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Customized system development case study in an aeronautical integrator company

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***Résumé* – Divers aspects contribuent pour l'augmentation de la complexité du produit et du procès dans les étapes de conception et de fabrication. Comme conséquence, les entreprises ont besoin de trouver les solutions pour rester dans le marché de façon compétitive. Cet article présente une étude de cas dans une entreprise d'intégration de systèmes du secteur aéronautique, soulignant l'analyse de la phase prototype du développement des systèmes de customisation. On met en évidence un certain nombre de problèmes pertinents pour l'équipe de conception du produit et pour les activités de l'équipe de production – planification, atelier de fabrication, assemblage final et provisionnement. Le travail identifie les possibles causes et conséquences de ces problèmes, et finalement, les actions pour améliorer la performance dans les étapes du concept et de la production pendant la phase du prototype. Comme la gestion du cycle de vie du produit est une stratégie, une méthodologie et un outil recommandé pour la gestion de projets de produits complexes, produits customisés dont la chaîne de manufacture s'avère également complexe, c'est une solution puissante à travers laquelle les entreprises parviennent aux résultats escomptés.**

***Abstract* – Several aspects contribute to the increase of the product and process complexity and also for its design and its manufacture. As a consequence, the companies need to find solutions in order to remain in the market and be competitive. This article presents a case study in an aeronautical system integrator company, emphasizing the analysis in the prototype phase of the development of customized systems for aircraft. Some relevant issues have been noted in the product design and the manufacture – planning, manufacture workshop, assembly line and procurement – activities. The study identifies the possible causes and consequences of these issues, and finally, actions to improve the performance in the design and manufacture stages during the prototype phase. As the product life-cycle management (PLM) is a strategy, a methodology and a tool, recommended for the project management of complex products, customized products whose production chain can be also complex, it is a powerful solution for companies to achieve the expected results.**

***Mots clés* – customisation, développement du produit, fabrication, PLM, prototype.**
***Keywords* – customization, product development, manufacture, PLM, prototype.**

1 INTRODUCTION

Several aspects contribute to the increase of the product and process complexity as well as for its design and its manufacture.
Regarding the product, some factors may be enumerated, such as the increase of the diversity of products in the market, the time to market and to launch new products, the increase of products' functionalities and also the intrinsic complexity of certain products, e.g., the aerospace product, as stated by [Earl et *al.*, 2005], complex products are composed of many parts or sub-assemblies which are interdependent.
On the other hand, regarding the process the factors can be described as, there are different team domains working on the product and they may also be geographically separated [Tripathy, et *al.*, 2011], the partner suppliers are more involved in the product development and they need more product access information, software is being used to design and to manufacture products, the procedures' requirements are being more controlled by the regulatory agencies. This increase of complexity difficulty

the process management, resulting in more activities and more interfaces. It is also difficult to performance the activities, as there are more inputs to be taken into account [Zancul, 2009].

As a consequence of this modern context of complexity, the companies need to find solutions for remaining and being competitive in the market [ElMaraghyet al., 2012], i.e., increase their productivity, achieving more results with less working hours, less resources; eliminate non-value added activities [Brandao, 2009]; delivery excellent quality products; reduce engineering changes late in the lifecycle and reduce the faults during development and manufacture stages [Stentzel et *al.*, 2014].

The product life-cycle management (PLM) is a strategy, a methodology and a tool able to provide these results [Vieira et al., 2013]. Besides, [Stentzel et *al.*, 2014] recommend PLM for the management of complex products; for shorter product lifecycles and customized products whose supply chain can also be complex.

An example of this is the customized system for aircrafts. In the past, they were less complex, the electrical signals were, for the major part analogical, and less cables were needed to interconnect the systems, due to the computer and digital systems; the present customized systems are much more complex and more integrated to the aircraft. As the complexity of the systems has increased [Tripathy, et *al.*, 2011], also have increased the requirements of the regulatory agencies to assure the new system integration's airworthiness. As a result the product life-cycle management for the development of the customized systems also became important and necessary for the aeronautical system integrator companies.

