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Analysis of the application of critical chain project management in the product development process and portfolio management of an aircraft manufacturer

Análise da aplicação da gestão de projetos por corrente crítica no processo de desenvolvimento de produtos e na gestão de portfólio de um fabricante de aeronaves

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Abstract: Products portfolio management, as a part of a product development process, presents challenges as the products life cycle of many sectors, has been continuously diminished. Though several academic studies support the thesis that the Critical Chain Project Management (CCPM) method tends to bring good results in multi-project management, most of these studies do not focus on product development environments and, more specifically, the way in which CCPM endorses product portfolio management in these environments. This perception proves interesting when considering that some scientific studies show the difficulties of an effective portfolio management. This work aimed to study the CCPM application as a support method in the product development process in general, and for portfolio management specifically, seeking to verify, by means of a case study, its forms of application in a company with formal product development processes. The results lead to the conclusion that CCPM is relatively beneficial to the projects performance, contributing both to the product development and product portfolio management.
Keywords: Product portfolio management; Product development process; Critical chain.

Resumo: *A gestão de portfólio de produtos, como parte de um processo de desenvolvimento de produtos, apresenta desafios na medida em que os ciclos de vida dos produtos, para muitos setores, vêm sendo continuamente comprimidos. Trabalhos acadêmicos defendem a tese de que o método de Gestão de Projetos por Corrente Crítica (CCPM – Critical Chain Project Management) tende a trazer bons resultados na gestão de multiprojetos, mas a maioria desses trabalhos não foca ambientes de desenvolvimento de produtos e, mais especificamente, a forma pela qual a CCPM apoia a gestão de portfólio de produtos nesse tipo de ambiente. Tal percepção ganha em interesse quando se considera que alguns trabalhos científicos apontam as dificuldades no fazer uma efetiva gestão de portfólio. Dessa forma, este trabalho tem como objetivo estudar a aplicação da CCPM como método de apoio ao processo de desenvolvimento de produtos em geral e de gestão de portfólio em específico, procurando verificar, na forma de um estudo de caso, suas formas de aplicação em uma empresa com processos formais de desenvolvimento de produtos. Os resultados permitiram concluir que a CCPM trouxe ganhos quantitativos relevantes ao desempenho dos projetos, contribuindo para o desenvolvimento de produtos e a gestão de portfólio de produtos na empresa em estudo.*
Palavras-chave: *Gestão de portfólio de produtos; Processo de desenvolvimento de produtos; Corrente crítica.*

1 Introduction

Delivery time has assumed a relevant role as a competitive advantage. There is a growing tendency among clients to evaluate suppliers by taking into account various factors, such as price, quality, service, with a predominance in terms of relevance given to delivery time (Agarwal et al., 2010).

Many organizations have been pressured into making commitments to deliver more and more innovative projects, including new products in ever shorter deadlines. On the other hand, despite technological devices and robust management software, projects still take the same or longer time than ten years ago,

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and are very often delivered late, over-budget, or their requirements and specifications are cut to meet original deadlines. In this environment of uncertainty, conventional project management practices are no longer adequate (Li & Moon, 2012).

Product development is a process that involves the generation of ideas, product design and detailed engineering. The development process is different from the production process because it can involve hundreds of functional activities. With the increase in product complexity, not only does the number of functional activities increase, but also the relationships between them become more complicated. The traditional product development and project management tools, such as PERT (*Program Evaluation and Review Technique*) and Gantt Chart, are no longer sufficient to support these activities. These traditional processes may fail to meet the requirements for complex product development (Ahmad et al., 2013).

Product development projects have peculiarities which need to be considered. This is proven by the existence of many theoretical reference models in Product Development Process (Markham & Lee, 2013). PDP constitutes one of the key processes of any company that intends to compete by creating its own products in the pursuit of technological leadership. Considering the way in which product life cycles reduce year on year, the study of Product Portfolio Management (PPM) techniques presents enormous challenges (Rozenfeld et al., 2006).

Given the difficulty of using formal methods for prioritizing projects, the prioritization and allocation of resources, in particular, are generally treated by mathematical optimization methods that are difficult to apply, leading companies interested in improving the PPM process to create their own methods of decision making (Magdalena, 2013).

Naor et al. (2013) highlight that Critical Chain Project Management (CCPM) is a project management method which aims to overcome two of the main challenges in this area: to complete each project in the shortest time possible and execute more projects without the need for additional organizational resources. In this sense, CCPM can potentially contribute not only to project management in general, but with PPM in PDP, specifically.

