Features of integration management tools in the aviation industry

Darli Rodrigues Vieira*

Research Chair in Management of Aeronautical Projects,
University of Quebec at Trois-Rivières,
3351, boul. des Forges, C.P. 500,
Trois-Rivières (Québec) G9A 5H7, Canada
Email: darli.veira@uqtr.ca
*Corresponding author

Raimundo Kennedy Vieira

Technology Faculty,
Federal University of Amazonas,
Av. General Rodrigo, Octávio, 6200,
69077-000, Manaus, Amazonas, Brazil
Email: maneiro@ufam.edu.br

Milena Chang Chain and
Adalena Kennedy Vieira

Research Chair in Management of Aeronautical Projects,
University of Quebec at Trois-Rivières,
3351, boul. des Forges, C.P. 500,
Trois-Rivières (Québec) G9A 5H7, Canada
Email: milenachain@gmail.com
Email: adalenakennedy@gmail.com

Abstract: Environmental concerns have increasingly led companies to optimise their production processes. Thus, the search for greater efficiency has led to the desire to better integrate management tools. This has also been the case in the civil aviation industry, due to its stringent requirements, particularly regarding safety aspects. The objective of this article is to propose an integration of management tools, specifically including the value chain and product lifecycle management (PLM), with an emphasis on new product development (NPD), supply chain management (SCM) and maintenance, repair and overhaul (MRO) in the civil aviation sector. To better describe the relationship between PLM and the tools related to its best use within a value chain, a critical review of the literature was performed. The main result of this study suggests the integration of the SCM, MRO and PLM management tools.

Keywords: civil aviation industry; integration; product lifecycle management; PLM; maintenance; repair and overhaul; new product development; NPD; maintenance, repair and overhaul; MRO; supply chain management; SCM; management tools.

Copyright © 2019 Inderscience Enterprises Ltd.

Reference to this paper should be made as follows: Vieira, D.R., Vieira, R.K., Chain, M.C. and Vieira, A.K. (2019) 'Features of integration management tools in the aviation industry', *Int. J. Product Lifecycle Management*, Vol. 12, No. 1, pp.20–36.

Biographical notes: Darli Rodrigues Vieira is a Professor of Project Management at the University of Quebec in Trois-Rivières (UQTR). He is currently the Head of the Management Department and Director of the Master program in Project Management at this university. He also holds the Research Chair in Management of Aeronautical Projects. His current research focuses on project management, logistics chain management, strategy and management of operations, and management of maintenance, repair and overhaul (MRO).

Raimundo Kennedy Vieira is a Coordinator of the Post-graduate Program in Industrial Engineering and Associate Professor at the Federal University of Amazonas. He has over 20 experiences working in the areas' engineering of civil, materials and industrial, with emphasis on developing green materials, environmental management and production management, acting mainly in the reuse of industrial waste.

Milena Chang Chain is a DBA candidate and a researcher in management of aeronautical projects at the University of Quebec at Trois-Rivieres. She holds a degree in Production Engineering from the Catholic University of Paraná (PUC-PR) and Business Administration from the Federal University of Paraná (UFPR). She also holds an MBA in Logistics Management Systems from the UFPR.

Adalena Kennedy Vieira has over five years of experience in project management. Currently, she is a researcher (postdoctoral program) at the Research Chair in Management of Aeronautical Projects at the University of Quebec at Trois-Rivières (UQTR). She has a PhD in Chemical Engineering from the Universidade Estadual de Campinas (Unicamp).

1 Introduction

At present, environmental concerns are leading companies to increasingly rethink and optimise their production processes. A consequence of this has been improvements to the product lifecycle management (PLM) approach, which has gained increasing importance due mainly to its intrinsic environmental character. In accordance with the improvement in PLM, new tools have been increasingly incorporated into the system, starting from the product development stage and particularly focused on the development of new products. Computer-aided design (CAD), which had been used in isolation before the creation of PLM, is included in this design stage. Subsequently, there was the introduction of computer-aided technologies (CAx) (Mas et al., 2015a), such as computer-aided product development (CAPD), which were linked by Culler and Anderson (2016). As the name itself indicates, these tools aid in the development of products through the use of computational methods. One consequence of these tools is that the product development stage became the most impacted among the PLM stages (Lee et al., 2008).

There is therefore a gap in the application of these tools in other stages. Another factor to be considered in PLM is the usage life of the product. For example, the lifecycle of an aircraft can last more than 50 years (Mas et al., 2015a). This usage life will impact the maintenance and repair stage and should influence the design stage, which will inevitably affect the manufacturing stage of the product (Lee et al., 2008). In this study, the manufacturing stage will be considered to cover both supply chain management (SCM) and the manufacturing and assembly stage.

As maintenance increases in importance in the value chain, product servicing has gained a greater hold; that is, instead of companies selling products, they start selling the services that these products can provide (Qu et al., 2016). An example of this is car sharing, in which the end users only pay for the use of the vehicles. Thus, the companies that make the vehicles available become responsible for providing a car in the optimum usage conditions for customers, with the maintenance and repair of the vehicle being the company's responsibility.

This trend has led to a growing preference for products with longer lifecycles and thus with strong maintenance and repair systems such that their lifecycles are increased (Tukker, 2015).

