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CONTROLLING PRODUCT RELATED ENGINEERING CHANGES IN THE AIRCRAFT INDUSTRY

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Abstract

The management of engineering changes at the development stage of a product life cycle is a key issue in the aircraft industry. Changes at the design stage can have some terrible consequences on both the product and the organization so they must be kept under control.

In this paper, we first make a review of the key publications in the engineering change control domain and we try to highlight actors' needs as well as the improvements that could be brought into this process. In the second part, we propose a solution for an efficient control of the engineering change process. This solution is based on a product model that contains all the information required during the process as well as the components connections that can propagate changes within a system. These models enable the creation of a cooperative environment dedicated to the actors involved in the process. Within this environment, actors can access pertinent information quickly, share their results and access some methods to investigate the impacts of a change and to assess the solution they have developed. Furthermore, for this process to be efficient a set of treatment strategies has been defined according to the different kinds of requests.

Keywords: Engineering Change Management, Aircraft Industry, Configuration Control, Design Process.

1. Introduction

Configuration management is a key issue in the aircraft development process. It enables a complex product to be designed and manufactured concurrently by several industrial entities spread all over Europe. It ensures them that the information they manipulate represent the current configuration of the items they work on and that all these items can be integrated in a product.

In this paper, we will focus on an activity encompassed in configuration management: the management of engineering changes [1]. An efficient control of engineering changes at the development stage is strategic for aircraft manufacturers. As a matter of fact, most of engineering changes are requested before the aircraft entry in service. It is important to process them as early as possible in the product life cycle as, afterwards, rooms for engineering changes are narrower and the implementation of changes becomes extremely expensive (the rule of ten of [2]). Secondly, the aircraft business is a highly competitive market and the ability of manufacturers to deal with airlines changes requests in customization during the negotiation process is a key advantage. Finally, a transparent and efficient change process enables airworthiness authorities to certify the product so it can be introduced in the market.

The main objective of this study undertaken is to provide actors involved in the engineering change process with methods and applications to develop technical solutions fulfilling the needs identified in the request while minimizing the impacts on the product and the organization. This work is undertaken as part of a PhD at the GILCO laboratory (Grenoble – France) in partnership with EADS Corporate Research Centre (Toulouse – France). It will be complete by the end of 2003.

In the first section, we will point out the researches that provides us with a better understanding of engineering changes and we will highlight the needs and rooms for improvement within this process. Then, we will propose a solution for a better control of engineering changes requested for aircraft under development.

2. Improving the Engineering Changes Process

At the product development stage, the engineering change process suffers from numerous limitations, which restrict the efficiency of actors and the responsiveness of the organization. In this section, we strive to understand the engineering change phenomenon through a review of the literature and try to identify the improvements that could be brought within the process.

2.1 Research in Engineering Change Management

In the literature, much attention has been paid to engineering change management. Research results that have been published for the past twenty years can be classified in two categories. In the first, those that help to get a better understanding of engineering change phenomenon (sometimes illustrated by use cases). In the second category, we will find the studies that suggest a new method or tool to get a better control over engineering changes.

Dale has first tackled the engineering change issue in [3] by studying changes at the design-manufacturing interface. In 1990, Nichols in [4] identifies the critical success factors in the management of engineering changes. In 1997, Wright in [5] provides a synthesis of the key publications in this domain and highlights the design issues that should be further investigated. Wänström and al. in [6] choose to tackle the problem of engineering changes from a logistic perspective. Some other researchers focus their attention on specific issues at the different stage of the process. For instance, Loch and al. in [7] study the capacity and congestion effects in the process. The phenomenon is also illustrated with some industrial case studies undertaken in different countries and business [8, 9]. Computer-aided tools for engineering change processing are particularly important in industry. Huang and al. give an early overview of this systems in [10] which should be up-dated according to the major advances in PDM systems (Product Data Management systems).

