Impact of critical chain project management and product portfolio management on new product development performance

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Abstract

Purpose – This study aims to analyze the relationship between the adherence to critical chain project management (CCPM) practices and the new product development performance, in terms of the results of product development programs and product portfolio management (PPM).

Design/methodology/approach – A survey was conducted with 79 innovative companies operating in Brazil. Data were analyzed using correlation analysis and non-parametric tests.

Findings – Significant and positive correlations were found between CCPM adoption and the performance factors proposed. The adoption of CCPM offered stronger correlation with PPM performance than with the adoption of traditional methods. The results further indicate a possible indirect contribution of CCPM practices to the product development program by means of PPM improvement.

Originality/value – This study deepens the knowledge of the joint study between project management and new product development, by bringing empirical evidence that the adoption of specific practices suggested by CCPM is used by organizations with superior performance. Moreover, the results broaden CCPM literature by attesting that companies do not necessarily have to apply the CCPM approach in a formal and explicit way to obtain the performance results given. The analyses still have practical value when indicating which CCPM practices should be prioritized by managers seeking high performance in PPM.

Keywords Survey, Theory of constraints, NPD performance, Critical chain, Product portfolio

Paper type Research paper

1. Introduction

For marketable new product development (NPD) performance, it is essential that the initial decisions of the process are taken properly, because they will justify and restrict future decisions. One of the principal decisions of new product management occurs during its planning stages, when companies decide which product projects should be approved and how to allocate resources among these projects (Cooper *et al.*, 1999). These are strategic decisions in relation to the innovation and NPD policies of firms, which present a high degree of complexity and involve the evaluation of occasionally conflicting alternatives (Zhang *et al.*, 2019).

With the aim of improving the performance of both innovation and NPD processes, the literature presents various practices, methods and tools in product portfolio management (PPM) (Cooper *et al.*, 1999; Jugend and Silva, 2014). Some of these methods aim to minimize time-to-market, which is necessary for various reasons. First, a company that delays its product launches will find it difficult to completely amortize development costs before product generation becomes obsolete. Companies that reduce cycle time have a greater probability of being the first to introduce products which embody new technologies, bringing the advantage of being market leaders. One of the main advantages of pioneering is that the company can define and have ownership of the dominant design that will be the industry standard (Schilling and Hill, 1998). In this way, the PPM practices, aiming at, among other objectives, the integration of new product projects with the needs of customers and the reduction of development time, must be understood in the scope of the marketing function or, more specifically, product marketing (Kotler and Keller, 2016; Voss, 2012).

There are practices in the literature that are known to have a time impact on NPD, such as the use of cross-functional teams (Jugend *et al.*, 2016) and stage gates (Cooper, 2008; Kahn *et al.*, 2012), involving senior management, technology

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roadmap (Carvalho *et al.*, 2013) and concurrent engineering (Ferrarese and de Carvalho, 2014), among others. Cross-functional teams allow for better use of capacity by leveling the workload among participants and for faster collaboration between functional areas. This greater functional integration facilitates the implementation of concurrent engineering that reduces development time by coordinated work. Senior management can formulate strategies aimed at reducing time-to-market as rewards and prioritization. Also, the use of technology roadmaps can reduce development time by providing a structured procedure.

However, as suggested by Dooley *et al.* (2005), there is a gap in these traditional methods that makes integrating projects and dealing with resource conflicts difficult. These gaps will be discussed later in the theoretical background section of this article. Further, these traditionally known methods still do not completely resolve not only questions related to time-to-market but also other decision-making issues in PPM, such as, for example, alignment between product projects and company strategy (Acur *et al.*, 2012), communication and product project control (Ouriques *et al.*, 2019) and multi-project knowledge management (He *et al.*, 2011; Wang and Chen, 2018). Also, there is a gap in the literature of practices adopted in the early stages of the NPD process (fuzzy front end) to reduce uncertainties in product portfolio decisions (Zhang *et al.*, 2019). Moreover, the importance of portfolio management of product projects in the context of marketing has been little studied empirically (Levin *et al.*, 2019).

In this way, it is understood that critical chain project management (CCPM) (Goldratt, 1997), being a method that deals with the interaction between projects and time management, could contribute to PPM literature, presenting ideas that have not as yet been considered for the resolution of the challenges posed. By means of specific techniques, CCPM looks to reduce promised development deadlines – allowing, in the latter instance, the launch of products before the competition – and increase the probability of achieving planned schedules (Marris, 2011), a common problem in companies that manage product portfolios (Yang and Fu, 2014). Through the analysis of resource sharing between product projects and the use of practices such as project freezing (Goldratt, 2009) and full kitting (Morais and Sbragia, 2012), CCPM permits that even in more complex environments with many interdependent projects, it is possible to obtain high rates of deadline compliance, in accordance with the planned scope and budget. Project freezing allows better use of resource capacity by limiting the number of projects in progress. Full kitting is the practice of making sure that everything that is needed to perform an activity is available before starting it, avoiding unnecessary delays because of the lack of resources shared by multiple projects.