The product service system (PSS) approach considers the cohesion of product development and related services (Zhu et al., 2012). The main idea is that the assignment of a product becomes that of a service: the company stops selling the product and instead makes the service that this good can provide available to the consumer. The main advantage of this change is in the perception of the product by either the manufacturing company or another company related to that product. By making the service available rather than selling the product, the company is responsible for the installation, use and post-use of the product. The responsibility of the company does not end with the sale of the product – in fact, it is continuously linked to the sound performance of that product. Thus, the company will have an interest in increasing the lifecycle of the product, and it will tend to improve its maintenance system.

There is one industry in particular that, due to its business structure, already fits this approach profile: the commercial aviation industry. Although the main occupation of this industry is the production of aircraft, its value chain is gaining an increasing share in the repair and maintenance sector. With airplanes having a lifecycle of up to 50 years, maintenance contracts generate more revenue for aircraft manufacturing companies and maintenance, repair and overhaul (MRO) partnerships than the sale of the product itself. This profitability is driven by aircrafts' complexity and safety concerns, and thus maintenance and repair services are tied in to the sale of the aircraft. Thus, everything stated above about product servicing is relevant to the commercial aviation industry, and consequently, the integration between maintenance and the other PLM stages is important. According to Bertoni et al. (2013), there is a gap between the product development stage and the PSS. However, the servitisation approach servitisation will force companies to produce increasingly durable and efficient products, which will lead to greater integration of the flow of materials and information along the entire value chain.

Thus, the objective of this study is to propose an integration of management tools that involves the value chain and PLM, with emphasis on new product development (NPD), SCM and MRO in the civil aviation sector. This article is organised in five sections: Section 1 presents the subject to be addressed; Section 2 contains a brief discussion of PLM applied to the various tools; Section 3 presents the research methodology; Section 4 presents the results of this study, which demonstrate the need for interrelationships between the approaches and tools applied to PLM and for the integration of the management tools that structure these interactions; and Section 5 presents the main findings and limitations of this study together with suggestions for future research.

2 PLM applied to selected tools

In this section, PLM will be related to NPD, the supply chain, the sustainable supply chain and MRO.

2.1 NPD and PLM

The PLM system originated in the 1990s and was derived from product data management (PDM) (Cantamessa et al., 2012). In terms of products, it presented a holistic view of knowledge management within a company that considered all stakeholders involved in the process. Although it was expected that PLM would be applied equitably across the value chain, most studies have shown a greater tendency to use it in the NPD stage or in the product improvement stage (Lee et al., 2008). PLM is considered to be one of the main enabling technologies for NPD (Gecevska et al., 2011).

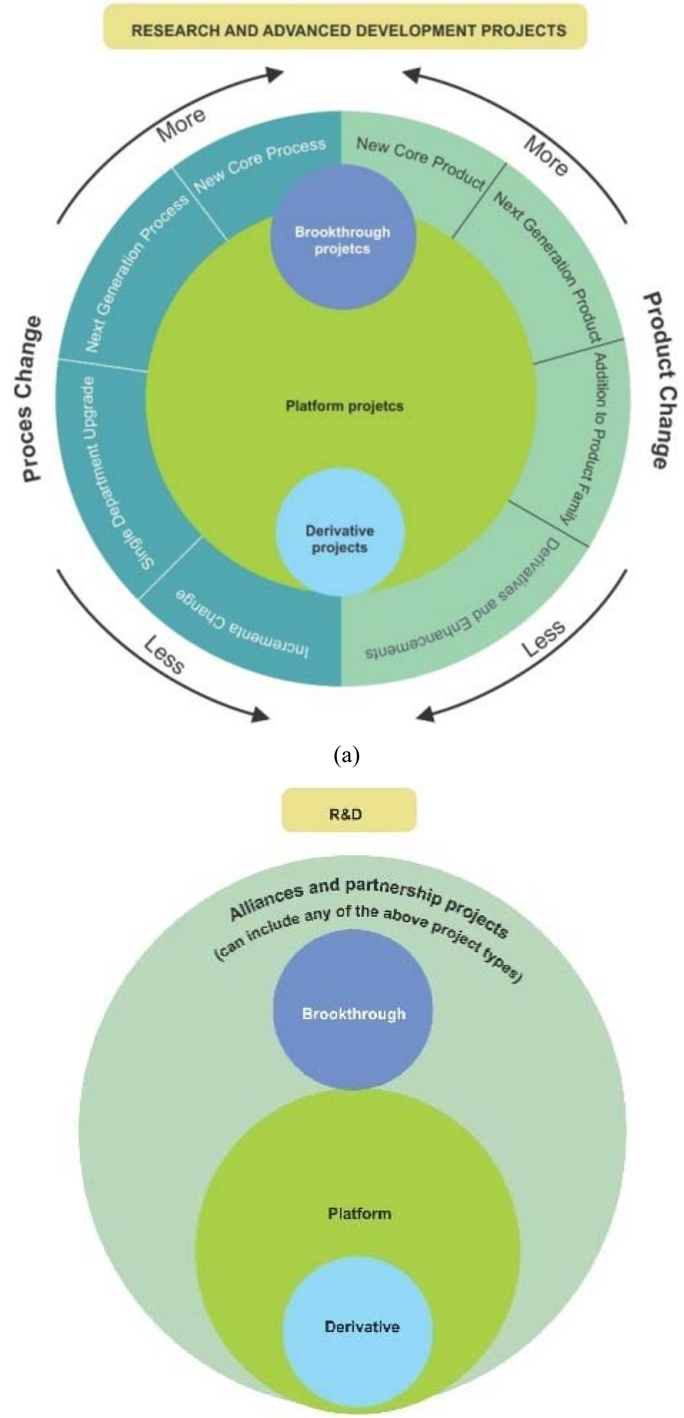
The PLM system was created precisely to encompass the production process from NPD to product disposal and to include all companies in the new system as well as their partners and suppliers (Cantamessa et al., 2012).