Effort is applied to define, design, manufacture and manage the customized system development. [Zancul, 2009] mentioned that 70% to 85% of the product costs are defined during the product design stage, which is not a negligible value, therefore, special attention needs to be done to this phase. A new development, including a customization product, is an uncertain environment since it usually changes as long as the project advances in the production chain. This demands a robust product configuration management as well as the product change management.

The development of an aerospace customized system, as well as other projects, has to meet deadlines, respect the established budget and satisfy the customer, while considering product quality and functionality [Tripathy, et *al.*, 2011].

This is the reason that this study aims to shed light on some relevant issues related to the concept and the manufacture stages of the development of customized systems for aircrafts during the prototype phase. This study also aims to evaluate the possible causes of these issues and propose solutions.

This study is organized as follows: session 2 describes a customized system as an aerospace product; session 3 presents a product development life-cycle of a customer-driven industry, describing the relevant stakeholders; session 4 presents the PLM definition and its importance related to the product data management; session 5 presents the aeronautical company characteristics that motivated this study and justifies the necessity of a prototype phase in a complex product development context; session 6 presents some product life-cycle issues considering the customized systems development in a real aerospace environment during the prototype phase; session 7 discusses the possible causes of the problems presented in the previous session and some possible solutions. Finally, session 8, presents the conclusions of this study.

2 CUSTOMIZED SYSTEMS, AN AEROSPACE PRODUCT

When an aerospace product is mentioned, it is common to associate it to an entire plane or an entire helicopter. In fact, the aircrafts are a set of different aerospace products, i.e., the aircraft is decomposed into systems and the systems are decomposed into sub-assemblies. According to the system definition presented by [Verries, 2010] in the aerospace context, the systems are the combination of interconnected elements for implementing a function or a group of functions in an aircraft.

When the customers want to change or include functionalities in their aircrafts, this implies new systems installation or changes in the systems already installed in the aircraft [Gautier *et al*., 2004]. It is mandatory that the aircraft's continued airworthiness not be compromised by the changes. Also it is necessary that the regulatory agencies approve the installation or change and issue the supplemental type certificate (STC). These systems are customized systems, ones that are not likely to have been designed in the original aircraft concept [Gudmundsson, 2014].

Some of these systems, also named assemblies, are conceived, manufactured and assembled by the aircraft manufacturer or an authorized installer and others are conceived and manufactured by a supplier (a partner), as presented by [Rivière, 2004].

This study will discuss the systems which modify the original design of the aircraft by means of installing new equipment that looks to customizing the aircraft to satisfy the customer's necessity.

As mentioned by [Earl *et al*., 2005], a customized assembly will imply design efforts due to the development of a new aerospace product where a set of equipment will be specified and integrated into the aircraft.

For instance, consider a civil police as a customer who executes a car chase during the night. The customer necessity is to have its helicopter installed with an infrared camera, a screen to observe the images captured by the camera, a joystick to control the camera movements and an image recorder. All the equipment mentioned represents a customized assembly that will need to be integrated into the helicopter. This assembly will change the original design of the aircraft, but it is not supposed to affect the aircraft's continued airworthiness.

3 PRODUCT LIFE-CYCLE

[Siemens PLM, 2010] and [Gudmundsson, 2014] present a product life-cycle of an aerospace industry that conceives and manufactures its product. A typical product development flowchart is presented in figure 1. It considers only the most relevant internal and external stakeholders who are briefly described in the sequence.

The external stakeholders are represented by customers, regulatory agencies and suppliers.

- The customers are one of the main objectives the industry wants to attain with its products, considering it is a *customer-driven* industry, the product is manufactured according to the customer order. According to [Brière-Côté, 2007] and [Papinniemi, J. *et al.*, 2014], industries that customize products have this characteristic.