Even though there are studies that evaluate the impact of CCPM practices in project portfolios (Seider, 2006) and in sectors that commonly develop products (Kania *et al.*, 2002), there is a lack of studies that evaluate the impact of practices recommended by CCPM in the performance of NPD (Luiz *et al.*, 2019). Furthermore, there are studies on NPD performance (but not related to CCPM practices) carried out in several regions such as North America (Cooper *et al.*, 2001; Kleinschmidt *et al.*, 2007; McNally *et al.*, 2013) and Europe (Dangelico *et al.*, 2013; Kleinschmidt *et al.*, 2007; Kock *et al.*, 2015), but there is still a gap in studies in emerging countries. Thus, this research aims to fill this knowledge gap by analyzing the relationship between CCPM practices and the performance of PPM (in terms of strategic alignment of product projects and resource allocation, portfolio balance and financial objectives) and of NPD programs (in terms of strategic company results and profitability and competitiveness objectives of individual projects). Additionally, the type of relationship between the adoption of CCPM and the performance of a product development program or whether this performance is a consequence of successful portfolio management will be analyzed. Besides the empirical investigation of the existence of these relationships, this research still intends to evaluate them in terms of their strengths. The study consists of a survey with companies operating in Brazil, whether national or international, and that frequently develop new products.

To meet this objective, the article initially presents a theoretical review and the research framework. Subsequently, the research method used is presented. The results are then presented and analyzed. Finally, the conclusions are outlined.

2. Theoretical development

This section will present the theoretical grounds that form the framework of the research. The research hypotheses will be based on the definition of the constructs and variables used.

2.1 Product portfolio management

In the context of new products development, portfolio management is a dynamic decision-making process in which the list of the active new product projects of a firm is periodically updated and revised. In this process, new products are evaluated, selected and prioritized; existing projects can be accelerated, killed off or have their priorities reduced; the resources are allocated or reallocated to active projects (Cooper *et al.*, 2001).

The literature presents an expressive variety of formal portfolio management support methods (Dutra *et al.*, 2014). The financial methods are designed to maximize the value of the product portfolio. Models based on scoring suggest that product projects be classified and prioritized in accordance with the expected average of their performance and their respective degrees of alignment with the business strategy (Jugend and Silva, 2014). For Oh *et al.* (2012), both the financial and scoring methods would belong to the category, named as such by the authors, of comparative methods. In the opinion of the authors, this category demonstrates uncomplicated and useful methods, despite being limited when applied to the objective of portfolio balance.

Many of the traditional PPM methods deal with each project as an isolated entity, without going deeper into the influential relationships between different developments. As PPM matured and the complexity and interdependence of the projects increased, new methods that explored dependencies between projects were required (Killen and Kjaer, 2012). Thus, methods and tools based on visual representations, such as graphs, maps and matrices, were adopted for this type of analysis. Emblematic examples are the BCG matrix, bubble charts and strategic buckets (Jugend *et al.*, 2015). According to the classification of Oh *et al.* (2012), the methods belong to the strategic management approach category, as they narrow the relationship between product development projects and the organizational strategy.

Table I summarizes the main portfolio management practices, mainly applied in the fuzzy front end, and the main gaps that can be addressed by other approaches.

2.2 Critical chain project management

The principal concepts and tools of CCPM are widely covered by the literature (Leach, 1999; Rand, 2000; Steyn, 2001). The book 'Theory of Constraints Handbook' brings together a considerable part of what has already been developed in Theory of Constraints (TOC) and CCPM (Cox and Schleier, 2010). Thus, this section does not seek to carry out a systematic review of CCPM knowledge but, rather, define the variables of the construct that sought to measure the level of adoption of CCPM practices and to base the discussion on the results.

2.2.1 General critical chain project management concepts in single project environments

The starting point for CCPM is a list of tasks, together with their duration estimates and dependencies. The first step involves devising an initial schedule for the tasks of the project. This is done taking into account the dependencies between tasks and the limited availability of resources. The resulting schedule is susceptible to being longer than the scheme obtained with the critical path method (CPM) or program evaluation and review technique (PERT) algorithms, because the critical activities are delayed while waiting for the necessary resources.

CCPM identifies the "Critical Chain" as a set of tasks that results in the longest project completion path after applying resource leveling. The next step in CCPM planning involves recalculating the project schedule based on the shortest activity time estimates (probability of completion equal to approximately 50 per cent) (Zhang *et al.*, 2016).

Buffers appear as activities in the project plan but do not have work assigned to them. According to Leach (1999), CCPM protects project completion from uncertainties by means of a project buffer, added at the end of the critical chain. This buffer exploits the statistical law of aggregation, protecting the project from individual activity uncertainties using buffers at the end of the path. Other buffers proposed by CCPM are the feeding buffer that protects the critical chain from delays in the paths that feed it, allocating a buffer at the end of each of these paths, and the resource buffer, which protects the critical chain from non-availability of resources (Zhang *et al.*, 2016).

Budd and Cerveny (2010) affirm that another important use of CCPM buffers is to offer a tool for project managers to know when they should take action and when such interference is unnecessary. Buffer management (BM) offers an environment with priorities that are updated and constantly applied across the whole organization on an hourly, daily or weekly basis. To support decision-making, a set of support practices was also developed to adapt the prioritization system. For more details about BM, the way buffer consumption is calculated and its use for control, a reading of Budd and Cerveny (2010) and Agarwal *et al.* (2009) is recommended.

Recent studies have sought to hone the original buffer management method, incorporating resource costs and schedule stability variations (Hu *et al.*, 2017a), activity sensitivity measures (Hu *et al.*, 2016), uncertainty activities (Zhang *et al.*, 2015), resource tightness (Zhang *et al.*, 2016) and other approaches such as earned value management (Colin and Vanhoucke, 2015).