According to Millhiser & Szmerekovsky (2012), there are various organizations which have related successful cases of CCPM method use, such as: Boeing, Space & Intelligence, Bosch Security Systems, Daimler Chrysler, Delta Airlines, Hewlett-Packard, Honeywell, Pratt & Whitney, U.S. Army, U.S. Air Force, U. S. Navy and Votorantin. Kishira (2009) cites a statement from the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT), stating that all Public Works Projects from that country are now managed by CCPM, approximately 20 to 30 thousand projects per year, since November 2008.

Specifically in the world of Brazilian studies, numerous research papers have dealt with the use of CCPM, studying the methodology as a tool applied to specific situations by certain Brazilian industries, such as plant shutdowns or as an alternative theoretical proposition to other project management methods (Silva et al., 2012).

In the international literature, one can find many studies on CCPM. Academic studies which deal with the comparison of CCPM with other project management methods are common. Among them Newbold (2008) and Millhiser & Szmerekovsky (2012) can be highlighted. Others, such as Leach (1999) and Steyn (2012), affirm that CCPM is a technique which tends to bring about good results in multi-project management; but the majority of these studies do not focus on product development environments and, more specifically, the way in which CCPM supports PPM in these kinds of environments.

Some studies reveal difficulties in implementing PPM effectively (Machacha & Bhattacharya, 2000; Avineri et al., 2000; Chang et al., 2010), thereby stimulating interest in evaluating the effectiveness of new management methods. Thus, the present study starts from the premise that empirically evaluating the particularities of CCPM applications in product development environments is relevant to better understand how CCPM adapts to these types of environments as well as, potentially, how it can help expand the knowledge base in PDP and PPM. In this context, the study proposes to verify, in a real product development environment, how CCPM can contribute effectively to PDP in general and to PPM in particular, shedding light on and contributing, in this way, to the boundaries of knowledge surrounding CCPM, PDP and PPM project management issues.

Thus, the motivation of this work is to find answers to the following problem: in what ways can CCPM support Product Development Processes (PDP), in general, and Product Portfolio Management, in particular?

To this end, the main objective of this work is to evaluate, by means of a singular and longitudinal case study, the application of techniques recommended by CCPM, as much for the management of individual projects as multiple ones, as a method of supporting PDP activities, in general, and PPM in particular, seeking to verify potential forms of application in a company with formal product development processes and also CCPM utilization. The company selected for the study is an aircraft manufacturer which has received recognition for the way it makes use of CCPM in the development of its products.

The remainder of this article is organized as follows. The next section summarizes the literature on the main themes, namely PDP, PPM and CCPM. Section 3 presents the methodological procedures adopted for the development of the case study, whose data are presented and discussed in section 4.. Finally, Section 5 highlights the main conclusions reached by the study.

2 Literature overview

This section summarizes the relevant concepts that concern the three principal themes of this study: Product Development Process, Product Portfolio Management and Critical Chain Project Management, with an emphasis on the last, being the main focus of this article.

2.1 Product development process

In a wider sense of the objectives to be achieved by PDP, Rozenfeld et al. (2006) mentions four general aims: identification of market needs; identification of alternative technologies; development of products in accordance with market expectations in terms of quality, time and cost; and consideration of the possibilities and limitations of the manufacturing process.

Project development management can be systematized through business processes, with well-defined stages that an organization can use to transform its opportunities and ideas into final products. It is important that these steps are consistent with the organization's competitive strategy (Echeveste & Ribeiro, 2010). The development of products covers all activities performed by the various functional areas of the company, allowing information on market needs to be transformed into data and resources for the production of a specific product (Akroush, 2012).

According to Li & Moon (2012), the PDP is a process for the generation of ideas, through production project and manufacturing, with the objective of bringing a new product to the market.

For Ceccagnoli (2010), PDP is a source of crucial competitive advantage for a company, and one that can create competitive differentiation, establish barriers to entry, open new markets and eventually increase revenues and profits. Two factors are indicated as determiners for the development success of a new product: product innovation speed and innovation of the product itself.

Sheng et al. (2013) affirm that the presence of a multi-discipline environment is one of the characteristics of PDP, in that each group can be seen as having its "own worlds", which create interpretive barriers. Cooperative teamwork means that employees of different functions should cover these limits to find effective ways of interaction and communication.

According to Felekoglu et al. (2013), multi-functional teamwork, internal and external communication, strong interrelations, knowledge transfer and senior management support are considered important issues that influence the success of a PDP. The effect of communication and the interaction between stakeholders are consistently considered important factors for the PDP success. Thus, PDP is an inherently multi-functional activity and it is widely recognized that its multi-disciplinary nature produces interactions that can hinder its management (Majava et al., 2013).

A study by Richtner & Ahlstrom (2010) investigated the relationship between control mechanisms and the creation of knowledge in the development of a new product. They distinguished between formal and informal control mechanisms: little control can be negative, because the team lacks feedback, while excessive control can reduce team performance.