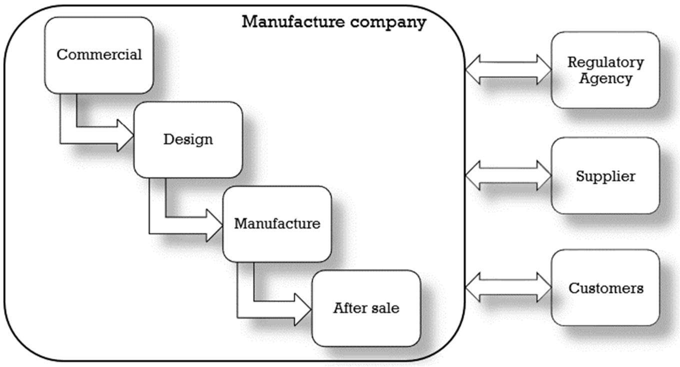

Figure 1 - Product development life-cycle.

- The regulatory agencies are mainly responsible for developing regulations and inspection of the industry activities.
- The suppliers, also considered partners, are the providers of raw material [Li, 2011], systems and equipment [Bertoni, 2013], expertise and know-how [Zeng *et al*., 2012].

The internal stakeholders are represented by the following departments: commercial, product design, manufacturing and after-sale.

- The commercial department is responsible for selling the product to the customers; consequently, the customer need should be identified for future transformation into a product [Saaksvuori, *et al*., 2008].
- The product design (1) is initiated by a preliminary step whereby the system engineers translate the commercial information into a macro technical idea. The management of the requirement takes place, to assure that the customer's requirement is well represented by the technical solution. (2) The preliminary step is followed by a detailed product design step whereby the specifications are defined through means of drawings, bill of materials and working instructions for the internal clients: the procurement and manufacturer teams [Debaecker, 2004]. The modification management starts to assure the traceability and the history of the product design [Alemanni *et al*., 2008].
- The manufacturing department: (1) initiates through ~~by~~ a methods and processes team that is responsible for launching the data from the product design for the manufacture. This team is also responsible to define how the manufacturing process will occur, i.e., all the tools, materials, proceedings necessary during the manufacturing step [Gunendran *et al*., 2010]. (2) The manufacture workshop produces the pieces that will be used in the assembly line. (3) The assembly line is responsible for the assembly and installation of all the sub-parts to prepare the final product and also perform the final tests. (4) The global supply chain is responsible for the synchronisation between the manufacturer workshop, the assembly line and the suppliers, by means of global manufacture planning. This is mandatory to ensure the resources necessary to accomplish the activities in each step in the production chain.
- The after-sales is the department which is in contact with the customer after the product has been delivered. This department is responsible for the evaluation of the performance of the product during the period that it is being used by the customer; it is responsible for the maintenance procedures and spare parts logistic [Goswami *et al*., 2014].

Since the flowchart starts from the customer necessity and ends with the delivery of the product to the customer, it can be considered an *ideal* product development flowchart. It does not take into account the errors, the reworks, the feedback activities, the process bottlenecks, the non-anticipated problems, interruptions and so on.

4 PRODUCT LIFE-CYCLE MANAGEMENT

Product life-cycle management (PLM) is a strategy, a methodology and a tool to manage the product life-cycle, i.e., the product design, passing through design, production, and maintenance until product disposal [Vieira *et al*., 2013].

- A *strategy* because, through the PLM, the company business process will target areas such as cost reduction all throughout the production chain, assure product and process quality, and guarantee the cycle reduction during concept and manufacture stages. PLM will also support on the decision take related to the product, service and operation;
- A *methodology* once the company needs to restructure its processes in such a manner that the process, information and teams will be integrated;
- A *tool*, since PLM has a set of software available that is able to standardize product information, improve the interface between the software from different domains, e.g., design, manufacture, supplier teams, and facilitate the reuse, finding and access of the product information.

