the applied approach initiated with the establishment and approval by top-management of a macro model of the process. From this point the attention moved towards the lower level of the ED process. Functional teams were assembled and trained with the goal of modelling their own "portion" of the general ED process. As soon as these local "partial processes" were written, we moved to the stage of modelling 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 this project has 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. The details of this modelling approach implementation are explained in the topic bellow.

2.5 The method

From the research point of view, the project described in the paper can be understood as composed of two distinct stages (see Figure 1). In Stage 1 we focused our efforts in deriving (constructing) a modelling approach (Figure 1(1)) customised to the specific situation, including *modelling method*, *notation* and *implementation strategy*. This was done based on (a) literature investigation, and (b) on investigating the experiences and lessons learned at Embraer and other aerospace companies in similar process modelling efforts.

The depth of the model: What level of detail is enough?

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 ED process-modelling 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 ED practice and the availability and level of involvement of people to carry out the project internally.

Executed/supported by consultants or internal personnel?

This is a typical question asked by companies when they first get involved in modelling 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 modelling the company's ED process, since the beginning of the project, that the only people that really know the company's process, and therefore that are able to describe it, are the ones that "live" the process, that is, the ED practitioners. The conclusion is that all of the modelling activities must be executed by the ED practitioners, and not by "outsiders" (consultants, trainers, researchers, etc). It is also fundamental to get the ED practitioners to have the real sense of ownership for the modelled 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.

Based on computer (software supported) or not?

Regarding computer-based tools to support modelling, 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 modelling 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 modelling 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 modelling tools is the software *KPM*Ò, from a company named 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 out.

In Stage 2 the approach was implement through a design process modelling project setup internally at Embraer as can seen in the Figure 1 (2).

Most process-reengineering authors are keen to advocate that the first thing to do before starting any modelling effort is to have the right understanding of the "real" project goals. Thus, for the project described in the paper, the following goals were discussed and agreed by all of the engineering managers: "To have the ED process modelled as a MEANS to:

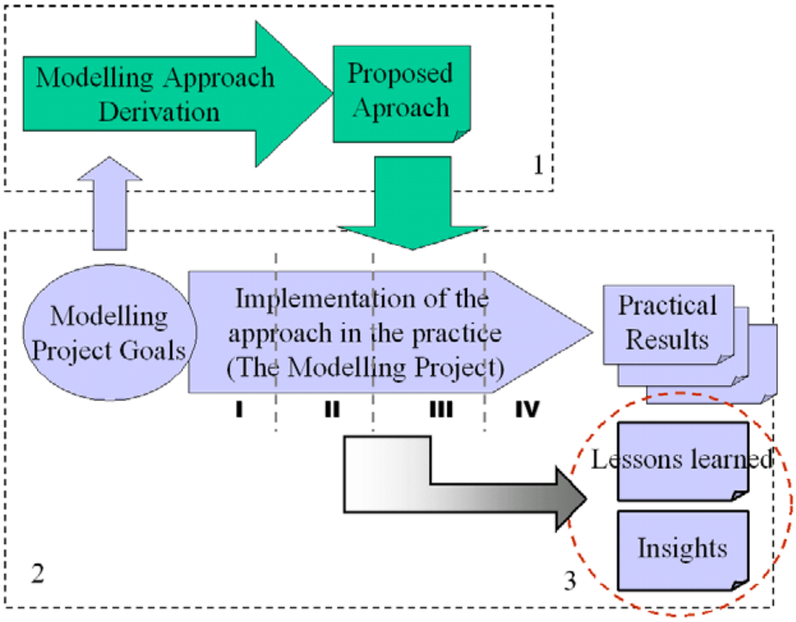

Figure 1: A general view of the project

- *Improve the company´s ED practice.*
- *Support in the training and adaptation programs to new engineers.*
- *Explicit the "know-how" of the ED organization.*
- *Generate internal procedures, when needed.*
- *Map and understand interfaces among inter-related process.*
- *Support the new programs´ planning task.*

The established goals drove, among other things, the modelling approach itself, the degree of involvement request from functional personnel and, mainly, the final format and level of detail of the modelled processes.

The particular way that we implemented the derived approach was determined based on certain key context-specific variables, including (a) results achieved from past similar experiences – positive or negative results, (b) attitude of the involved personnel in relation to this type of project (climate), (c) availability of specialists (the ones that "really" know the process, and are therefore capable of describing it), (d) priority given by top management to the project. Considering all of these variables, a project proposal was presented in the year 2000 compositing of 4 phases:

Phase 1: Identify Embraer´s ED processes and activities and set priorities

The following steps were conducted during this initial phase:

1. Organize the modelling project (organization of the effort, modelling teams, etc).
2. Equalize understanding of Embraer ED [13] among team members.
3. Train all of participants on the proposed modelling approach (steps, method, plans, priorities, etc).
4. Identify the EDmain processes and validate with the functional areas
5. Identify core technologies and technological domains involved in the process.