In order to gain competitive advantage, Chan & Ip (2011) and Graner & Mißler-Behr (2014) emphasize the importance of client relationships in the development of a new product, because client satisfaction raises its loyalty and, in the long term, promotes business profitability. In this way, new products are a key factor of customer satisfaction, playing a fundamental role in business sustainability (Graner & Mißler-Behr, 2014).

2.2 Product portfolio management

According to Blichfeldt & Eskerod (2008), portfolio management can be defined as a centralized administration of one or more portfolios, which include the identification, prioritization, authorization, management and control of projects, programs and other activities to reach the business strategic objectives. There are many types of portfolio management: portfolios of investments, of commercialized products, of resources, amongst others. However, for the purposes of this research, portfolio management refers only to projects whose results are new products for the company.

The decision-making process in portfolio management is comprised of three major stages. The strategy phase involves excluding projects that do not meet the business strategy guidelines. The evaluation phase of a project evaluates, principally, individual projects, and in the portfolio selection phase projects that offer the biggest benefits with limited resources are selected (Cooper et al., 1999).

The needs of an organization and the PPM models already developed should be well-known by those responsible for implementing the PPM process, allowing an effective selection of the most appropriate stages and techniques. Indeed, Castro & Carvalho

(2010) affirm that there is no singular process or PPM method that is effective for all organizations.

According to Oh et al. (2012), the literature offers a range of project portfolio analysis methods, which can be classified in three main categories. The first category is a prioritization approach, in which the expected results are evaluated and the projects prioritized based on them. The second category involves a mathematical optimization approach. These methods attempt to optimize different objective functions while simultaneously considering the resource constraints, the project rationale, and the dynamics, technology and strategies relating to the project. The final category involves a strategic management approach. This approach aims to overcome the limitations of the prioritization approach and ensures a balanced portfolio. Jugend & Silva (2013) propose a classification of these methods and suggest that the principal ones are: financial, stage evaluation (*stage-gates*), score and ranking, portfolio charts, graphs and diagrams and checklist method.

According to Chang et al. (2010), the decision-making process for selecting a portfolio can be divided into three phases. The Strategic Consideration Phase is a pre-operational phase, established from different project types, such as: new development projects, new business projects, process improvement projects and ongoing projects. The idea is to support decisions that eliminate inferior projects and select those that better meet the strategic objectives. In the Project Evaluation phase, the selected projects are individually evaluated by means of cost, profit, technical capacity and risk indicators. During the Portfolio Selection Phase, projects are selected in order to obtain the maximum benefits while operating within limited resources.

2.3 Critical Chain Project Management

According to Rand (2000), the reason for the development of Critical Chain Project Management (CCPM) is the existence of chronic problems that the existing methods, approaches and even software have not been able to remove, such as delays, overspending, the need to cut specifications and other undesirable effects common to project environments. The inability to deal with these problems demands a complete and rigorous analysis, making room for CCPM approach implementation.

For Naor et al. (2013), originally, CCPM was principally used for project scheduling management; later on, it was also applied to other areas of project management knowledge. But there are some difficulties in the application of this technique, such as the determination of the time buffer, a parameter whose calculation has a certain level of subjectivity.

The majority of businesses use a project management model that, after defining the project scope and its subdivision into work packages are identified as activities that will be performed to generate the final product to be delivered. After estimating the duration of these activities, according to this model, a network diagram should be drawn up with early (start and finish) and late (start and finish) dates calculated, and the critical path, which is defined as the path that will determine the duration of the project, identified. Any delay in this process will delay the conclusion of the project.

The starting point for the application of CCPM in a project is a list of tasks, together with their duration estimates and dependencies. The first step involves developing an initial schedule for the project tasks (Rand, 2000). CCPM identifies the "Critical Chain" as the set of tasks that result in the longest way to project completion, after the elimination of conflicts between tasks that share resources. The Critical Chain provides the forecasted project conclusion date.

An initial basic premise of CCPM is that proper time management brings benefits in the management of scope and costs (for example, a late project incurs increased costs and / or cutting of initial specifications to ensure on-time delivery). Another premise is that the traditional way safety is added to the individual tasks of a project is at the root of the problems observed in time-management practices (Goldratt, 1998).