[Brandao, 2009] presented some information about capture and re-use of knowledge in his study. He mentioned that the reason the product design and manufacture teams are often disturbed, are related to inquiries about their knowledge regarding either the product or the business. As some information is transferred informally, such as messenger chats, emails, meetings, telephone calls or kept in personal documents, in the expertise's heads, about 80% of the existent product data is not structurally organized and available for the other domains of the company. To further reinforce this problem, the annual turnover rate of these important collaborators who detain the product information, is around 20% and within 5 years, is expect to be 60%.

The PLM, as an integrated management of the product data and processes throughout the product life-cycle, favors the product knowledge storage, data access at any time by the authorized teams, collaborates to reduce the time consumed in the development of new products and also prevents collaborators working with outdated information [Zancul, 2009].

5 CASE STUDY

The case study is an empirical investigation that examines the interest phenomena in a contextualized manner, mainly when the boundaries between the phenomena and the context are not well defined [Yin, R., 2001]. The case study essence, according to [Schramm, 1971], is that it try to clarify a decision, i.e., why the decision was taken, how it was put into practice and what were the results.

This study is limited to discuss some issues, during the initial phases of a project, faced by an aeronautical system integrator company which has less than 1 000 employees and more than 30 years of expertise. The project objective was to conceive and manufacture different customization systems. After the prototype phase of each new customization, close to 50 aircraft were supposed to receive the assemblies – depending on the aircraft configuration.

Although the organisation had a lot of expertise, the project status in the initial phase was: new engineer team (formed by juniors and seniors), new software and data basis in the product design stage and manufacture stage (also new for the users), new aircraft model and new working process to be defined.

The product development presented in this study had a duration period of close to 2 years, beginning with the product design stage to the final assembly tests and the issue of the authorization by the regulatory agency.

Since the same product may be manufactured more than once, for example, because of a new sale, and due to its complexity, it is necessary to execute the conception and manufacture stages into two different phases: prototype and serial.

The prototype phase takes place to verify if: (i) the technical definition and the product feasibility are correct; and (ii) the data launched from the concept stage (drawings, bill of materials and working instructions), to the procurement and manufacture teams, is correct too [Debaecker, 2004].

After validation of the data, it can be frozen and launched for the serial production, i.e., the manufacture process can be repeated. It is important to state that a product will be kept in the prototype phase until the data is considered valid [Zeng et al., 2012]. This idea is indicated in figure 2.

6 PROTOTYPE PHASE, BASED ON THE CASE STUDY

Here, some relevant issues which occurred in the product design and manufacture – planning, manufacture workshop, assembly line and procurement – stages of the product life-cycle of the development of the customized systems, during the prototype phase in a real aerospace environment, are evidenced.

There is an important difference between the stages of product design and manufacture. In the first one, the solution proposed as a working paper, can be also virtual when considering the computer aided software, but they are still in the office, a sort of an ideal, virtual reality. The second one does not matter if one is referring to the manufacture workshop, the assembly line or even the global supply chain, in the manufacture stage, the environment is real.

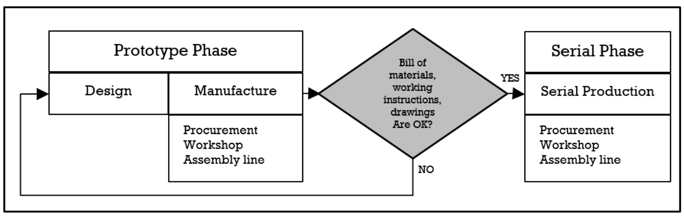

Figure 2 - Prototype and serial phases.

That is why it is important to launch the concept product data (drawings, bill of materials and working instructions), to the manufacture teams when the data is frozen, even in the prototype phase, in order to reduce the risk of rework according to [Eger et al., 2005]. Other sources of concept changes are expected in the manufacture stages, problems such as incompatibilities, interferences, and others associated to design feasibility arise; also for the supply chain activities, for instance, parts specified by the engineers that are not available in the market because they are already obsolete.