Table I Summary of traditional product portfolio management practices

Traditional PPM practices	Gaps to be explored	References
Financial techniques (payback, net present value and internal rate of return)	Poorly chosen financial indicators may not be aligned with the organization's primary goals Difficulty in dealing with the uncertainty of information They disregard non-financial factors	Cooper *et al.* (2001), Killen *et al.* (2008)
Scoring templates (attribution of scores to each potential new product project)	They may not be sufficiently responsive to sudden changes in the development environment Subjectivity in the data collected Difficulty in establishing weights among several criteria	Hubbard (2012), Lindstedt *et al.* (2008)
Checklists (pre-defined list of requirements that the product must meet to compose the portfolio of the company)	Usually, they do not provide prioritization mechanisms among the requirements Difficulty in including clear, specific and observable topics	Dickinson *et al.* (2001), Jerbrant and Karrbom Gustavsson (2013); Seoane (2001)
Diagrams (BCG matrices and bubble diagrams)	Scope limited to market or financial aspects Restricted number of variables considered (BCG) They are often based on unreliable estimates and are not suitable for the short term They can lead the decision-maker to overlook profit maximization	Abdalah and Sicotte (2018), Archer and Ghasemzadeh (2007); Øivind Madsen (2017)
Maps of products or technologies (roadmaps)	Difficulty in establishing connections in markets and technologies with a high degree of uncertainty They are not recommended for simplified, everyday decisions They need to be constantly reviewed	Hussain *et al.* (2017), Kanama and Kondo (2007); Kappel (2001)

TOC proposes further concepts focused on CCPM operation, such as full kitting. According to Budd and Cerveny (2010), full kitting is the process of elucidating project requirements, project approval by those involved, the preparation of materials and resources for general use and other necessary actions to ensure the smooth implementation of the project. It is important to distinguish between full kitting and actually carrying out tasks: activities that permit that project tasks are done without interruptions are included in the full kit list, while activities that play a direct part in project progress are excluded (Souza and de Moraes, 2016).

2.2.2 Multi-project management according to critical chain project management

Specifically, for multi-project management, CCPM proposes the scheduling buffer. In multi-project environments, each project is programmed in the same way as a single-project environment but without taking into account the use of resources in other projects. Because of high task duration uncertainty, it is not possible to level all resources in all projects and expect that this initial leveling will remain effective (Luiz *et al.*, 2017).

To reduce the need for resource sharing and certify that delays in one project do not affect other projects, the entry of new projects to the system must be controlled. To this end, a scheduling resource is defined. The capacity of this resource is monitored to establish a scheduling for the initialization of portfolio projects. It is chosen between the resources that participate in most projects. A specific buffer is defined in each project ahead of the first task to be carried out by the scheduling resource, to minimize the impact of problems occurring in one given project from the entire project portfolio. This protection is known as the scheduling buffer (Budd and Cerveny, 2010). It is possible to stagger tasks from different projects, using the same critical resources, thus eliminating conflicts between activities that share the use of these resources (Yang and Fu, 2014).

Multitasks can lead to significant delays when multiple projects share the same resources (Robinson and Richards, 2010). One solution to reduce the bad multitasking in such environments is to simply define a maximum number of open projects, even if this means freezing projects (Holt and Boyd, 2010). The reason for this is that, from a certain number of open projects, there is an inverse relationship between project completion flow and the number of projects open. Many open projects increase the potential for bad multitasking effects, reducing the flow even more, which further increases the number of ongoing projects. CCPM combats this vicious cycle by freezing open projects.

The practice of project freezing offers varied contributions to PPM. This practice differs, for example, from the signaling theory literature that predicts benefits in suspending projects, demonstrating to investors and partners that more robust and marketable ideas are being prioritized, which increase the generation of value (Hu *et al.*, 2017b). The purpose of project freezing is to postpone the start of projects – avoiding overloads, resource contention and bad multitasking – and not abandoning them. Projects waiting in line to be initiated have already been approved and are part of the project portfolio of a company.

2.3 Performance in product development

In spite of its importance for NPD, determining the success of this process is not a trivial activity (Sandstrom and Toivanen, 2002). First, the success of the development can be measured on two levels: for the general product development program and for individual projects. This can cause conflict between the program objectives, that are, generally, financial and the individual objectives of projects. Rarely will a project have superior performance in all dimensions simultaneously, the sacrifice of one dimension to achieve success in another being necessary (Griffin and Page, 1996).

The current literature defines high NPD performance in different ways, offering complementary visions for a system of measures for product development. Godener and Soderquist (2004) identified four measurement areas most frequently used by the literature studied: financial performance, customer satisfaction, process management and innovation. A simpler and more practical classification for NPD performance measurement is to divide the measurements into financial, that can be measured objectively, and non-financial, that evaluates the results using subjective perceptions. Among the most utilized non-financial measurements are those that measure the alignment of NPD with organizational strategy (Kleinschmidt *et al.*, 2007).

There is evidence in the literature that indicate that proficiency in NPD management tends to improve marketing performance (Cooper, 2019; Kou and Lee, 2015; Wang *et al.*, 2019). One of the results of Kou and Lee (2015) indicates, for example, a significant relationship between new product performance and marketing performance, as measured by indicators such as growth in market share and sales volume.

2.4 Product portfolio performance

Cooper *et al.* (1999, 2001) point out the current best practices for project evaluation and the dimensions most used to evaluate the performance results of a portfolio. These dimensions are value maximization, balance and strategic alignment (Cooper *et al.*, 1999, 2001). In relation to value maximization, managers evaluate NPD projects based on the financial returns that they can generate, such as long-term profitability or investment payback, considering that this dimension is used most of the time. The performance of portfolio in terms of strategic alignment is monitored by evaluating projects in terms of their reflection on company strategy. Each portfolio project must individually support the strategy expressed by the company, adapting to its technological and market peculiarities (Kester *et al.*, 2014).