Most of the methods and applications developed in research deal with the traceability of engineering changes and the analysis of their impacts. Studies on traceability have been focusedon modeling the product architecture using the EXPRESS language supported by the STEP exchange standards [11]. The most promising findings in the analysis of engineering changes impacts are probably those of Clarkson and al. who propose a method to predict their propagation [12] and those of Ollinger and al. with the application REDESIGN IT [13] which can evaluate the influence of a change in a requirement on the final product performances.

All these researches provide some local optimization, a help at a specific stage of the engineering change process. But, some global improvements are also requested by praticioners to control the overall process, as we will see in the next section.

2.2 Identified Needs & Rooms for Improvement

From the different surveys we have conducted, it has been possible to identify some major needs and concerns about the engineering change process.First of all, configuration managers in charge of the process do not have a global view on the process once it is triggered. Sometimes, according to the agreed objectives, it leads to a deviation in cost, quality and delays of the solutions developed. Because, they do not have much visibility on actors work between milestones and because no indicators are implemented it becomes almost impossible to identify these deviations. Furthermore, the processes that have been implemented through workflow in PDM systems seem to be a copy of the old paper-based systems. It does not take ant advantage of the recent advances in IT technology and have not been re-engineered for that purpose.

Secondly, when a new engineering change occurs in a system, it is difficult for configuration managers to find information related to the changes that have been previously processed for this system although it could help them to identify potential consequences of the new change. A better use of the engineering change history of a system could also help designers to understand the origin of a technical solution and the context in which it has been developed.

Thirdly, actors involved in the process spend a lot of time looking for information related to the product and to the ongoing process. This situation has been observed when the requested information are stored in various applications within the organization. An optimal use of their time should be possible if they are provided with a fast access to the right and everlasting information.

The engineering change process remains highly sequential while the responsiveness required by requesters would asks for some parallel sequences of activities. This is the reason why concurrent engineering principles should be introduced within the engineering change process. This introduction should encompass some means of collaboration and coordination dedicated to actors.

Finally, because aircraft can be considered as complex products, there are two stages of the process that can be critical: the analysis of engineering changes impacts and the selection of the best solution to be implemented.

In the next section, we will try to address these different issues by proposing an environment designed for a better control of engineering changes.

3. An Engineering Change Management Environment

This proposal should enable configuration managers to have an overall control of the engineering change process and to provide a support to actors at the different stages of their investigations. The next section describes the objectives we will try to reach details the proposal.

3.1 Objectives

At the organizational level, the first objective we target with this proposal is the enhancement of the company 's responsiveness to answer engineering change requests. This responsiveness is based on the organization ability to:

- Detect potential engineering changes as early as possible.
- Record engineering change requests as early as possible in the product life cycle.
- Trigger a process adapted to requests.
- Ensure requesters that the solution to be developed will fit their requirement in the agreed time frame.

The second objective is to provide configuration managers with an overall control over the process so they can supervise the progress of the treatment and detect as early as possible its deviations. But, before looking at the control means, the organization must be ensured that the triggered process is adapted to the request that has been formulated. It reveals a need for defining at the management level a treatment strategy for each kind of request.

Two types of decisions must be taken in the process. The first one, at the beginning must state whether or not a request should be further studied. After investigations, the second decision is the selection of the solution to be implemented among the alternatives that have been developed to answer a request. The third objective is to support this decision-making process with some methods ensuring that all information have been taken into account.

For the organization, the last objective is to enhance cooperation among actors in this process. As a matter of fact, the change process can be considered as a "micro design process" and the best solution will emerge from this collaboration.

At the tactical level, the improvements brought by this proposition should fulfilled the following objectives [14]:

- *Front-Loading:* Trigger changes as early as possible by speeding up their detection and feed back loops.
- *Effectiveness:* Assess whether or not changes are necessary and beneficial.
- *Efficiency:* Strive to get an optimal use of resources such as time and budget when treating a change.
- *Learning:* Increase efficiency and effectiveness of the process by continuous learning from previously performed changes.

From an operational point of view, the solution we will describe in the next sections is based on four main features:

- A product architecture model enabling the treatment of engineering changes.
- The management of resources to be involved in the process.
- The definition of strategies defined according to the different kinds of engineering change requests and then translated into process.
- An environment enabling actors to process engineering changes efficiently.