Goldratt (1998) affirms that inherent project uncertainties are the principal source of problems in project management. Uncertainties arise from difficulties predicting obstacles early in the project that, being unknown and immeasurable, become a problem for project planning, specifically for duration estimates activity (Herroelen & Leus, 2001; Raz et al., 2003). To compensate for uncertainties, traditionally, the activity time estimates are inflated, adding safety (Silva et al., 2012). For Gupta & Andersen (2012), one way to prevent activity protection being wasted is to simply not add them to their own activities, but in time buffers at the end of the critical chain. Buffers appear as tasks on the project plan, but do not have work allocated to them. According to Leach (1999), CCPM protects the project conclusion date by means of a *Project Buffer*, added to the end of a Critical Chain. The buffers exploit the statistical law of aggregation, protecting the project from individual task uncertainties using shared protections.

Other buffers proposed by CCPM are (Leach, 1999; Herroelen & Leus, 2001) the *Feeding Buffer* - that protects the critical chain from delays in paths that feed it – and *Resource Buffer* – that, by means of warnings, protects the Critical Chain from the unavailability of resources that will carry out tasks pertaining to it.

CCPM controls project progress through *Buffer Management* (BM). The quantity of buffer used provides information to the project management regarding the state of the project and when to take corrective action. The buffers can be divided into three equal time periods, indicating, respectively, "expected variation", "normal variation" and "abnormal variation" (Budd & Cerveny, 2010).

Patanakul & Milosevic (2009) define the multi-project environment as an organizational environment in which several projects are generated simultaneously. Researchers have proposed various methods of resolving the constrained resource problem in multi-project environments. From the operational research point of view, the problem of multi-project organization management has been well exploited, with the development of various algorithms and methods.

However, operational research methods might not be the best choice to face the challenges of multi-project management if the organizations are in positions of uncertainty. Moreover, such methods demand that projects be independent, which is not the case in the majority of industries working with technology transference (Shanlin, 2013).

Gupta & Andersen (2012) highlight that, in an environment where a critical resource is considered to be shared between multiple projects, delays in one project may cause delays in the others. So, when a resource bottleneck is simultaneously shared between multiple projects, the term of the project extends and the critical resource remains congested, with no room for the recovery of delays.

According to Yaning (2011), in order to apply the CCPM technique in a multi-project environment, the current project portfolio should firstly be identified. Then, the system constraint must be located. Constrained resources, or bottlenecks, determine the subsequent sequencing of the project portfolio.

Specifically for multi-project management, CCPM proposes the Scheduling Buffer. In multi-project environments each project is programmed in the same manner as a single project environment. To minimize the need for sharing resources and to certify that project delays do not affect other projects, the addition of new a project to the system must be controlled. To this end, a Scheduling Resource is defined. It is chosen from among the resources that participate in the majority of the projects. A specific buffer is defined in each project ahead of the first task to be carried out by the Scheduling Resource. This protection is known as the Scheduling Buffer (Budd & Cerveny, 2010; Yang & Fu, 2014). The projects are accommodated by combining the individual project scheduling with CCPM principles, especially the emphasis on the reduction of multitasks (multitasks occur when the demand for tasks forces the resource to interrupt each task before its conclusion).

There are other concepts focused on CCPM implementation, such as full kitting and project freezing. Full kitting is the process of project requirement clarification, from project approval by the parties involved, to the preparation of materials and resources to be used, as well as every other action necessary to ensure smooth project implementation (Realization Technologies, 2010).

Bad multitasking is common in multi-project environments where shared resources are working in several projects in parallel. One solution to drastically reduce multitasking in such environments is to simply define the maximum number of open projects, even if this results in project freezing. According to this idea, when one project is finalized, another is opened (Holt & Boyd, 2010). This should be done before critical chain planning and the use of any software. The maximum number of open projects should be less in comparison to that normally run (Herman & Goldratt, 2010). According to the strategies and tactics (S&T) tree, CCPM implementation should reduce the project load by 25%, which would decrease the presence of bad multitasking without leaving insufficient projects running, also impacting on the project conclusion rate. In addition, projects are thawed at a rate that maintains the reduced load (Souza & Baptista, 2014).

3 Methodological procedures

The current study was conducted as a single, longitudinal case study, with the purpose of profoundly analyzing new management practices (Miguel, 2007). According to Seawright & Gerring (2008), the chosen unit should meet the criterion of representation and variation in terms of the theoretical interest dimension of the research. To carry out the research, a case study of a company that defines itself as a user of CCPM to support the products development management and products portfolio management was adopted. A second criterion is that the unit under observation should have a representative and diverse portfolio, as well as a structured product development process. A third criterion is that the application of CCPM by the company can be characterized as a reference for CCPM use.

Based on these criteria, the unit chosen for analysis was a large national aerospace company, whose revenue and investment in Research and Development (R$737 million in 2013) makes it strategic for the country. Product development is a strategic business process at the company and CCPM is seen as an important support method for this process. The implementation of CCPM by the company meant it received an award, as the second best innovative project of the year, from "Mundo PM" magazine, and it was highlighted by the same publication in February/March 2012.