Managers evaluate projects based on the extent to which they ensure that the mix of development projects is proportional among various parameters, such as the project conclusion date, technical risk, investment payback and project innovation. Guaranteeing that projects are aligned to available resources is also a balancing factor (McNally *et al.*, 2013).

2.5 Development of hypotheses and research framework

There is evidence in the literature that good project management practices contribute to support smaller development cycles, enabling an increasingly complex, dynamic and non-deterministic process (Hall, 2015; Pons, 2015; Swink *et al.*, 2006).

Specifically, CCPM offers important project management contributions in environments of high uncertainty and where making appropriate use of available development resources is necessary (Steyn, 2002). The development of a new product typically unfolds in a multiple project environment, in which different teams should share limited design and engineering resources (Long and Ohsato, 2008). In this sense, CCPM provides mechanisms to deal with the administration of the project portfolio of the company. Moreover, one of the most common dysfunctions in PPM is the occurrence of resource conflicts because of lack of focus, that is, the difficulty in prioritizing a large number of projects under development (Elonen and Artto, 2003). One of the main objectives of CCPM is to undo this type of conflict, as according to TOC few points in a system must be managed for performance to be significantly improved (Goldratt, 2010), which reinforces the importance of this approach to support portfolio decisions.

By reducing prejudicial multitasking, CCPM can increase value creation in product development (Ronen *et al.*, 2012). The constant switching of tasks promotes reduction in productivity derived from the adverse cognitive impacts of those involved in development. In addition, the fact that no task is finalized in advance, because of the simultaneous progress in multiple activities and projects, delays may occur in the achievement of the value generated by the projects (Ghaffari and Emsley, 2016).

Based on this discussion and on the contributions described in the review regarding CCPM, two preliminary research hypotheses can be proposed:

H1. The level of adoption of critical chain project management precepts and practices is positively related to portfolio performance.

H2. The level of adoption of critical chain project management precepts and practices is positively related to the performance of product development programs.

The practices presented in the "Product Portfolio Management" section (e.g. financial, checklists….) are widely recommended by the literature on PPM. Therefore, it is expected that companies which adopt them will achieve superior performance portfolios (Chien, 2002; Cooper *et al.*, 1999; Jugend *et al.*, 2016). The literature also recognizes that effective portfolio management practices increase the development of new products (Yang and Xu, 2017). For example, methods such as checklist allow the most promising projects to receive larger investments, increasing the probability of success of individual projects (Cooper, 2019). Thus, this study, developed in the context of Brazilian companies with innovative profiles, further aims to confirm the following hypotheses:

H3. The level of adoption of traditional practices in product portfolio management is positively linked to portfolio performance.

H4. The level of adoption of traditional practices in product portfolio management is positively related to the performance of product development programs.

McNally *et al.* (2013) brought evidence, through marketing simulation exercises, of which three of the main results in PPM (value maximization, balance and strategic fit) are positively related with NPD performance. The results of Yang and Xu (2017) also support this relationship to demonstrate that the more the products portfolio is aligned with the business strategy, the greater the NPD success rate will be. The adoption of NPD performance measures itself improves the performance of the development process (Godener and Soderquist, 2004). In this sense, the recurrent use of practices such as scoring models and financial techniques in PPM can create a culture of performance evaluation through indicators. These results give rise to the following hypothesis:

H5. Product portfolio performance is positively related to the performance of product development programs.

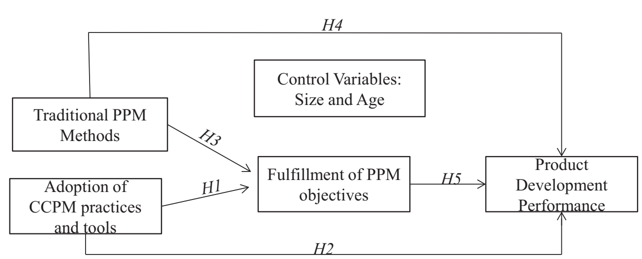
Figure 1 represents the research framework that includes revised factors, the hypotheses presented here and control variables – such as the number of employees and the age of the company. We consider as "age" the time since the foundation of the organization.

3. Research method

The target group of this survey was made up of businesses that develop products and that preferentially form part of economic sectors considered innovators. For this reason, the database used in the survey brought together companies from sectors recommended in the past Industrial Research on Technological Innovation in Brazil (primarily known by its acronym in Portuguese: PINTEC) report: electronic, chemical, aviation, optical, aeronautical and industrial automation (IBGE, 2013). The subjects came from the following contact lists: the Brazilian Electrical and Electronics Industry Association (mostly known in Portuguese by the acronym ABINEE) and the American Chamber of Commerce for Brazil (AMCHAM).

The analysis was carried out at the company level, which is the unit of analysis, that is, the largest entity of interest in the study. Although the source of data collection is based on individuals who work in the company, they provided, by means of the collection instrument, information about the organization in which they work. We sought to direct the research instrument, by means of instructions in the invitation letter indicating the focus of the product development research, to those individuals who represent the sector of the organization that deals directly with product development and

Figure 1 Conceptual research framework



managing portfolios. This intention was reiterated during telephone contacts.