Product simulation is an indispensable tool in product development. As the ideal of sustainability is being increasingly incorporated into production processes, the demand for practices that incorporate this approach – from the planning stage to final product disposal – has been growing. Among the approaches, PLM has acquired a major role in this process.

There are many studies focused on optimising production; however, they tend to be narrowly focused on the individual equipment and tools and to lack a more holistic view of the whole production system (Belkadi et al., 2015). In addition to this lack of vision, there is also a need to expand the view of the production system to include the suppliers and the maintenance system of the product.

Product development simulations can be rerun after the changes that are commonly made to the product following the development stage. It would be interesting to consider the energy issues that are addressed on the production line, in the distribution system, and in the packaging that is incorporated into the product; the inclusion of all suppliers and inputs that would be part of the product maintenance system should also be considered (Belkadi et al., 2015). At this point, it is necessary to determine how and where the exchange of information between the maintenance and the design stage for PLM within NPD would make sense. This communication channel would only be needed in manufacturing industries that use NPD with derivative and platform projects (see Figure 1) because in these types of projects, the information coming from the current project could be used in the development of a new project and because there would be a large amount of information relative to the part of the product. This proportion will remain unaltered or will be precisely altered due to the information already coming from the maintenance. Therefore, in this project, the idea of integration between PLM, NPD and MRO will be considered in the civil aviation sector, due to its peculiarities adapted to the study.

Figure 1 (a) Mapping the five types of development projects (b) Five types of development projects (see online version for colours)



(b)

Adapted from Wheelwright and Clark (1992) and kindly provided by Vieira et al. (2017b).

As shown in Figure 1, there are five types of projects (Wheelwright and Clark, 1992):

1 *Research and development* –projects for developing knowledge, generally focused on the state of the art, and in which the idea is to develop new technologies and new materials.

2 *Derivative* – projects that consider small changes to products already being produced by the company.

3 *Breakthrough* – projects that are substantially different from previous generations of the product.

4 *Platform* – projects that encompass changes similar to those seen in breakthrough and derivative projects; however, in platform projects, the changes are more profound than those in derivative projects but not as advanced as those in breakthrough projects.

5 *Alliances and partnerships* – as the name implies, these projects are grouped more according to how the project is executed than to its type.

PLM must offer improvements, including greater agility within both production engineering and production that will lead to a better use of the expertise in various engineering areas considering the expected lack of collaboration (Daniels et al., 2013). In the specific case of PLM, a lack of collaboration and knowledge management are the two main challenges associated with the use of integration tools (Ferreira et al., 2017).

The reuse of knowledge has a large impact on the development of new products. Exploiting a core of knowledge by transferring it from one product to another is known as knowledge modelling. There are various types of knowledge that can be considered to have been modelled because there are experiences, adjustments, errors and innovative techniques that have been used in one product and can be reused in other products based on the experiences of experts (Merlo et al., 2017) regardless of whether the product was based on breakthrough, platform or derivative projects in its development.

The actions to be taken and decisions to be made – whether by a project office or by the project team – should always seek to adapt or create an innovative organisational culture. This innovative culture should lead to the creation of a decision-making protocol within the group responsible for development. An innovative organisational culture will only be possible if two practices are implemented. The first is recording how the decisions were made, which criteria were used and which tools were used. This record will allow the development team to have an idea of which path may or may not be taken, and over time, it will provide a modus operandi for how to act to make a decision, which will reduce the risks inherent to project. Another action that should be part of this series of actions is ensuring that all information flows continuously along the entire value chain.

Generally, each company has its own array of tools and software for managing information and production lines that connect with the design, planning and production process to integrate with the business system (Culler and Anderson, 2016). Additionally, multiple types of management software much as enterprise resource planning (ERP) and PLM are developed with their own interfaces and functionality. This often results in overlapping functions and hinders integration not only within the same company but also within the network of companies that constitute the value chain. Although widely used, not all corporations have successfully implemented ERP, PLM, computer-aided process planning (CAPP), SCM and customer relations management (CRM) systems (Culler and Anderson, 2016).

In addition to the areas addressed in this section, it is necessary to consider the issue of organisational culture, which is one of the main reasons for a lack of success, whether due to difficulty adapting to the required management practices or even inaction in the face of changing an already-established practice within the organisation.

2.2 Supply chain and PLM

Considering the context of sustainability, focusing efforts only on the exclusive application of sound practices to the production process within the company does not guarantee financial benefits and improved competitive advantage. It is necessary to encompass the entire value chain in any integration of the production process – for example, the transportation of the raw materials and of the finished product in addition to the entire supply chain between those two tasks. Given that the planet's population is increasing and the level of natural resources is decreasing, organisations have begun to see that supply chains need to adapt to these natural constraints (Carter and Jennings, 2002). This scarcity of natural resources – or the prospect of their depletion coupled with the growing demand of the population (Govindan et al., 2013) has become a major challenge for the supply chain. This challenge becomes more visible when one realises the number of requirements placed on the supply chain. These requirements include the need to implement more energy-efficient technologies, improve the use of resources (e.g., reuse and recycle), purchase materials that incorporate sustainable processes, adopt greater carbon emissions control and assume greater social responsibility both internally and externally. All of these factors may even generate short-term economic costs, but in the medium and long term, they will lead to competitive advantages for both the company and its trading partners, in addition to economic benefits. However, it is only possible to meet these demands if the entire value chain for the product or process is interconnected and integrated.