Data collection was planned and carried out in three stages, predominantly qualitative: application of questionnaires, direct observation and document analysis. Questionnaires were administered through face-to-face interviews with five managers chosen for their degree of understanding of the company's product development processes, its portfolio management and of the CCPM method itself. The managers interviewed were: an engineering planning manager (responsible for the planning of engineering activities at the company and for the implementation of CCPM in all engineering areas of the company), an engineering manager (responsible for the engineering activities of a manufacturing unit of the company), two program administrators,- being one representative from the commercial aviation segment and another representative from the aviation defense segment - and an engineering project management supervisor. Such respondents are herein referred to as Interviewees 1, 2, 3, 4 and 5 respectively. The questionnaire was organized in three parts with open and closed questions addressing the themes of PDP, PPM and CCPM, always focusing on their application in the case study company. Due to the different degrees of involvement of each respondent in product development and the company's portfolio management, certain questions were not directed to all respondents, and some were not answered by all. Data collected during the interviews was recorded, transcribed and analyzed in the light of the research problem. Essentially, based on the literature, the researchers sought to identify which, and how, the methods related to CCPM were utilized by the company through its product development management. The access to documents and reports available on the company's management systems, including those supplied by ProChain® Project Scheduling (software that plans and controls company project activities based on CCPM logic), allowed that information could be validated, as well as complementing it with more objectives data associated with certain performance indicators. Along with direct observation, the sources were compared (triangulation) and the data validated.

4 Case study: presentation and analysis of the results

This section presents the company and analyzes the data collected from the case study, identifying the way in which the company conducts their PDP and PPM activities, to assess if and how CCPM supports these activities.

4.1 The company

The company analyzed in this study is one of the largest in the world, being considered the most important company of its sector in Brazil and figuring amongst the principal national exporters.

Founded in the 1960s and established as a joint stock company - in which the federal government was the majority shareholder - the company was privatized in 1994 and is currently the leader in the manufacturing segment of commercial jets up to 120 seats. The company designs, develops, manufactures and sells aircraft for the commercial aviation, defense and security and executive segments, representing 45%, 33% and 22% of total revenue of the company, respectively.

4.2 The product development process

All those interviewed affirmed that the company has formal mechanisms for taking decisions aimed at defining which product projects should be developed. However, "Interviewee 1" supplied greater details regarding this process: the company has an Products Integrated Development (PID) policy with its suppliers. This policy is based on the company's own model that includes development process stages as well as the principal processes applicable to its achievement, organization of the development effort and its main procedures. "Interviewee 5" reported that "[...] *in commercial aviation there is a Program* (a group responsible for deliveries, development and modifications to certain aircraft models) *that carries out project portfolio management*". It was emphasized that PID is responsible for coordinating internal and external resource activities, for the generation of the products approved by the Program.

With access to the company document entitled "Products Integrated Development Process", the product development process adopted by the company could be understood. PID is a business process, also known as 'Create, Develop and Certify New Products and Services'. The activities of the PID are distributed in macro processes and phases. The processes are divided into: PP (pre-project), CS (conceptual studies), PS (preliminary studies), ID (initial definition), JD (joint definition), DET (detailing, fabrication, testing and certification), POP (pre-operation), SER (series) and PO (phase out). The following phases form part of these processes: manage product development, design products, define product and service, detail products and services, develop production processes, develop suppliers, test and certify the product.

There are transition criteria (between each phase), which function according to stage-gates logic and are the main elements of this process, being the basis for decision making. They make up a list of structured questions with a check-list of requirements and documents that demonstrate their completion. In terms of monitoring, there is a multidisciplinary team responsible for conducting the project, whose mission is to deliberate on identified risks. Thus, at each stage there is a processes review with the objective of ensuring the results match the requirements, identifying potential risks, approving the continuation of the project and, if necessary, setting out the recovery plans. This process is similar to the product development model given by Rozenfeld et al. (2006). Despite the differences in phase designation and in the way activities are grouped, the content is similar. For example, in the company PDP, production preparation is included in the Project Detailed and Certification phase, while in the model given by Rozenfeld et al. (2006), this phase is considered separately.

Besides high-level administration, Engineering, R&D and Commercial areas are all involved in the product development process, according to that reported by the five respondents. "Interviewee 2" cited the involvement of the Intelligence and Market Strategy areas and "Interviewee 5" mentioned the additional participation of the Production area. The decision regarding which products to develop takes into account the concept of platform, derivative and radically new products. "Interviewee 5" affirmed that "[...] *technical analyzes, for capturing the product scope and design, are carried out and then presented to contractors* (Program and Customer Support) *for approval*". Interviewee 2, in turn, pointed out that there is requirements management where commonalities between products are considered, mainly because there are airplanes of the same commercial aviation or executive aviation family. In this way, commonalities between aircraft of the same family are assured, facilitating future products development, the manufacture of replacement parts and pilot training. Another example given was of the business division aircraft, developed from commercial airplane platforms.