3.1 Measurements

The research instrument adopted was a questionnaire comprising affirmations in which the respondents indicated their level of agreement by means of a seven-point Likert scale (from 1 = completely disagree to 7 = completely agree). Appendix 1 shows the questions used, organized by research factor, together with the principal references that validated the scales. Each variable that composes a given construct has been addressed by all the references presented for this construct. By using objective constructs, theoretically based and already tested in the literature, we reduce the bias of the research instrument itself. Also, the technique used is in agreement with other studies in NPD that use questionnaire survey as collection method (Athaide *et al.*, 2019; Kou *et al.*, 2018).

The questionnaire consists of questions that aim to:

- give guidance regarding the research and completing the questionnaire;
- verify if the company actually develops products, software or engineering projects; if this question was answered in the negative, then the electronic questionnaire was automatically terminated;
- evaluate the traditional PPM methods adopted by the company;
- measure how closely company practices adhere to those recommended by CCPM;
- evaluate company performance in terms of meeting its PPM objectives; and
- evaluate the results of company product development programs.

Questions regarding the characterization of the responding company were also included, identifying its area of operation, its time in operation and the number of employees.

A pilot test of the questionnaire was carried out to improve the instrument, with the intention of eliciting the most useful information from it. A small number of respondents were invited to answer and critically evaluate the questionnaire. This group was made up of two professionals that work with product development and three researchers with experience in the research subject, providing distinctly different views of the instrument. The pilot test resulted in changes to the wording of some questions, aiming to make them clearer for the responders to understand. The questionnaire, thus, modified by the pre-test was then considered satisfactory, and no additional pre-tests were carried out.

3.2 Data collection

A website was developed to assist with the collection process and the initial organization of the data collected. A database of companies with the profile described at the research method was included on the site. Contact information, such as e-mail addresses and telephone numbers, was added to the database.

The final data collection instrument was made available on the site and could only be accessed by the respondent through a link sent to the e-mail registered on the site database. After sending three invitations by e-mail to each company, the researchers sought to make contact by telephone with the unresponsive companies, updating e-mail information whenever possible and requesting contact with the product development areas of the companies. Once the questionnaire had been completed, no further e-mails were sent to the participating companies.

At the end of the collection phase, the survey resulted in a sample of 90 companies who had completed and returned the questionnaire. Of these, 11 stated that they did not have product development activity, operating only in product manufacture, commercialization and/or distribution, and were therefore disregarded. The resulting valid sample was 79 companies. We used G*Power software to calculate the minimum sample size needed in this correlation study. The result was 59 observations for an effect size of 0.4, power 0.95 and a significant value of 0.05.

3.3 Analysis

First, descriptive analyses of the sample were carried out, looking for the frequencies of respondents regarding the sector of performance, size of the company and the knowledge and application of PERT/CPM and CCPM, as well as the calculation of the mean and standard deviation for each question presented in the research instrument and for each factor researched. The value of Cronbach's alpha for factors, which is a measure of the reliability of the constructs that compound the questionnaire, was also determined.

This was followed by correlation analysis, which sought to measure if the level of mutual relationship between two variables is significant. We understand that correlation analysis is sufficient to meet the research objectives, as the intention is to evaluate the joint variation between pairs of variables and constructs. Previous research in PPM and NPD has adopted correlation analyzes to test the strength of the relationship between variables (Barbalho *et al.*, 2017; Fettermann and Freitas, 2017; Kock *et al.*, 2015).

The linear correlation was calculated using the Spearman rank correlation coefficient as a measure, being the most appropriate in dealing with ordinal and discrete variables such as were studied in this paper. Considering the scale as ordinal, as pointed out in many studies (Coombs, 1960; Jamieson, 2004; Kuzon *et al.*, 1996), the usual form of analysis is through non-parametric tests such as the Spearman's rank correlation test. Non-parametric tests still have the added benefit of not requiring data normality and can work with smaller samples. Still, there are studies pointing out that the conclusions resulting from analyzes using Pearson or Spearman are not significantly different (Murray, 2013; de Winter *et al.*, 2016). The significance levels adopted were 1 and 5 per cent. The significance represents the probability of rejecting the null hypothesis (in this case, that the correlation between the variables is 0) when it is true.

This research adopted as a rule for the interpretation of the correlation coefficient value the suggestion of Hair *et al.* (2015) for Business research (Table II). This interpretation of acceptable association forces assumes that the correlation coefficient is statistically significant.

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Table II Rules adopted regarding the correlation coefficient value

Variation of the coefficient	Strength of association
±0.91-±1.00	Very strong
±0.71-±0.90	High
±0.41-±0.70	Moderate
±0.21-±0.40	Small, but defined
±0.01-±0.20	Light, almost imperceptible

Source: Hair *et al.* (2015)

4. Results and discussions

The sectors with the highest representation in the sample were: Electronic industry (19 per cent), Mechanical metal industry (15.2 per cent), Computing, Software or Hardware (15.2 per cent), Chemical/Petrochemical industry (11.4 per cent), Industrial Automation (8.9 per cent) and Automotive industry (7.6 per cent).

The companies were also characterized by size, using the Brazilian Support Services classification for small and micro companies (SEBRAE, 2016). The sample contained 12.7 per cent micro-businesses (up to 19 employees), 27.8 per cent small businesses (20 to 199), 27.8 per cent medium companies and 31.7 per cent large companies. It can be seen that the sample was varied in respect to the 'number of employees' classification.