In this context, the concept of a sustainable supply chain or green supply chain clearly becomes increasingly relevant and important in a globalised world. The desire to support supply chains has led many companies to make a certain level of commitment to sustainable practices (Govindan et al., 2014). Within this search for sustainability, these companies have begun to implement sustainable actions in one or more product lifecycle stages. However, many companies are still hesitant to commit to sustainability actions as long as they are not obliged by law to comply with them (Hassini et al., 2012). A number of studies have stated that in addition to benefiting the process, the search for sustainability in supply chains has brought economic benefits (Baidya et al., 2017; Khatri and Srivastava, 2016; Lhafiane et al., 2015). The main tools used to support sustainable practices include PLM, reverse logistics (RL), the 3Rs (Favi and Germani, 2014), accreditation of the environmental management system by ISO 14000 (Marques, 2016) and the implementation of lean actions (Khanchanapong et al., 2014) within the production process. In summary, there are many tools and approaches that can assist in the implementation of sustainable practices in the supply chain. However, this study seeks actions that effectively integrate the supply chain – not only independently but also with the manufacturing process – with the maintenance system and the product development process.

2.3 Sustainable supply chain

Hassini et al. (2012) define sustainable supply chain management (SSCM) as "the management of supply chain operations, resources, information, and funds in order to maximize the supply chain profitability while at the same time minimizing the environmental impacts and maximizing the social well-being".

The major difference between SSCM and integrating a chain between PLM and SCM is that the former seeks to apply sustainable actions in a fractional manner (Hassini et al., 2012), with the implementation of measures such as the 3Rs (reduce, reuse, recycle) and RL, among other environmental mitigation tools, but not jointly. In contrast, in addition to offering a philosophical vision of the entire business system, the integration of PLM and SCM presents a strategic vision in which information and material flows interact (Bouhaddou and Benabdelhafid, 2017). This means that an alteration in the manufacturing of the product, a modification in the final destination of the product or even the documentation of changes made in an earlier generation of the product can be received by the product development team and subsequently impact the flow of material through the entire business system. This holistic approach offers advantages to not only the current process but also all future product generations. Moreover, managing the value chain by integrating these tools means that information coming from the maintenance sector, for example, can be sensed quickly.

This manner of acting means that the information that flows through the value chain can influence the dynamics of the material flow in real time; thus changing the material flow sequence, which is generally directed from the supplier to the consumer. Accordingly, the information flow will lead to real-time changes, impacting the exchanges between the supply chain and the value chain partners (Bouhaddou and Benabdelhafid, 2017).

2.4 MRO and PLM

Currently, the importance of the maintenance business is increasing in aviation (Thomas et al., 2015), becoming almost as important as the sale of the product. The demand for the more sustainable use of products and services has necessitated an increasingly longer lifecycle and greater product use intensity. One consequence of this trend – in addition to sustainability – is increased profitability. This naturally leads to a greater requirement for services related to MRO (Uhlmann et al., 2013).

In terms of production processes, it becomes difficult to talk about sustainability without considering, at some point, the PLM process. Thus, the relationship between PLM and MRO appears to be a natural one when considering sustainability in products and services. Despite its holistic view of the process, because it seeks to centralise and organise the entire production process (Marra et al., 2018), PLM still remains quite isolated from maintenance processes (Madenas et al., 2016). Similarly, Lee et al. (2008) concluded that when considering the design of aircraft, PLM is used only one-tenth as often in MRO. Due to the long lifecycle of aircraft, this means that PLM's potential in the MRO activities of aviation has not been achieved.

In the commercial aviation industry, the maintenance system is directly or indirectly dependent on the company that manufactures the aircraft. This is due to the complexity of the product, in addition to the infrastructure costs necessary to perform the work required by the regulatory agencies (Machado et al., 2016). Given that an aircraft can have a lifecycle of up to 50 years (Mas et al., 2015a), the maintenance market has become very important – according to Papakostas et al. (2010), it can account for between 10 and 20% of the direct variable costs of an aircraft.

Thus, if PLM were integrated with MRO to provide interconnected information to SCM and NPD, it would result in gains for the entire system. Updated maintenance and repair records could help decision makers choose the type of material to use when remodelling or developing a new product. Additionally, SCM would have real-time information regarding the type of material most demanded, and it could be prepared not only to meet demand but also to improve the quality of the current product. Consequently, usage information could provide support in terms of identifying the excessive wear of parts, identifying how parts could be better worked on in current maintenance and the possible use of current parts in the development of new products. This real-time monitoring in the maintenance sector would provide information to the NPD sector that could help predict not only the entire maintenance manual for the new product but also the reuse and/or final destination of the waste involving replacement parts due to maintenance. Other information that would also be useful concerns estimation of the service life of the product and the potential for reconditioning, which increases its lifecycle even more.

3 Methodology

To better describe the relationship between PLM and the tools related to its best use within a value chain, a literature review was performed. Studies about this subject written in English and published between 2014 and 2018 were searched using the Google Scholar search engine (http://www.scholar.google.com). The key words used were PLM, tools, commercial aviation, SCM, SSCM, PSS, MRO and NPD. The studies reviewed were also selected based on the amount of information that each could contribute to the subject. It should be noted that studies outside of the previously specified time period were selected if they conceptualised certain terms or presented specific information not found in more recent publications.