Two key aspects were highlighted by "Interviewee 3" as product development process difficulties: predicting which technologies will be needed in a few years time and how to develop them. To these aspects, "Interviewee 3" associates: a) marketing uncertainties (in what way will a new product be received by the market? How is it possible to perform in advance of the competitors?) and b) aspects of technological nature, exemplified by the technical definitions and requirements that will be necessary to obtain product certification. "Interviewee 5" raised uncertainties due to market scenarios as a potential problem, as there are many difficulties with the review of portfolio priorities and projects scope.

The questionnaire results show that the company seeks to integrate the development of products to other company business, using multidisciplinary teams located in the same environment, which means all project objects are wholly considered, in a simultaneous and apparently efficient way. Certainly, an important feature of the product development process is the joint participation of suppliers. In general, these are people responsible for the integration of parts and systems on the aircraft as a whole. Moreover, decisions made during the process appear to always take into consideration questions of cost, quality, delivery time, logistics and environment.

4.3 New products portfolio management

In relation to portfolio management, "Interviewees 2, 3 and 4" were not able to say how company portfolio management occurs. Regarding the commercial aviation business unit, "Interviewee 5" said that, "[...] *initially, there is a definition of business unit strategies; subsequently, a project classification is made and, finally, the formation of a priority order queue*". In relation to prioritization procedures, it was highlighted that "there are clear rules and projects are compared within each business unit in order to prioritize them. There is a project placement rule that takes into account the importance (strategic level) and cycle of projects in meeting commitments." "Interviewee 1" commented that, "[...] *there is no prioritization of projects between business units* (commercial, executive or defense)*: they should all be treated with the same importance*."

"Interviewee 1" emphasized, however, that

> [...] *projects enter at the end of the line to check the position of these new projects in the timeline. At this point, estimates of difficulty and duration based on previous project history are carried out. Thus, it is possible to generate a map of needs from a load and capacity simulator from which hiring, subcontracting or any product development postponing decisions are taken.*

Also, according to "Interviewee 1", the main challenges facing product portfolio management are:

> [...] *organizational* (need for leadership sponsorship and the clear definition of roles and responsibilities of those involved)*, technical* (lack of process knowledge and experience in the team as a whole) *and the power of engineering in decisions and management.*

External aspects of the organization, such as analysis and the anticipation of customer needs, were also cited. "Interviewee 5" emphasized "[...] *priority review and the need for compression of timelines as portfolio management challenges*."

"Interviewees 1 and 2" highlighted, in turn, the use of stage-gates and check-lists as support methods for portfolio management at the company, as well as noting a concern about formalizing all activities. The dominant method in decision making is the scoring model. The use of other methods of PPM were questioned, in addition to those found in the literature and mentioned in section 2.2 of this article, but none of these were cited, in the same way that no other method not on the list was recalled.

According to the company document entitled 'Modifications Portfolio Management', portfolio management aims to analyze project demands coming from different areas of the company and check how they are adhering to the company's strategic plan, with a view to approving the projects that ensure greater profitability, customer satisfaction and better use of resources.

Considered by the majority of respondents as fundamental for the competitiveness of the organization, new product portfolio management is carried out by the company in a similar way to that found in the portfolio selection framework proposed by Chang et al. (2010), with the presence of the following stages:

1. Definition of business unit strategies;
2. Classification of projects;
3. Formation of priority order queues.

The company has clear rules on the management of their portfolios, and their projects are compared and prioritized taking into account their importance (in strategic terms) and project cycles in terms of fulfilling the company's commitments. The formalization and standardization of the process of new products portfolio management was also identified. The greatest difficulties raised by the respondents are related to the review of priorities and the need to compress schedules due to market pressures and uncertainties.

4.4 The application of CCPM to support the products development process and portfolio management

CCPM has been in use at the company for around seven years, and was motivated by the top leadership's contact with the very successful implementation of the CTA (Center for Aerospace Technology), according to "Interviewee 1". "Interviewee 5" mentioned the search for a competitive advantage in the marketplace as motivation for utilizing CCPM, and commented that today all commercial aviation projects over 100 engineering hours make use of it. The method was initially adopted in the commercial aviation multi-project environment and, afterwards, in the executive aviation product development environment. Since then, CCPM has also been adopted for defense aviation.