The majority of the respondents claimed not to apply PERT/CPM (65.8 per cent) and did not know of CCPM (45.6 per cent). Because they are mostly companies from innovative economic sectors, it is possible that the companies do not use PERT/CPM because they apply other more recent development techniques, for example agile methodologies such as SCRUM and Extreme Programming (XP) (Naz and Khan, 2015). One evidence for this hypothesis is the proportion of respondents with knowledge of CCPM (45.6 per cent), a more contemporary approach being superior to those which use PERT/CPM (34.2 per cent).

Half of the respondents that knew CCPM said they adopt this approach in product development. This does not prevent any of the 18 companies that have alleged they do not apply CCPM in their NPD from using CCPM in other projects, such as process improvement, for example.

The internal reliability of the questionnaire, that is, its internal and homogeneous consistency among items in the scale, was confirmed through a Cronbach alpha calculation for each factor. Alpha values above 0.7 are considered acceptable (Kline, 2013). Appendix 1 shows the average, standard deviation and Cronbach alpha for each factor. It was verified that all the values exceeded the alpha value considered acceptable, demonstrating the reliability of the research instrument.

In relation to traditional methods in the sample, the use of checklists for product projects analysis (average 5.15) and financial techniques for portfolio management (4.87) can be highlighted. The methods least used by the companies studied were charts such as the BCG matrix and the bubble chart (average 3.59). Probably the companies prioritized tools that were simpler to implement and that are already used in other company activities.

In regard to the adoption of concepts and tools recommended by CCPM, the low use of buffers for the protection of a chain of activities, in place of protecting each activity individually, can be highlighted (average 3.95). This practice is probably not used as much as others by the sample companies because the statistical concept of aggregation of securities is not intuitive enough.

With relation to two dependent factors, strategic alignment presented the strongest positive relation with PPM objectives, according to the evaluation of respondents. Realizing strategic objectives also stood out within the factor related to product development program performance.

Despite having surpassed 4, the middle value of the scale, the factors which measured the adoption of traditional PPM methods and the concepts and tools of CCPM scored the worst.

4.1 Results related to performance factors

This item details the results that most supported the resolution of the research question, measuring the association of independent factors, principally the adoption of CCPM concepts, with the factors that measure performance. Table III includes the Spearman correlation coefficients for the factors studied and control variables.

H1 of this research paper is supported by the positive and moderate correlation coefficient (0.637) and statistically significant to 1 per cent between the adoption of CCPM practices and the fulfillment of PPM objectives. Thus, the companies from the sample that more adopt CCPM concepts and tools show a greater PPM performance.

The adoption of CCPM concepts and tools also correlated positively and moderately (0.409) with new products development program performance, supporting *H2* of this research. The confirmation of these hypotheses is in accordance with the results of previous studies that support the definition of these hypotheses (Hall, 2015; Long and Ohsato, 2008; Steyn, 2002).

The use of traditional methods correlated both positively and moderately with the achievement of PPM objectives (0.511 with 5 per cent of significance), confirming *H3*, and with the results of the new products development program (0.456 with 1 per cent of significance), confirming *H4*.

From these results, the performance of CCPM adoption and the traditional methods of PPM can be compared. First, the results indicate that companies from the sample that adopt, in a more recurrent manner, the practices recommended by CCPM also adopt traditional methods with greater intensity. There is a correlation of 0.546 of significance to 1 per cent among these factors. Despite conceiving premises that often oppose the more usual methods, CCPM and TOC is generally being used positively with other project management policies in product development (Bevilacqua *et al.*, 2014), and the correlation is one more evidence for the possibility of use between these approaches.

Despite the high correlation, some distinctions between the factors can be mentioned. While the adoption of CCPM practices correlated better with the performance in PPM than traditional methods, the use of consolidated PPM practices presented greater association with the new products development program performance.

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Table III Spearman coefficients between the factors studied

Factors	Traditional methods of portfolio management	Adoption of CCPM concepts and tools	Fulfillment of products portfolio objectives	Generation of opportunities	Results of new products development program	Size	Age
Traditional methods of portfolio management	–	0.546**	0.511*	0.379**	0.456**	0.288*	0.157
Adoption of CCPM concepts and tools		–	0.637**	0.348**	0.409**	−0.055	−0.085
Fulfillment of products portfolio objectives			–	0.534**	0.474**	0.098	0.023
Generation of opportunities				–	0.548**	0.097	−0.081
Results of new products development program					–	0.259*	0.059
Size						–	0.511**
Age							–

Notes: $^{**}p < 0.01$; $^{*}p < 0.05$

H5 (fulfillment of PPM objectives relates positively with the product development program result) is supported by the result of this research. This outcome is in accordance with the results of Killen *et al.* (2008), who indicated positive relationships between these factors. The correlation between these factors showed a coefficient of 0.474 to 1 per cent. This relationship is more intense than that verified between CCPM adoption and product development program performance, which could be evidence that CCPM collaborates with the development of products in an indirect way, positively aiding performance in PPM (correlations among these variations was the highest in the research).

4.2 Results related to control variables

The control variables studied were the age and size of the company studied. Among these variables, moderate positive correlation between age and size was found (0.511 to 1 per cent). Companies generally take time to reach complex structures; therefore, this result was already expected.

The number of employees at the companies studied (size) presented a small and positive correlation, statistically significant to 5 per cent, with the adoption of the traditional methods of portfolio management (0.288) and with the product development program result (0.259). There were no significant correlations between size and the other factors. Therefore, no relationship was found between the adoption of CCPM practices and the size of the company, in contrast with traditional methods, which are more common in larger companies. Previous studies showed positive correlations between the size of the company and NPD innovation performance (Gomes *et al.*, 2009; Lau *et al.*, 2010). Lau *et al.* (2010), however, did not find correlation between size and product performance.