Phase 2: Carry-out the modelling 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 modelled processes and activities with the owners of the processes.

For the project in question, this phase consumed a total of 18 months, with the participation of more than 250 engineers. 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. Another important point was to 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 its activities as can seen in the Table 1

Table 1: Essential attributes for processes and activities models

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 identified as the owner of the process)
3	Skills need to carry out the process/activity
4	Inputs (information which must be supplied) and Outputs (which are generated)
5	Who provides the information (functional area, or process that generate the information) and Who uses the output information (functional area that use the generated information)
6	List of the activities that composes the process and list of task for the activity
7	Key systems (*Nastran*Ò, *CATIA*Ò, *SAP*Ò, etc) and documents (manuals, procedures, norms, etc) that specify how the process/activity must be executed
8	New technologies and tools that should be investigated
9	Main problems faced by the ED practitioners with the execution of the processes
10	Suggestions of improvement and tips

Phase 3: Transport of the process and activities models to a computer based modelling system

In this phase, all of the modelled processes and activities will be entered into a corporate-wide computer based process-modelling and visualization 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 database. There are a lot of advantages that justify the utility the computer based modelling tool, such as:

1. Provides a single database for the modelled process;
2. Supports the development of software systems or workflow systems;
3. Allows the publishing of the modelled process in order to allow the access via WEB;
4. Makes analysis of the processes;
5. Identifies improvements of the process;

All these advantages were defined as requirements to select the modelling tool. A lot of tools are available on the market and the *ARIS toolset*Ò was selected to implement the modelled processes.

Phase 4: Translate (derive) the process models into specific applications

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

Most of the failed modelling projects had as their goal merely the description and delivery of the processes models (Phase 1, 2 and 3, only). 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 ED engineers and managers can use in their daily work, always considering specific interests and expectations of the various functional areas and projects. 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. If the goal is to automate some activity in the process, a system (intranet, workflow, etc) should be built using the process information, and so on.

3. Concepts and Adopted Terminology

At Embraer the following terms are formally used to describe the company processes in their different levels: *(1) Business Process; (2) Process; (3) Sub-process; (4) Activity; Task*, and were adopted in the project.

The first level is known as the Business Process. Integrated Product Development process is one of these business processes and the case study of this project.

In some cases, and with the goal of facilitating the modelling of a business process into the lower levels, it is possible to split the business process into a number of simultaneous 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 as can seen in the Figure 2, levels 1 and 2.

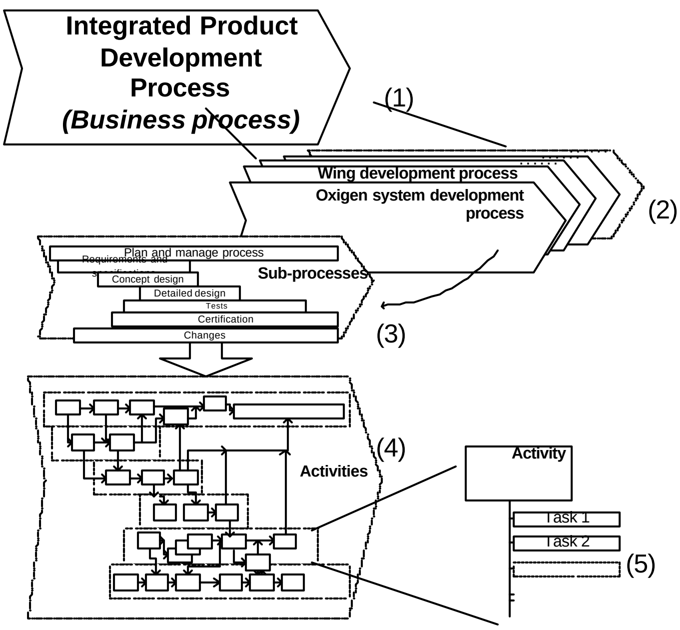

Figure 2. IPD process levels at Embraer

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. 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 2, 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 modelling project were focused in identifying and modelling the activities that composes Embraer ED process.

Bellow the level ACTIVITY we have the level TASK (Figure 2, 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.