3.2 People Involved in the Engineering Change Process

This proposal is first dedicated to configuration managers. A configuration manager is responsible of the configuration of a sub-assembly of the aircraft. He must maintain its consistency to ensure people can work with updated information. Consequently, he is responsible of the treatment process of all engineering change requests related to this system. As an aircraft can be considered as a cascade of assemblies then, from an organizational point of view, it is possible to have a cascade of configuration managers.

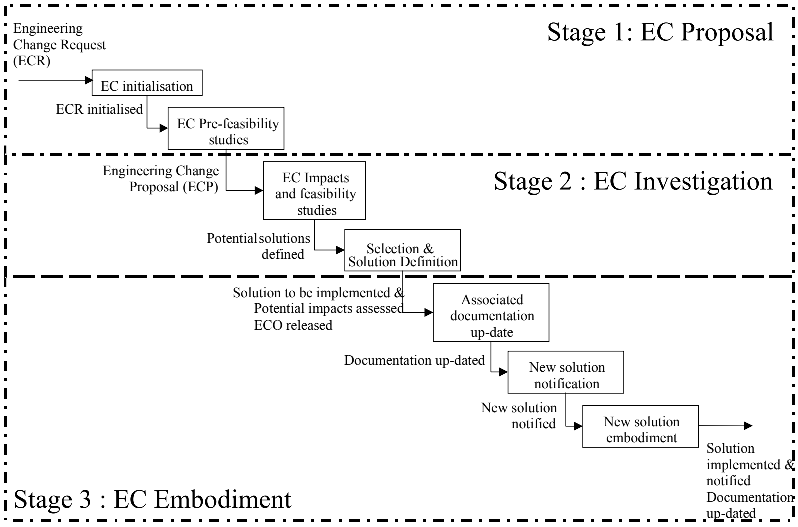


Figure 1: The Engineering Change Process [15]

This proposal is also dedicated to actors involved at the different stages of the engineering change process: designers, analysts and experts. Finally, this proposal could benefit to decision-makers involved in the process.

3.3 A Product Architecture Supporting Engineering Changes Management

Basically, no significant improvements can be brought if product architectures are not modeled in a way to facilitate the management of engineering changes. Two modeling efforts are required. First, for each component or assembly some engineering change attributes must be defined. Secondly, a typology of links between components must be defined in order to investigate the influences of a modified item on other components of a system.

3.3.1 Engineering Changes Attributes

Engineering change information relative to the product are not modeled in the product architecture in current PDM systems. This weakness does not enable knowledge of the change behavior of components and assembly within a system to be used.

Consequently, we propose a product model that takes into account the following types of information (these information depend on the types of items and assemblies that are considered):

- *Information on actors involved in the process.* When the impacts of an engineering change are investigated, it is important to identify the actors involved as well as the configuration manager who has the responsibility of the system.

- *Information on items lifecycle.* The lifecycle of an item can be different from the lifecycle of a product. Consequently, it is important to take the maturity of the design in consideration in order to avoid a change in a frozen design. Furthermore, it is necessary to limit the changes in a system when it is close to a decision milestone.
- *Information on activities related to a particular milestone.* Using the lifecycle of an item, and if a development WBS (Work Breakdown Structure) is attached to it, then it becomes easier to define the activities, which can be impacted by a change.
- *Information on items requirements.* An item should be linked to its requirements in order to identify those that can be impacted and lead to some deviations at the end of the development process. Further, it would help to identify the frozen requirements that can not be changed.
- *Information on items behaviors to engineering changes.* For technical or strategic reasons, it can be forbidden to change an item because some of them as considered as "blocks". This "block" concept gives some fixed points in the product structure. Furthermore, it is important to highlight that some components can propagate engineering changes and some other can absorb them.
- *Information on the engineering change history of an item.* Knowing the change history of an item can help to understand the current state of its design because of the different changes that have been applied. It gives the creation context of a technical solution. Furthermore, it can help in the investigation of the impacts of a new engineering change request.

These more complete models help to treat engineering changes at the items level but does not give a better understanding of engineering changes at the system level.