The age of the company only presents significant correlation with the size, as cited at the beginning of this section. The other factors did not present significant correlation. Therefore, there was no relationship between the age of the company and adoption of approaches and the age and the performance.

4.3 Correlations between specific critical chain project management practices, dependent factors and control variables

In this item, the association between each CCPM practices and other variables of the study will be discussed (Table IV).

All of the CCPM concepts obtained statistically significant and positive correlation with the fulfillment of PPM objectives. Four practices with moderate correlations can be highlighted: definition of critical chain, the use of buffers both to guarantee compliance with deadlines and to control projects and identification of a programming resource. The most recently developed concepts in CCPM through project S&T trees (full kitting and freezing) only had a small correlation. Therefore, the results suggest that the more basic CCPM practices can be prioritized when better PPM performance is sought. The literature, in general, supports the idea that simpler and more user-friendly approaches are generally more accepted and tend to lead to better decisions (Liesiö *et al.*, 2007).

Table IV Spearman correlation coefficients between critical chain project management practices and other factors studied

Factors	Fulfillment of the product portfolio management objectives	Generation of opportunities	Results of the new products development program	Size	Age
Protection buffers	0.409**	0.296**	0.393**	0.045	0.112
Definition of critical chain	0.474**	0.168	0.252*	−0.044	−0.234*
Identification and use of program resources (bottleneck)	0.466**	0.350**	0.187	−0.166	−0.117
Buffers for project control	0.645**	0.395**	0.375**	−0.057	−0.154
Project freezing	0.375**	0.265*	0.258*	−0.013	−0.055
Full kitting	0.384**	0.053	0.153	−0.031	0.054

Notes: $^{**}p < 0.01$; $^{*}p < 0.05$

In addition, full kitting did not correlate significantly with any other factor and the project freezing variable is only weakly correlated with performance factors. This result is unexpected, in a certain way, as these practices, principally freezing, are strongly recommended by the literature on CCPM for multi-project environments (Souza and de Moraes, 2016) and typical in companies that develop products. Recently, Ghaffari and Emsley (2016) found experimental evidence that some controlled levels of multitasking can be beneficial in portfolios managed by CCPM.

In relation to product development program performance, four practices demonstrated positive correlation, but with weak association: critical chain definition, use of safety buffers, use of control buffers and project freezing. Therefore, these practices can be prioritized when the objective is to improve this type of performance.

The only significant correlation between CCPM practices and the control variables was the negative association between age and critical chain definition, which, according to the classification adopted, is small.

Figure 2 presents an update of the research framework, summarizing the conclusions reached by the study.

5. Conclusions

Through a survey with innovative companies that develop products, this study verified the relationships between the adoption of practices and principles of CCPM and the performance of PPM and product development programs. The main theoretical and managerial contributions are described below, as well as limitations and suggestions for future research.

5.1 Theoretical contributions

This research paper deepens the knowledge of the joint study between project management and NPD, by bringing empirical evidence that the adoption of specific practices suggested by CCPM is used by organizations with superior performance, especially with regard to PPM. Moreover, the results broaden CCPM literature by attesting that companies do not necessarily have to apply the CCPM approach in a formal and explicit way in order to obtain the performance results given. Another relevant theoretical conclusion of this study was the low influence of the control variables (size and age) among the variables studied. The results show, therefore, that good performance can be achieved when the assumptions of CCPM are assumed to be true, independently of the size of the company, its age or formal implementation of CCPM.

By expanding existing knowledge about the influence of NPD project management methods and portfolio management, the results of this study may also be of interest to scholars and practitioners in marketing. After all, marketing activities can be facilitated or benefited by a product portfolio that adequately meets customer needs and is more balanced in terms of radical and incremental (balancing) innovations. In addition, PPM management proficiency can shorten NPD process time to market and generate competitive advantage through a more rapid introduction of the product on the market.

The results reinforce the key role of time management for NPD. Although the CCPM's focus is on scheduling management issues, understanding to be the main constraint to product development performance, there has been a significant positive correlation between the use of CCPM and the results of NPD programs in terms of earnings financial, strategic and competitive.

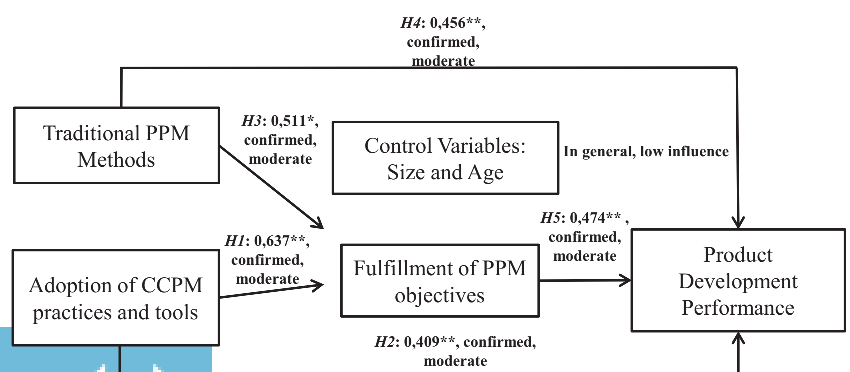
Another theoretical contribution derived from this work is the construct that measures the level of adoption of CCPM practices, which showed good reliability, as verified by the Cronbach's alpha factor calculation. This scale is available for future research that studies the adoption of practices recommended by CCPM.