"Interviewee 3" believes that, due to the success in commercial aviation, the system is migrating to a solution encompassing all engineering processes. Today, according to "Interviewee 3", all new product development processes utilize CCPM, and each business unit (commercial, executive and defense) uses it separately. The next step, according to this respondent, is to analyze whether all the concepts are being fully used, to enable further integration across the PPM process.

According to "Interviewee 2", the potential of the method in PPM was found in balancing features and portfolio delivery design, highlighting records (lessons learned), project monitoring and the development of a common language as positive points.

"Interviewee 5" reported that CCPM "is used in the creation of resource activities scheduling to support the PPM of the company, to the extent that the schedule created from CCPM is used for the prioritization of projects and for formalizing commitments with customers."

"Interviewee 1" pointed out that the strategic guidelines are already considered when establishing the portfolio and thus running projects are not halted, since such costs are high. The allocation of the resources pool is carried out weekly, according to the development stages of the projects. Bad multitasking is reduced by the greatest focus possible of the people to projects and the separation of project support activities. The fact that there was project stoppage because of changing requirements from customers was cited.

According to "Interviewee 3", the benefits observed are the simplicity and facility provided by visual management - despite the degree of uncertainty inherent to a project -, the probability of meeting deadlines, so long as the main points are informed, that is, where time, resources and effort should be applied, the method allows decision support for real problems.

"Interviewee 4" reports that CCPM brought a managerial gain in that it provides visibility for programming tasks. He also commented that new reliability levels have been achieved, because the planned durations are now more commonly observed. According to this respondent, by offering a visual way to manage time and allow focus where it is really needed, project quality can be managed. The project management supervisor considered the visibility and agility of the integrated planning of resources as successes (tangible and intangible).

All the respondents considered the actual implementation of CCPM very successful, although its application in the management of the company's entire PDP cannot be considered complete.

The results indicate that the company uses activity duration estimations and buffers effectively, always seeks to eliminate milestones, and to sequence the activities in accordance with the concept of Critical Chain (positioning project protection buffers). Such practices are in accordance with those recommended by Goldratt (1998) and Naor et al. (2013).

One aspect to be considered in the analysis is how CCPM implementation focus has been different in the commercial, defense and executive aviation business unit areas. Interviews have identified different directions given to CCPM. While commercial and defense areas effectively employ CCPM in the management of its multi-project environments and as support for decisions regarding how projects are run, the executive area uses CCPM as a tool for the evaluation of delivery capacity, in that it analyses the workload in comparison to project demand.

Thus, in the executive aviation business unit, the increase observed in project delivery and resource pool productivity, reducing the average lead time of projects and the largest number of projects concluded in the period, may be more strongly related to an general increase of team maturity in project management practices. In turn, in the commercial and defense aviation segments, advances in identified multi-project environment management seem to have a high relationship with the adoption of CCPM.

Additionally, the study has identified that project and resource managers have a key role in driving the multi-project management environment through CCPM application. The resource management has the responsibility to appoint professionals suited to each task, while the project management are responsible for establishing the expectations of time, cost and quality of the projects, the necessary communication to the different project stakeholders and the clear benchmarks for staff in performing their duties.

Documents and reports, for the year 2012, present numerical evidence of the results from the application of CCPM in the commercial aviation business unit, as well as some intangible results, confirming why they consider it to be such a successful application:

- Increase in the flow of projects: in 2010, 284 airplanes were delivered, 354 in 2011 and 414 in 2012;
- Reduction in the average project lead time from 344 days (2011) to 273 (2012);
- Better utilization of the resource pool, measured by the ratio of the number of projects and the number of engineers, referred to as the delivery coefficient. From 2010 to 2011 this coefficient increased by 46%, and from 2011 to 2012 there was a further increase of 67%.

In addition, the company's satisfaction with the implementation of CCPM is confirmed by its intention to adopt it in other areas and operational units. On the other hand, questioning the methods and CCPM tools used by the company, the data collected indicates that CCPM has not been fully adopted by all business areas of the company, which may mean some potential for additional improvement. Chart 1 summarizes the perception of respondents 1, 3 and 5 regarding the use of these techniques and tools.

Chart 1. CCPM techniques utilized at the company.

	Interviewees		
	1	**3**	**5**
Elimination of individual securities or buffers	4	4	4
Elimination of milestones, whenever possible	4	3	3
Sequencing of activities according to Critical Chain	4	4	4
The use of buffers against uncertainties in single project environments	4	4	4
The use of buffer management to control single projects	3	4	3
Sequencing of projects in multi-project environments (Drum)	3	4	4
The use of buffers against uncertainties in multi-project environments	2	4	3
The use of buffer management to control multiple projects	2	4	3
Implementation guide by means of S&T	3	3	3
Use of the Full Kit concept	2	3	3
Freezing of projects	2	3	3
Thawing of projects	2	3	3

Respondents 2 and 4 preferred not to respond to questions regarding techniques used in the company. The scores shown in the Chart conform to the following criteria: 1- Not known, 2- Known, but not applied, 3- Known and partially applied and 4 - Known and fully applied.