4 Analysis of the results

The aviation industry is a very complex industry. Due to this complexity and the increasing demand for innovation in virtually all engineering fields, multidisciplinary cross-sectional teams are required, starting with the product development phase (Mas et al., 2015b). Cross-sectional actions include practices that aim to integrate and enhance the knowledge of each discipline participating in the process. In this situation, PLM is already a reality for most companies and has been incorporated into their daily operations (Merlo et al., 2017). For this reason, the results presented here are directed toward the civil aviation industry.

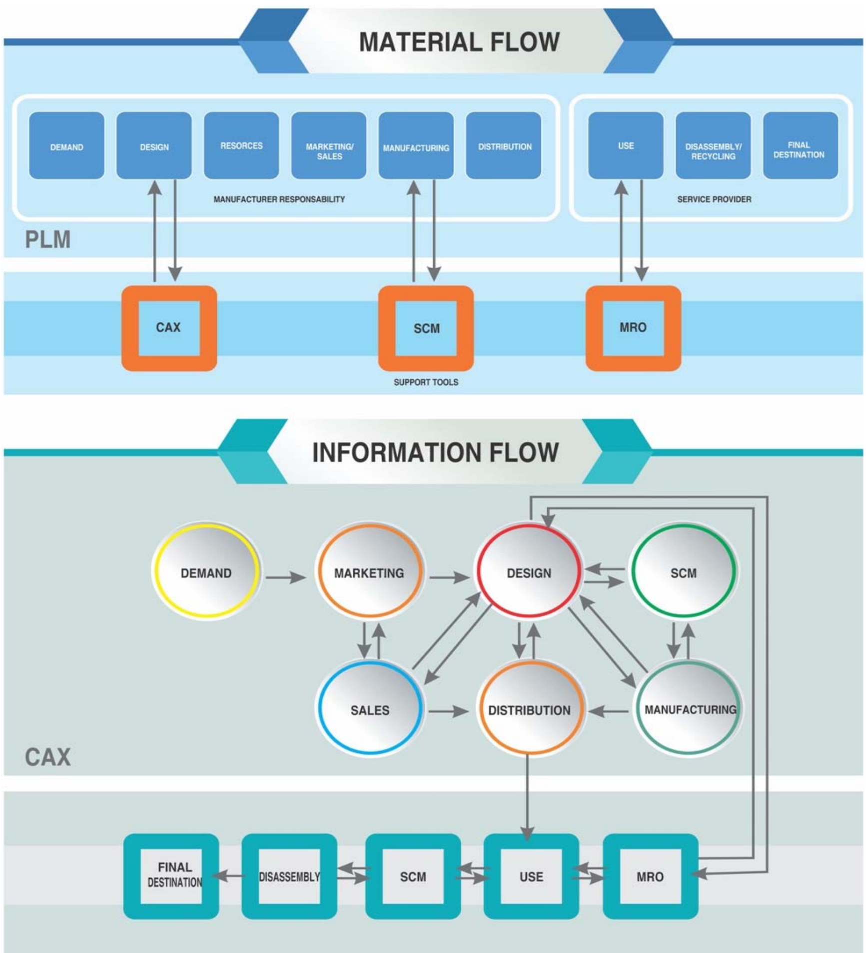
Based on the literature survey, it was possible to develop an integration of management tools that could link the MRO, SCM and NPD management tools within a PLM approach.

As mentioned earlier, much of the focus of the PLM approach is concentrated on the design phase. This makes considerable sense because many of the decisions made in the design phase will impact the entire value chain of the product. As noted above, part of the information generated within a value chain only makes sense if product development can take advantage of the information generated by both SCM and MRO. Thus, derivative projects could benefit the most from an integration between these approaches. Later, this situation will be more specifically addressed with respect to the constraint of applying the tool integration process to other types of projects. The proposed integration of management tools with PLM will now be addressed.

4.1 Integration of management tools with PLM

The integration of management tools with PLM is illustrated in this section. Figure 2 is divided into two phases, with the *first* presenting the material flow within the value chain based on the decision-making points.

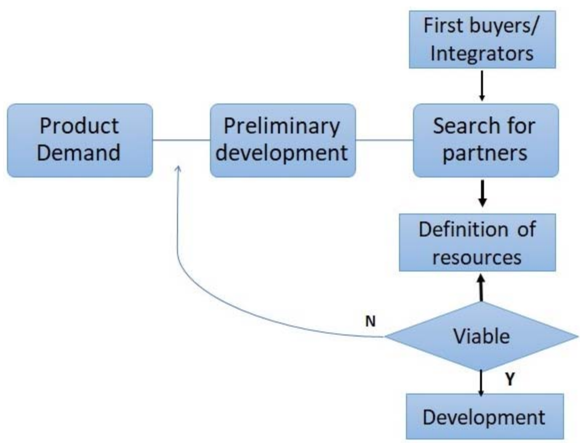
Figure 2 Integration of management tools – PLM, CAx, SCM and MRO – in the commercial aviation industry (see online version for colours)



4.1.1 Material flow

As shown in Figure 3, based on the customer's demand or the assessed need for a given product, a preliminary product development process begins that seeks to define the viability of the product. Once development of the product has been deemed viable, advance sales of the product begin along with a search for initial partners who will invest in the product before its launch. A portion of these partners will be part of the SCM (possibly as integrators) of the product or the buyers. The main features comprising the project are defined in this stage. Once this stage is concluded, the marketing and sales activities proceed to define the initial buyers of the product. Subsequently, the actual development of the product moves forward, thus creating a loop with respect to the definition of the viability of the product. If it is feasible, the stage for definitive development of the product proceeds; otherwise, the project is terminated or the company returns to the previous development stage.