6.1 Product design

In the product design stage, during the prototype phase, some problems and their main consequences were identified. The design office and the provision departments are the major players in this context.

6.1.1 Design office

Problems with the software tools

As already mentioned, in order to execute the project, the organization needed to form a new technical team and also needed to implement new software for conceiving the products. Moreover, the period for getting to know the software and also to perform the trials, in order to confirm that the tools were working properly, occurred at the same time the project had started. This situation favored the occurrence of some problems, such as: delays to begin and finish the concept activities as scheduled; low quality during the product design, considering that the efforts were not totally dedicated to the technical specification, on the contrary, the technical team was trying to troubleshoot the software issues.

[Stark, 2007] presents a similar case, in Airbus A380, there was a delay in the electrical harness installation as a consequence of the late implementation of the software tool – 3D Digital Mock up – and the design team was in their learning curve, i.e., was not familiar with the tool.

Incomplete input data

At the beginning of the project, during the prototype phase, not all the input data necessary to execute the concept product activities was available. [Debaecker, 2004], stated that 25% of design hours are spent waiting for decisions to be made or information confirmation on several aspects.

Sometimes, the sub-assemblies are outsourced for the partner suppliers, and the interface control document is expected to be received from them, [Zeng *et al.*, 2012], i.e., the documentation that contains the equipment specifications, and an example of the incomplete input data problem is when the supplier delays delivery of this document. Another example of incomplete input data problem is related to the customers, when they are not sure about what product functionalities they want. This problem also led to delays in finishing the product specifications as scheduled, impacting all the following activities.

Change management

As the project starts, the uncertainties began to be clarified, the input data became more complete, and, as a result, some of the decisions that have been taken need to be updated. Otherwise, the teams that have already received the old data, would work with the wrong information and this could lead to re-works and wastes.

6.1.2 Procurement

Incomplete input data

During the prototype phase, the team responsible for the parts provisioning is totally dependent of the concept product team information [Brandao, 2009], because the concept product team is responsible for specifying all the parts and quantities that have to be bought for the product manufacturing. At this moment, as the concept product does not have all the necessary input data, they are not able to provide a complete and mature part list. As a consequence, the procurement team did not have the reasonable input data to begin their activities and this led to delays in ordering and receiving the parts.

Provision as early as possible

Some parts provision has to be done in advance due to their lead time and also to be able to accomplish the manufacture necessity [Eger *et al*., 2005]. The responsible for deciding when the parts are expected to arrive in the organization, is the manufacture planning, which indicates when the parts will be used in the manufacture workshop and in the assembly line.

Due to the pressure, at the beginning of the prototype phase, the procurement team purchased all that was demanded by the concept product team, although they did not evaluate the current stock or even evaluate the rate that the parts were consumed by manufacture, in order to update the resource planning system and establish the purchase order warnings. As a consequence, they purchased several parts that were never used or the quantity was not enough for manufacturing.

Supplier negotiation

The prototype phase put the part procurement team in a delicate situation regarding negotiation with the suppliers; they did not have mature data, part volume and even after all this, they needed to bring the parts to the organization as soon as possible. A similar problem was presented in Company A in [Chou *et al*., 2012].

Change management

As long as the product design progresses, the part list shared with the procurement team changes. Similar to Company A in [Chou *et al*., 2012], it is difficult or even impossible to update the part order. Some consequences occur as the parts will be bought but not used due to the specification change, which will cause overstock, inventory storage times, and also the procurement team will need to purchase the new parts that have been updated in the part list, in some cases, in an emergency situation depending on the part lead time.

That is why it is mandatory that the procurement team be aware of the changes, so that they can negotiate with the suppliers. It is necessary to control the changes by means of part list versioning, keeping it historical.