The Chart shows a higher degree of adoption of CCPM techniques and tools in the perception of respondents 3 and 5, managers working in the commercial aviation segment, as well as a convergence of these perceptions, which confirms the strong presence of CCPM in this area. Another important point refers to an apparent disagreement with the results provided by respondent 1, perhaps because this person has a more global vision of the company and the assessment is that implementation of CCPM is only partial in some areas.

From the Chart, it can be seen that estimated activity durations with elimination of individual securities, sequencing of activities according to critical chain, allocation of buffers to protect projects against uncertainties, buffer management and sequencing of projects are techniques utilized effectively throughout the company. However, the use of the full-kit concept, and project freezing and thawing are not, or only partially, employed by the company.

According to the nature of the product manufactured and due to the need for better control of deadlines due to possible changes in the product, the use of CCPM is seen in activities related directly to product development, such as definition, detail, testing and product certification. The utilization of CCPM in manufacturing activities or development of suppliers was not identified. The latter derives from the perception mentioned, by all respondents, that the majority of suppliers do not know and / or are not culturally adapted to make use of CCPM. As CCPM was not implemented for the management of a product that is being discontinued, its use in the PO (phase out) process was not identified.

5 Conclusions

This study confirms the views of Zanatta (2010) and Li & Moon (2012) regarding the growing need to address the pertinent challenges of managing multi-project environments and project management solutions that are different from the classical ones. To this effect, the study throws light on PDP and PPM field of knowledge, contributing to the principal methods recommended by the literature. The use of these methods can provide managers involved in PDP with tools for improving the selection of new product designs, as well as prioritizing those that best meet the company's strategy. To improve the performance of PDP and its innovation in companies, the systematization of PPM methods can provide essential information for managers. The field research produced evidence that the organization studied has achieved positive results in the management of its new products development projects by means of the application of CCPM.

In relation to PPM, this study reinforces the view that it is a relevant factor for good company performance. The use of formal implementation methods may support prioritization decisions, resource allocation and strategic alignment, minimizing the risks of a new product project being unsuccessful.

It can be seen that CCPM techniques such as the elimination of individual securities in the estimates of activity duration, sequencing of activities according to critical chain, allocation and management of buffers, and project sequencing in multi-project environments are used effectively in the scheduling of products development project activities at the company. This CCPM-based prioritization of projects seems to bring highly positive benefits for company PPM and the result has been used to formalize commitments with customers and suppliers.

The case study identified techniques to combat delay problems in projects that share the same resource, such as introducing buffers between the projects and the regulation for the release of new projects, so that the pace of this release is directly proportional to the resource capacity, whether considered critical or strategic. Similarly, CCPM contributes in another way to portfolio management by limiting the number of active projects, starting from the premise that, if this limit is exceeded, the projects delivery flow decreases due to the effect of bad multitasking. Despite not being the intention of this study to offer new models or expand the PDP, PPM or CCPM theory, this work reveals its relevance by permitting an empirical contribution to the field of knowledge surrounding these issues.

This study also shows that the adoption of CCPM produced substantial gains for the studied company, especially for its commercial aviation unit. Evidence was found that the implementation of CCPM, initially occurring in one area, should be expanded to other sectors and manufacturing units of the organization; concluding that, in the eyes of the company's senior management, CCPM is seen as strategic in the way it supports its PDP and PPM.

This study did not show that CCPM enables direct gains to the quality or costs reduction of projects, but the conclusion, by deduction, is that, from the perspective of time management, the product quality benefit from the use of CCPM. Goldratt (1998) comments that pressures for on-time delivery can lead to cuts in the scope and quality losses. Thus, to improve the flow of projects and on-time deliveries, CCPM may indirectly benefit the quality of products. However, as scope cuts are not allowed in aviation, such indirect benefit was less evident in the case study.

As suggestions for future studies on the topics herein addressed, multivariate statistical analyzes of the data collected are recommended for response trend validation and variables (qualitative) correlation so that it can be said that the extrapolation of the data sampled for a given population is valid. It is also proposed that implementations of CCPM in other market segments be followed up, in the form of case studies or surveys, as well as investigating potential CCPM contributions in other business processes, in addition to product development and portfolio management. Furthermore, given the complexity of interfaces between different management areas through CCPM implementation and its relationships with PDP and PPM, research geared to different perceptions by different groups involved in the application of new project management methodologies could give rise to interesting contributions to change management knowledge fields and organizational culture.

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