Figure 3 Material flow in preliminary development (see online version for colours)



The sequence from this point onward is the same as that for any other product. The responsibility of the producer is defined as extending until product delivery. In the case of commercial aviation, at this point, the airlines share responsibility for product maintenance with the manufacturers: in this industry, repair and maintenance are directly linked to the manufacturer (Wang, 2010) and performed through a sales and maintenance contract, which will last the entire lifecycle of the product.

At the end of the product's operational life, it goes through a dismantling stage, in which the pieces that can be recycled return to the supply chain or become raw material for another type of product (Vieira et al., 2017a). The material that cannot be reused continues on to its final destination, which may be an incinerator or a landfill.

This same system is presented in macro form in Figure 2, which shows where the management tools interact throughout the value chain stages. The CAx assist the development stage, and SCM assists in defining the integrators, the clusters and the materials to be used throughout the process. SCM is also involved in the manufacturing stage and in the final destination of the product. MRO is directly linked to the use stage.

4.1.2 Information flow

Figure 2 illustrates the links between the tools and PLM and the sequence of operations to be executed. It is worth emphasising that at this moment, the focus is on the management tools: how they integrate and how the integration impacts management. Thus, the highlighted part of the figure refers to the flow of information along the entire value chain.

The flow of information inevitably begins with the demand or need for the product; the marketing sector passes information regarding demand along to the design sector. The design sector manages the entire information system because in a system that uses PLM, it is necessary to consider the scenarios in the entire value chain, from the beginning of manufacture until the final destination. Therefore, it is of fundamental importance that information concerning each step of the process be available so that the decision makers can choose the best path to take when developing the product.

As mentioned earlier, in this stage, after the initial definitions regarding product viability, the sales/marketing sector is activated to identify those partners/customers that will be willing to 'bet' on the development of the product. In the next step, the integration of management tools proposes that the design sector go beyond the SCM to obtain information. It is worth clarifying that in the commercial aviation industry, the supply chain has a differentiated role in comparison to most industries. In this industrial sector, the manufacturer increasingly does not play the traditional role of producer (development and manufacturing). Instead, its role is closer to that of an integrator – its main function is to assemble the platform, manage all members of the supply chain and define the subintegrators responsible for producing certain parts of the aircraft, such as the propulsion system, wings, etc. The manufacturer's functions include developing a software system that can aggregate the different systems existing among the other members of the supply chain. Thus, the integration of the design system and SCM holds a decisive role in the product development stage. In this stage, it would be useful for the design sector to have information about the use of predecessors or similar products to that under development in addition to information about distribution. In particular, constant interaction with the assembly sector regarding either information about previous models or real-time information about the process is encouraged if there is still a need for changes and adaptations during the assembly process. The assembly process is understood as being the manufacture of product parts either in different regions or countries where the partners are established or in clusters forming a single conglomerate that constitutes the manufacturing industry. It would also be useful in the tool integration process during the disassembly step to have information about the process for reusing material rather than only having this material available in the product's post-use period. This information should be disseminated throughout the integration process as well as throughout the aircraft maintenance process – in this case, independent of the type of project being developed. Much of the maintenance information will be the same across the various aircraft models produced. Information about wear and tear from usage may depend, for example, on the geometry of the material. However, much of the information about usage, such as the material's fatigue process, may depend on other factors, and this information could help the decision maker – still in the design process – to implement improvements that would result in better use of that material.

At this point in the explanation of the tool integration process, it is necessary to return to discuss the type of project to which this process can be applied. As in many other studies, the positive impacts of integration between various factors of the value chain and how they can benefit a given sector as a whole are discussed in this study. However, it is necessary to place the reader in situations in which this benefit is both relevant and achievable.

In the commercial aviation industry, the development team participating in one project does not necessarily participate in the next. Moreover, the team may also change during the development period of a product. This may occur for various reasons, such as budget adjustments, actions by competitors, seeking the best professionals and retirement.

Changes in the development team occur because senior development engineers have participated in many projects, and based on this type of experience, they have developed expertise in making decisions when confronting similar problems. Moreover, senior engineers can clearly switch projects considering the knowledge acquired on the subject in question: product development.

It is precisely regarding this change in the development framework and, where appropriate, changes in the product (be it a breakthrough, platform or derivative project) that the topic of integration can be explored. This context will lend sense to a form of integration that considers all the information that cannot be used in the current project but could be used in a future project or information about old products that can be incorporated into the new one.

Obviously, the issue is addressed by the operations system of the company. Nonetheless, making substantial reports on the technical solutions devised at each development stage helps to record what could have been done, but it does not help in the managerial phase of a new project.

What is discussed here are managerial actions that make it possible to develop a protocol and assemble a series of strategies that offer practical guidance, such that all teams can progress. This does not mean that all decisions are linked, making the creative process inflexible – this process must always exist in this type of industry given that innovation comes from creation. In fact, what is sought here is to make the process flexible, so that the manner in which to act is configured but not the decision-making.