This problem get even worse when the part lists are distributed on paper or excel tables, i.e., they are not in an computer system, which makes accessing the information difficult and makes the teams work with outdated information [Wynstra *et al*., 2000].

6.2 Manufacture

At this point, there is a transition from the virtual environment to the real environment. The design documents conceived during the product design stage, which are necessary during the manufacture stage, are transferred to the manufacture team [Brandao, 2009]. Also the parts, tools and equipment that have been ordered, must be available to the manufacture (manufacture workshop and assembly line), in order to provide everything that the manufacture needs to assembly the product.

In the manufacture stage, the problems and consequences identified for the stakeholders in the manufacture workshop and the assembly line are presented in the sequence.

6.2.1 Manufacture workshop

Problems with the software tools

New software, which presented the manufacture work instructions, was implemented for the workshop collaborators. As the software was new, the collaborators were not familiar with the data format and this became the data comprehension deficient, leading to doubts during the manufacture process.

Incomplete input data

During the manufacturing execution, the workshop collaborators reported that the documents prepared for them were not as comprehensible as they should be. These documents were not clear in the description on how the collaborators might execute their manufacture activities. As a result, the person responsible for preparing the documents should intervene in the manufacture process. Another consequence was the scraps in the first manufacturing pieces.

Lack of parts and tools

A serious problem faced during the manufacture stage was the lack of parts, i.e., the materials were not available in the workshop when they were needed. This triggered some consequences such as delays in finishing the pieces and providing them for the next step (stock or assembly line); the manufacture planning leadership tried to push the design product team to come up with alternative solutions to replace the lacking parts, which could lead to quality issues and inconsistencies concerning what was designed and what was built in the workshop.

Another issue during the manufacture process was that the collaborators reported there was a lack of tools that they needed to manufacture the pieces. As these tools were not available, the production was interrupted until the tools were provided.

Change management

The discrepancies observed between the documentation and the activities execution must be incorporated in the documentation. Otherwise, the same errors and misunderstandings are going to be repeated in the next manufacture of the same item, mainly if there is a change in the collaborator that will manufacture the piece, causing new interruptions in the manufacture process.

6.2.2 Assembly line

At this point, all of the set comprising pieces manufactured locally, the pieces and equipment provided, will be installed and integrated into the aircraft.

Incomplete input data

The documents prepared for the assembly line team did not fulfil their requirements. Due to this, new documents needed to be prepared, increasing the workload of the teams that were responsible for elaboration of the documents and the assembly line team took much more time to complete their activities.

Lack of parts, pieces and equipment

The lack of parts, pieces and equipment, even at this point of the manufacture process, was still a problem. All this contributed to the delay in finishing the prototype assembly.

Change management

The serious problem at this point was that the assembly line team finished their activities but they did not involve the design product team. Feedback from the assembly line team was essential to finalize the specification and also to adjust the technical documentation. Because of this problem, the technical documentation that was supposed to be the final version, contained a lot of incorrect information.

7 DISCUSSION

The prototype phase has uncertainties that disturb the product development as it advances in the production chain, as represented by product design, procurement, manufacturer workshop and assembly line teams. This section will discuss the probable causes for the problems faced during the prototype phase, and some solutions, always considering the perspective of the organization of the case studied.

7.1 Problems with the software tools

The software deployment as well as the users' familiarization with the software, were not taken into account in the project master planning, probably because nobody imagined that this step would consume so much time. As a solution, it is important to include the activities in the planning in order to perform the software try-out and user training, looking to avoiding these problems and also accelerate the learning curve to use the software [Stark, 2007].

There was a delay caused exclusively by the problems associated to the software implementation and using it. This is not a new problem, as mentioned by [Zancul, 2009]. It is important to note that the objective for using the software, as a working tool, is to decrease the time spent for the product design and to manufacture the products, and also to increase the quality of the process, once the activities are aided by software [Zancul, 2009]. Thus, two scenarios are presented: to ensure that the software tools are correctly implemented, the users are trained, and then the product development and manufacture activities start or they begin all together, foreseeing more time for performing the concomitant activities.