3.3.2 Connectivity

During the investigations of engineering impacts, it is important to identify the consequences of a change in a component on other components. In the literature, this phenomenon is called change propagation [12].

With the current PDM capabilities, it is fairly difficult to identify these propagation that use the connections between items because, most of the time, they only represent the "uses / used by" links. Therefore, we propose to define and model a typology of links that can be used by propagation. This typology encompass the composition links as well as:

- **The association links.** A component can be described differently according to the different system life cycle stages. This is the concept of "views" described by Tichkiewitch and al. in [16]. These links help to define change impacts on a component and its documents at different stage of its life cycle. For example, if a change is requested for a system's function. Therefore, it is possible with this link to detect all the physical items impacted.
- **The Interface links.** This link defines the closeness of two components within the system. This link can be specified by using the following component information : positioning, geometry and assembly process. Consequently, it is possible to predict collision between components in case of a change.
- **The dimensioning links.** A component property can be used to specify another component. If the property of a component is modified (out of margins), then another

component definition could have to be modified as well. For instance, a pipe diameter partially depends of the pump delivery.

- **The organizational dependency links**. In the aeronautic industry, that type of links is particularly important because the work is shared between different partners and each of them try to limit the change propagation to the system they are responsible of.

With this typology, it becomes possible to investigate the consequences of a change within a system. Furthermore, the product can no longer be represented by a Product Breakdown Structure but by a Product Structure Network.

These models will be used to process engineering changes, and especially at the impact analysis stage.

3.4 Resources Management

An optimal use of resources is a key advantage to process efficiently engineering changes. This is the responsibility of the configuration manager to involve in the process the actors whose expertise is needed. Three different matrixes can support this task. First, the *notification matrix* that links the different systems of the product to a configuration manager. It will be used during the investigations when a change propagation is discovered. The second matrix is the *matrix of needs* that will identify for the different processes (Cf.3.5) the specialists and the experts who must be involved. Finally, the *matrix of available resources* will help to map experts and specialists to an actor according to its availability.

3.5 From Strategies to Efficient Processes

Each change request must be processed according to a strategy. As a matter of fact, a change requested by an airline when negotiating a contract can not be processed in the same way that the request of the engineering department who has identified an opportunity for improving a system in the future. Consequently, a typology of requests has been defined and some strategies have been formulated for each class of requests. An engineering change request can be characterized by its emergency; the commercial stakes associated to this request, the product lifecycle stage where the demand is raised, the objectives of the request and finally the item impacted.

This typology helps to identify different classes of requests. For each class, a strategy has been defined to develop a solution appropriate to the requester needs and to the objectives of the organization.

At the operational level, these strategies are translated into workflow processes with some dedicated indicators to control the delays and cost of the treatment. Consequently, all requests will not be treated with the same process

3.6 A Software Designed to Process Engineering Change Requests

This software can be considered as a "Change Portal" which provides an invidual environment to process each change requests. It is supported by the databases enabling the management of product information, strategies and process and the resources involved in these processes. Actors involved in the process can use collaboratively an environment, which is managed by a configuration manager. An environment is dedicated to the treatment of one change request and is valid from the initiation of the process until the selection of a solution among the alternatives developed. Once the process is complete, a part of this environment is saved so the information that have been used or created during the treatment can be used or accessed in the future. Each environment presents the following features:

- **Access to Information:**

Through this environment, users are provided with a direct access (or a link) to the impacted system information (from product models) such as 3D models, documents, etc. They can also have an access to information on the workflow. It means that each actor has a visibility on the different activities and actors involved in the workflow. Finally, they can access the information that have been created during the process such as the investigations results, the information on the solutions (and their alternatives) that have been developed during the treatment, the assessment of these solutions, and the decisions that have been taken. Consequently, for one request, this environment provides a single "portal" to access all information required for a change request treatment.