4. Past experiences and lessons learned

Various modelling efforts have been carried out at Embraer in the past, as well as in thousands of other companies, with various degrees of success. Modelling 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 modelling 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 modelling effort described in this paper, a careful investigation was conducted focused in identifying all of the good and bad experiences from past modelling attempts. These lessons (Table 2) 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.

5. Final Considerations

Engineering Design (ED) is a complex phenomenon, with a strong technical and creative nature. This renders most of the currently available modelling notations, tools and methods not applicable to model this type of process. A context based modelling approach was built as part of an ED modelling initiative at Embraer Aerospace, and is summarized in this paper.

The thesis for the project, that an specific modelling 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. Some final considerations, believed to be relevant to other companies involved in ED effort or investigation, include:

- Process modelling 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.
- Process modelling is a learning experience. The more we get involved in the modelling effort, the more we learn about the process being modelled, and therefore, the more inclined we are to change the initial description of the model. To accept this fact is key for a successful modelling initiative. Keep the focus on the project goals.

- Avoid falling in love with modelling software tools too early in the project. The major challenge in process modelling is not to get a model done, but get it agreed by all of the involved parties.
- 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 modelling strategy and planning, but never give-up the fundamental premises and assumptions established to the project (concepts, 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.

Table 2: Lessons learned and solutions implemented during the project

Lessons learned	Proposals
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!).	1) Top management must be fully involved in the project and have a correct understanding of the nature of the project 2) The modelling project must be included in the Engineering Department's annual action plan (or similar document) that establishes the priorities for the specific year. 3) The modelling project must have core team to coordinate and support the project.
Process modelling is conducted by people from outside the organization. The consequence is that the people responsible for the process do not feel the "owners" of the derived information, are rarely able to understand the description of the process. Therefore, not use the results of the effort.	1) The whole of the modelling 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.	1) The computer-based tool used to store the information of the processes must be friendly. Maintenance of the processes shall be easy and quick to perform. 2) The responsibility for the maintenance of the processes becomes part of the job description of the process. 3) The maintenance of the processes must be regularly included in the annual action plan.
The format of the process charts and description is too complicate for the typical engineer, rendering the whole effort useless.	1) To involve the process owners and actors in the choice of the right format (notation) for the description of the processes.
Project participants want to have access to a computer modelling tool too early in the project, and therefore lose the opportunity to discuss and settle an unified understanding of their own processes.	1) 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.

Finally, it is important to remember that process and activities, especially in ED 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.

References

[1] Barkan, P., 1994, "Benefits and Limitations of Structured Methodologies in Product Design". In Eastman, S.D.a.C (ed), Management of Design: Engineering and Management Perspectives. (1^{st} Edition), Massachusets.

[2] McGrath, M.E. (Editor), "Setting the PACE in Product Development, A Guide to Product and Cycle-time Excellence". Butterworth-Heinemann (Trd), 1996

[3] Pugh, S., "Total Design: Integrated Methods for Successful Product Engineering" Addison-Wesley Publishing Company, 1991.

[4] Ullman, D. G., 1992, "The Mechanical Design Process". McGraw-Hill, 1992.

[5] Ulrich, K.T. and Eppinger, S.D, "Product Design and Development", New York, McGraw Hill, 1995.

[6] Cross, N., "Engineering Design Methods - strategies for product design". John Wiley & Sons Inc, 1989.

[7] V. Daniel Hunt, Daniel V. Hunt, "Process Mapping: How to Reengineer Your Business Processes" John Wiley & Sons, 1996.

[8] Galloway, D., "Mapping Work Processes", American Society for Quality, 1994

[9] Manganelli, R.L., Klein, M. M., "The Reengineering Handbook : A Step-By-Step Guide to Business Transformation",1996.

[10] Harrington, H. J., "Business Process Improvement: The Breakthrough Strategy for Total Quality, Productivity, and Competitiveness". McGraw-Hill, 1991.

[11] Steve, H. and Robinson, L., "A concise guide to the IDEF0 technique, a practical technique for business process reengineering", Puyallup, Washington, Enterprise Technology Concepts, 1995.

[12] Rozenfeld, H., "Reference Model for Product Development", Anals of the XVII Encontro Nacional de Eng Produção / 3rd Int Congress Ind Eng- ENEGEP, Gramado, RS, Brazil (*in Portuguese*), 1997.

[13] Araújo, C.S., Cruz, J. L., 1999. "A View of the Product Development Practice at Embraer". Internal Publication – Eng Department. Embraer. Sao Jose Campos, SP, Brazil.

[14] Duffy, A.H.B. (1995). 'The Design Complexity Map and the Design Coordination Framework", IPS – Research Seminar, Fuglso, Denmark, Department of Mechanical Engineering – IKS, Denmark.

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