7.2 Incomplete input data

The problem of incomplete input data related to the design product team can be caused by the aggressive dates agreed upon the organization and the equipment supplier, i.e., as the organization looks for starting the project as soon as possible, it pushes the supplier to hurry in the specification of their product. In the end, the dates are not achieved, initiating the information problems delays. A solution to this problem could be spending more time during the preliminary phase, when the scope is being defined, considering the participation of the affected stakeholders and, therefore, setting deadlines that are more likely to be met [Eger *et al*., 2005].

It is true that the design product team does not work only with "finish to start" activities [Eger *et al*., 2005]. As there is lots of information that comes out during the development process, the activities need to be performed in parallel. In order to work around the problem of incomplete input data, it is important to assure an enclosed definition of the scope [Gautier *et al*., 2004], so that it can lead to better quality in the latter steps of the process. Another point related to incomplete data in the design product stage is the necessity of structuring the knowledge to share and reuse the product information. Studies by [Bandinelli *et al*., 2014], revealed that product knowledge management decreases the uncertainty and has a positive performance during new product development.

The problem of incomplete input data for the manufacture teams can be related to different causes. For instance, the perspective and necessity from teams who elaborate the documentation and the ones who use the documentation – to execute the work – are different, resulting in misunderstandings; the lack of a complete, virtual aircraft model during the product design step became the documentation difficult to elaborate; and also the lack of practical experience of the one who elaborated the documentation. A solution proposed for this problem is to validate the document's content with the elaborator and the user. Although it seems to be a rough activity during a long journey of work filled by other activities, it is necessary to align the document content. Also, after using the document, it is important that all the doubts be clarified and the feedback concerning the quality of the information and documentation, be assured.

During the investigation of this problem, it seems, initially, that the problem is caused by–the lack of technical information. However, after observation, it is mainly related to the lack of effective communication between the teams.

7.3 Change management

As long as product development occurs, the information is updated. This can be due to customer change requests, concept errors, and impossibility to manufacture or to assemble the product [Eger *et al*., 2005]. Therefore, it is mandatory that the documentation be updated, i.e., manage the technical file versions – mainly the official documents which are input data to one or more people – and the data be shared with the ones affected by the change.

The product life-cycle solutions are a good option to organize the product data, store knowledge and facilitate information access. All this is necessary for product development as well as to keep the existent documents updated [Brandao, 2009].

7.4 Procurement

There are some aspects that cause the necessity to provisioning the parts as soon as possible. The delay between the specification of the parts and the date that they are needed to be available in the organization, is normally very short. Besides, the majority of the part suppliers are international, and it can quite increase the delay in receiving the parts [Cheng *et al*., 2013]. In order to prevent delays, the parts should be ordered almost simultaneously to the concept product stage, even if the data is not mature enough and changes are supposed to happen.

As the organisation is not a big manufacturer, its stock is also not big and the idea is to keep the stock lean in order to assure no obsolete parts and no lacking parts in the manufacturing. One strategy is to evaluate the parts consumed of the stock and classify them as standard and specific items [Wynstra *et al*., 2000]. For the standard items, the risk associate to them is low, as mentioned by [Eger *et al*., 2005], because the purchase team is already aware of these parts, and are used for the manufacture of

other products. As for the specific parts, the risk associated to them is high, as they are new for the company, and require more effort to be ordered and also to be followed up.
Another strategy is to share the risk between the teams, in this case, the procurement team should allow the design product team to be aware of the contracts signed with the suppliers and its cost, so that the design product team be conscious during the specification of the parts and when they are making changes in the parts specification [Zancul, 2009].
Apparently, the lack of planning of an organization has been replaced by the excuse of a stress environment and the necessity to make decisions in a hurry. This problem is reinforced by the high costs due to the change specification of parts and the need to provide the new ones in an emergency and for the lack of time of the procurement team to deal and negotiate with suppliers.