- **The Communication Module:**

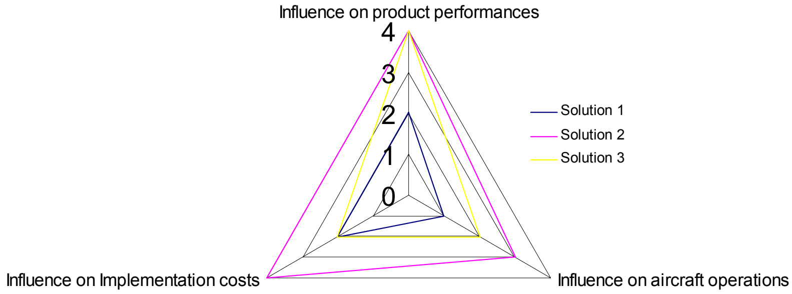
Like the design process, the engineering change process is a highly cooperative process because the quality of the investigations and solutions depends on the exchanges between actors involved in the process. Consequently, some communication tools have been implemented to facilitate the exchanges between configuration managers, actors and decision-makers. All information exchange are saved to trace the development of a solution and in oder to keep the design rationale of each solution.

- **The Impacts Analysis Module:**

The impacts analysis that take place during the investigation stages of the process are very important as they contribute to the identification of change propagations. To identify these propagation, we use the typology of links defined in 3.3.2. An algorithm allows the identification of the potential primary impacts of the propagation and alarms the actors. Then, it is up to them to investigate the alarms that seem the more relevant and realistic. This algorithm avoids forgetting an impact analysis on a particular link. A more complex algorithm should be developed to identify indirect propagation of changes.

- **The Decision Support Module:**

During the process, different solutions are developed in order to answer the request. These solutions need to be assessed to decide which one will be further developed and implemented. The environment provides an assessment method (through the decision suppot module) that helps to see the influence of the different solutions on product performances, aircraft operations and on the implementation costs of the solution. These parameters can be further refined but the advantage of this method relies on their aggregation. The aim of this assessment is not to give a detailed technical evaluation of the solution but to see if each of them influences positively or negatively business and product parameters. A value scale is provided to assess each solution (0 = very negative influence, 1 = negative influence, 2 = no influence, 3 = positive influence and 4 = very positive influence). Each actor involved in a change process and the development of alternatives first assesses the solutions individually. The results are then aggregated using the mean of the results expressed by each actor for the three parameters. The evaluation of the different alternatives against the three parameters is then compared using the following radar representation (C.f. Figure 2) can be used for comparison. This representation helps decision-makers to position the advantages and limitations of the different alternatives against each other. Consequently, they can select among the alternatives, the solution that will be further detailed and implemented as an asnwer to the engineering request. For example the final assessment represented on Figure 2 identidies the Solution 2 as the best solution. As a matter of fact this solution has a positive influence on all parameters and seems to be more satisfying than the two others solutions.



	Solution 1	Solution 2	Solution 3
Influence on product performances	2	4	4
Influence on aircraft operations	1	3	2
Influence on Implementation costs	2	4	2

Figure 2: Solutions Comparison

However, the experience of decision-makers in the treatment of engineering changes will also be an important factor in the selection of a solution. This fact highlights that the management of actors' knowledge and experience is becoming an important issues in the engineering change process.

4. Conclusions

After a presentation of the project context, this article first provides an overview of current rooms for improvement within the engineering change process. We highlight the current limitations of change management tools such as PDM systems. This investigation has pointed out that the management of engineering changes remains a business issue during the development of a new aircraft. Consequently, we can say that the design of such processes should be directed towards a better collaboration between actors, the implementation of strategies to treat the different change requests, an optimal use of ressources, a better access to pertinent information, the supervision of process progess by configuration managers and an efficient integration of experience and knowledge gained in previous treatment. In the second part of the paper, we have detailed the main features of a software which adress most of these issues. The originality of this software lays in the fact that one treatment environment is assigned to each change request. An environment supports (Access to information, decision and impact analys modules and communication means) the actors involved in the realization of their tasks from change initialisation to solution proposal. Such application should abolish the current limitations of PDM systems so industrial organization could limit the consequences of engineering changes. The first prototype will be released by the end of 2003 and will then be assessed on industrial uses cases provided by an aircraft manufacturer to determine integration feasibility as well as performances in use.

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