A strategy that can be used to help decision-making is to list the most important criteria and, from these, to establish a decision-making sequence in relation to the activities that should be performed, as proposed by Vieira et al. (2017b).

In accordance with this approach, the choice of a single development line can increase costs exponentially during subsequent decisions because at each step, the previous decision is always adding costs to the process, to the point where, on the one hand, it may be unfeasible to continue the project and, on the other, unfeasible to go back, especially in regard to research and development or breakthrough projects, where little information is known beforehand.

Another possible approach is to delay final decisions as much as possible, progressing along a few paths including different possibilities and scenarios. One advantage of this approach lies precisely in the possibility that several lines may lead to new technologies. Additionally, the solution from one line could be applied to other lines. Another advantage would be that the ideas developed but not chosen in the project could potentially be reused in other projects.

Thus, it is suggested that a unique method be developed for each company. This is not an easy task, because some restrictions are already known. It is known, for example, that in many cases, development engineers have no interest in sharing information that they believe to be crucial to maintaining their status quo within the company and within the market.

This type of protocol should be part of the organisational culture of the company. Thus, a sequence of actions is suggested that could make this process easier to implement.

1 Conviction of senior management.

   Senior management must have total conviction because at the outset, the use of a management protocol may seem burdensome, although it will certainly bring many rewards in the future, not only in the development of the product but also in the development of the company within its sector.

2 Knowledge of the organisational culture of the company.

   One should examine how the company functions and truly know its manner of thinking, so that the strategy is linked to a natural manner of operating within the company and it can be applied with the least possible resistance.

3 Alignment of the projects with the mission and the macro strategy of the company

   Additionally, the implementation method must consider the current managerial decision-making at the company and the company's mission and strategy.

4 Definition of a path for the projects

   In this phase, it is necessary to have brainstorming meetings with the entire management staff of the project office or of the company's development team in order to seek a standardised decision-making method aligned with the company's objectives. A strategy should be developed that treats the company as a project and that takes into account the entire set of decisions for each project, as if it were an assembly line, such that even if the team completely changes between each project, the decision-making behaviour remains the same. There is no doubt that the technical status and technical expertise of the product will already be established within the company. However, it is unreasonable to expect a different approach to be taken every time a problem or challenge arises when creating a new product. Obviously, it is expected that the solutions be different, given that the aviation industry is a dynamic sector that is continuously developing both technologically and in regard to the experience of the technical staff.

Thus, it is believed that for a company using this management approach, the integration of the management tools will make sense and bring benefits. The other explanations for the flow are shown in Figure 2: MRO can transfer information directly to the product development stage, and the SCM will be interconnected to the development, manufacture, use and final product destination stages. Thus, with respect to the information flow, it makes sense that the interaction between MRO, SCM and PLM would not only impact the current project but also be part of the company's organisational culture.

5 Conclusions

As the main result of this article, an integration of management tools that includes SCM, MRO and PLM is proposed. To make the integration of these approaches feasible in the development of new products in the civil aviation industry, it is suggested that a decision-making protocol be introduced. The implementation of this protocol would greatly facilitate the work of decision makers, since the strategies for addressing a given problem will already be established and will be part of a company's organisational culture. Even when the development teams change, the manner in which a company acts will be preserved.

The limitation of this study was the lack of application and testing of the integration of management tools. Thus, this is a suggestion for future studies.

References

Baidya, R., Ghosh, S.K. and Parlikar, U.V. (2017) 'Sustainability of cement kiln co-processing of wastes in India: a pilot study', *Environmental Technology*, Vol. 38, Nos. 13–14, pp.1650–1659.

Belkadi, F., Bernard, A. and Laroche, F. (2015) 'Knowledge based and PLM facilities for sustainability perspective in manufacturing: a global approach', *Procedia CIRP*, Vol. 29, pp.203–208.

Bertoni, A., Bertoni, M. and Isaksson, O. (2013) 'Value visualization in product service systems preliminary design', *Journal of Cleaner Production*, Vol. 53, No. 1, pp.103–117.

Bouhaddou, I. and Benabdelhafid, A. (2017) 'Product lifecycle management (PLM): a key to manage supply chain complexity', in Bourgine, P., Collet, P. and Parrend, P. (Eds.): *First Complex Systems Digital Campus World E-Conference*, Springer International Publishing, Cham, pp.375–382.

Cantamessa, M., Montagna, F. and Neirotti, P. (2012) 'Understanding the organizational impact of PLM systems: evidence from an aerospace company', *International Journal of Operations & Production Management*, Vol. 32 No. 2, pp.191–215.

Carter, C.R. and Jennings, M.M. (2002) 'Logistics social responsibility: an integrative framework', *Journal of Business Logistics*, Vol. 23, No. 1, pp.145–180.

Culler, D.E. and Anderson, N.D. (2016) 'A paradigm shift towards personalized and scalable product development and lifecycle management systems in the aerospace industry', *World Academy of Science, Engineering and Technology. International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering*, Vol. 10, No. 4, pp.755–763.

Daniels, M. et al. (2013) 'Product lifecycle management requirements gathering: industrial pilot cases', *IFAC Proceedings Volumes*, Vol. 46, No. 9, pp.1750–1755.

Favi, C. and Germani, M. (2014) 'A design for disassembly approach to analyze and manage end-of-life options for industrial products in the early design phase', in Henriques, E., Pecas, P. and Silva, A. (Eds.): *Technology and Manufacturing Process Selection: The Product Life Cycle Perspective*, Springer, London, pp.297–322.