7.5 Lack of parts and tools manufacture workshop

The cause of some problems seems likely to have the same source. The lack of material and tools in the manufacturer workshop is also caused for the short period between the part definitions (and when it has been ordered) and the necessity of the part in the manufacturer workshop. Another cause is that the team responsible was not able to foresee some other parts and tools that were necessary for the manufacturing, and, as a consequence, they were not ordered.
Sometimes, the parts were used for the manufacture of another piece, revealing a stock management problem. This is when parts are used to manufacture other products but not for the one that it was supposed.
The proposed solution for better planning in order to ensure the delay necessary to receive the parts and tools, is to define strategies of stock control for the specific parts, i.e., parts that were bought exclusively for a project, thus assuring that the part will be available for the manufacturing of the planned piece.
The lack of material and tools during the pieces manufacturing is a critical problem during the development process of a product; even the parts that were supposed to be classified as standards caused problems during the manufacturing, as they were also missing. The lack of material pauses the manufacturing [Chou *et al*., 2012], stopping collaborators, disturbing the working schedule – when the parts were available, extra hours were necessary to compensate the hours that the work was impeded. The lack of tools could imply problems associated to the final quality of the piece manufactured.
In the majority of the cases, the unfinished pieces were transferred to the assembly line, causing new discomforts. Once these increased the assembly line workload.

7.6 Lack of parts, pieces and equipment assembly line

The assembly line depends on the pieces manufactured internally and the parts, pieces and equipment from the suppliers. One cause, for the lack-of pieces manufactured internally verified in the assembly line, was that the manufacturing planning was not synchronized to the assembly line planning, creating necessity conflicts – this situation is also associated to the parts and manpower available that the manufacturing workshop has to start its activities. On the other hand, the assembly line will prioritize the assemblies for which the pieces and the equipment are available. Another restriction to the assembly line is the assembly sequence limitations.
The pressure imposed on the assembly line is a result of the problems presented in all of the production chain. A solution proposed would be to control the previous activities, and even if the intervention does not work, it is necessary to update the planning according to the new reality.
It is important to underline that during the prototype phase, the feedback from the assembly line to the design product team is essential in order to correct the technical documentation and ensure that the design is adequate for the final assembly.

8 CONCLUSION

Considering that the customized projects complexity is increasing as time goes by, i.e., the details and particularities are increasing, a good option is to have development system tools that can integrate, extract and facilitate access to the information. In this way, the collaborators can concentrate on the technical solutions more than spending time searching for work information. That is why the product life-cycle tools present an interesting solution.
Besides the PLM tools, the PLM methodology is also important as it favors better communication between the teams considering the process interfaces [Brandao, 2009]. This is a strong point for the elaboration of documents that are useful and appropriate for the users who are going to consult the documents.
Keeping the teams stable is a good option from the point of view of the learning curve. As long as the people get to know their activities and understand the product development processes, more rapidly they can perform their roles and gain more experience, thus avoiding repeating errors already identified.
Although long deadlines can be a weak point during negotiation with the customer, it is necessary to deal with realistic dates; some examples were presented in this study related to the bad consequences caused by deadline sub-estimation.
The organization has its ordinary activities and in the case of a new product development, the efforts and the activities are different and tougher [Brandao, 2009]. As supported by [Gautier *et al*., 2004]'s analysis, the meticulous definition of the scope of the new product, before the launching of the project activities, allow the improvement on how to deal with risk during the product development.
The PLM is a powerful solution for managing the data and the process during the development of complex products, as it provides an integrated environment between the teams involved, even considering geographically separated suppliers.
Therefore, this study presented and discussed some relevant issues related to the concept and the manufacture stages of the development of customized systems for aircrafts during the prototype phase.
New empirical studies are suggested to evaluate the applicability of the solutions proposed here in organizations which have similar characteristics.

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