Ferreira, F. et al. (2017) 'Product lifecycle management in knowledge intensive collaborative environments: an application to automotive industry', *International Journal of Information Management*, Vol. 37 No.1, pp.1474–1487

Gecevska, V. et al. (2011) 'Process of innovation in product lifecycle management business strategy', *Perspectives of Innovations, Economics and Business*, Vol. 3, No. 9, pp.53–56.

Govindan, K. et al. (2014) 'Two-echelon multiple-vehicle location–routing problem with time windows for optimization of sustainable supply chain network of perishable food', *International Journal of Production Economics*, Vol. 152, No. 1, pp.9–28.

Govindan, K., Khodaverdi, R. and Jafarian, A. (2013) 'A fuzzy multi criteria approach for measuring sustainability performance of a supplier based on triple bottom line approach', *Journal of Cleaner Production*, Vol. 47, No. 1, pp.345–354.

Hassini, E., Surti, C. and Searcy, C. (2012) 'A literature review and a case study of sustainable supply chains with a focus on metrics', *International Journal of Production Economics*, Vol. 140, No. 1, pp.69–82.

Khanchanapong, T. et al. (2014) 'The unique and complementary effects of manufacturing technologies and lean practices on manufacturing operational performance', *International Journal of Production Economics*, Vol. 153, No. 1, pp.191–203.

Khatri, J. and Srivastava, M. (2016) 'Technology selection for sustainable supply chains', *International Journal of Technology Management & Sustainable Development*, Vol. 15, No. 3, pp.275–289.

Lee, S.G. et al. (2008) 'Product lifecycle management in aviation maintenance, repair and overhaul', *Computers in Industry*, Vol. 59, Nos. 2–3, pp.296–303.

Lhafiane, F., Elbyed, A. and Bouchoum, M. (2015) 'Reverse logistics information management using ontological approach', *World Academy of Science, Engineering and Technology. International Journal of Information and Communication Engineering*, Vol. 394, No. 2, pp.396–401.

Machado, M.C. et al. (2016) 'A qualitative study of outsourced aeronautical maintenance: the case of Brazilian organizations', *Journal of Air Transport Management*, Vol. 55, No. 1, pp.176–184.

Madenas, N. et al. (2016) 'Improving root cause analysis through the integration of PLM systems with cross supply chain maintenance data', *The International Journal of Advanced Manufacturing Technology*, Vol. 84, Nos. 5–8, pp.1679–1695.

Marques, P.C. (2016) 'Building sustainable creativity: a conceptual framework', *European Journal of Sustainable Development*, Vol. 5, No.3, pp.433–439.

Marra, M. et al. (2018) 'A gap analysis methodology for product lifecycle management assessment', *IEEE Transactions on Engineering Management*, Vol. 65, No. 1, pp.155–167.

Mas, F. et al. (2015a) 'A review of PLM impact on US and EU aerospace industry', *Procedia Engineering*, Vol. 132, pp.1053–1060.

Mas, F. et al. (2015b) 'PLM based approach to the industrialization of aeronautical assemblies', *Procedia Engineering*, Vol. 132, pp.1045–1052.

Merlo, C. et al. (2017) 'Knowledge modelling for an electrical PLM system in aeronautics', in Ríos, J., Bernard, A., Bouras, A. and Foufou, S. (Eds.): *IFIP International Conference on Product Lifecycle Management*, Springer International Publishing, Cham, pp.642–654.

Papakostas, N. et al. (2010) 'An approach to operational aircraft maintenance planning', *Decision Support Systems*, Vol. 48, No.4, pp.604–612.

Qu, M. et al. (2016) 'State-of-the-art of design, evaluation, and operation methodologies in product service systems', *Computers in Industry*, Vol. 77, No. 1, pp.1–14.

Thomas, A.J. et al. (2015) 'Reducing turn-round variability through the application of Six Sigma in aerospace MRO facilities', *Journal of Manufacturing Technology Management*, Vol. 26, No. 3, pp.314–332.

Tukker, A. (2015) 'Product services for a resource-efficient and circular economy – a review', *Journal of Cleaner Production*, Vol. 97, No. 1, pp.76–91.

Uhlmann, E., Bilz, M. and Baumgarten, J. (2013) 'MRO – challenge and chance for sustainable enterprises', *Procedia CIRP*, Vol. 11, pp.239–244.

Vieira, D.R. et al. (2017b) 'Model for managing uncertainty in aeronautics projects', *International Journal of Product Lifecycle Management*, Vol. 10, No. 3, pp.258–278.

Vieira, D.R., Vieira, R.K. and Chain, M.C. (2017a) 'Strategy and management for the recycling of carbon fiber-reinforced polymers (CFRPs) in the aircraft industry: a critical review', *International Journal of Sustainable Development & World Ecology*, Vol. 24 No.3, pp.214–223.

Wang, W. (2010) 'A model for maintenance service contract design, negotiation and optimization', *European Journal of Operational Research*, Vol. 201, No. 1, pp.239–246.

Wheelwright, S.C. and Clark, K.B. (1992) *Creating Project Plans to Focus Product Development*, Harvard Business School, Boston, MA.

Zhu, H. et al. (2012) 'A web-based product service system for aerospace maintenance, repair and overhaul services', *Computers in Industry*, Vol. 63, No. 4, pp.338–348.