The inclusion of the research model construct regarding traditional portfolio management methods permitted a comparison of its relationships with the adoption of CCPM. It is concluded that CCPM exceeds traditional methods in the fulfillment of PPM objectives, while the traditional methods present a stronger relationship with development program results. This result differs from the literature, in that the traditional methods have been developed specifically for PPM, while the contribution of CCPM is indirect, through the improvement of project management. Future research should seek to better understand these results.

5.2 Managerial contributions

The results show that, in general, the companies with better product portfolio performance (significant correlation with all the performance factors) also tend to present practices that are more consistent with the principles of CCPM. The analyses

Figure 2 Updated research framework



made here do not allow to affirm that the use of CCPM practices was the direct cause of this better performance, but the adoption could be considered as an alternative.

A well-balanced and efficiently developed product portfolio can facilitate market positioning of products as well as assist with launch and marketing planning, which can support marketing activities. Despite the good results for PPM performance conferred by the CCPM, traditional PPM techniques remain relevant for the performance variables studied, especially for the NPD program performance factor. In addition, the results point to a recurrent joint use between traditional and CCPM practices, demonstrating that companies have not replaced traditional practices with the CCPM approach and vice versa. Thus, as another managerial implication, we still recommend the use of these techniques together with the practices of CCPM.

In addition, managers can prioritize the more basic CCPM practices, such as critical chain definition and buffers, because these practices got a more intense correlation with the performance factors. Besides, managers dealing with diverse environments in terms of organization size and maturity can benefit from the positive relationships between CCPM and performance, as there is no significant difference between these variables and a CCPM adoption.

5.3 Limitations and future research

To delimit the model used in the research, we opted to empirically verify the hypotheses with greater support in the literature. In this way, the most intuitive hypotheses were tested. In the future, it is recommended to verify the relationship of CCPM practices with performance variables in which their contribution is less evident. Also, some of the companies that comprised the sample did not know or formally apply CCPM, or even PERT/CPM. Future studies could verify if the results would be different with a sample composed exclusively of organizations that know and apply the approach. The use of survey as research technique presents some limitations of its own. For example, while meeting the sample size requirements as described in the method section, a larger sample size could give greater reliability to the analyses. In addition, because it is a cross-sectional study, it is not possible to track the development of variables over time. Another limitation is the exclusive use of digital questionnaires for data collection. Therefore, future studies using other methods and having temporal sensitivity, such as multiple case studies, are recommended. Also, to complement the correlation analyses performed, future studies could apply structural equation modeling for an analysis of the joint interaction of multiple factors.

Notwithstanding the methodological limitations intrinsic to all survey research, the analysis presented here was restricted to studying companies with operations in Brazil. Thus, future studies could collect evidence of differences among countries with distinct cultural and financial contexts, contrasting the results with this research. Even among Brazilian companies, this study could be replicated using other economic sectors and databases, for example, analyzing the relationship in companies from less innovative sectors.

Another suggestion for future research would be to investigate the integration of CCPM practices with other methods in development environments. This study evidenced similar performances both for the use of traditional PPM methods and for the adoption of CCPM, but these results are not sufficient to define at which point the integration is beneficial and which differences occur because of different premises adopted for each approach. In addition, the integration between CCPM and agile product development methods has still not been fully studied by the literature and could be a potential scope for future.

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Appendix

Table AI Questionnaire questions, organized by factors and their descriptive statistics

Variables	References	Average	SD	Cronbach's alpha
Factor: Traditional portfolio management methods				
Q01 Financial techniques are used in portfolio management (for example: payback, net present value, internal rate of return, etc.)	Cooper *et al.* (1999), Jugend and Silva (2014)	4.87	1.82	0.8061
Q02 Scoring templates are used in products portfolio management (attribution of scores to each potential new product project)		3.92	2.12	
Q03 Checklists are used to analyze product projects (pre-defined list of requirements that the product must meet to compose the portfolio of the company)		5.15	1.81	
Q04 Diagrams are used in products portfolio management (BCG matrices and bubble diagrams, for example)		3.59	2.02	
Q05 Maps of products or of technologies are used in products portfolio management		4.51	2.05	
Total for the factor		4.41	1.156	
Factor: Adoption of CCPM concepts and tools				
Q06 Time protections (buffers) are used for schedule activity chains and not for each individual activity	Rand (2000), Steyn (2001); Budd and Cerveny (2010), Yang and Fu (2014)	3.95	1.85	0.7721
Q07 The sequence of activities and the consequent minimum project duration are established considering the sharing of common resources, their capacity limits and the technological dependencies		4.61	1.51	
Q08 Each project of the portfolio has its start programmed because of the limited capacity of one or a few bottlenecked or strategic resources		4.87	1.30	
Q09 Projects are controlled and priorities are established due to the consumption of their global time protections (buffers)		4.30	1.55	
Q10 There is a control mechanism for the maximum number of projects in execution at the same time		4.14	1.88	
Q11 Projects are not initiated without all the necessary preparations or requirements for their execution being complete		4.52	1.76	
Total for the factor		4.40	1.66	
Factor: Fulfillment of product portfolio management objectives				
Q13 The set of product projects is normally aligned with the strategic objectives of the company	Cooper *et al.* (2001); Kock, Heising and Gemünden (2015); Mcnally *et al.* (2013))	6.08	1.06	0.7455
Q14 The product development projects reach the financial objectives of the company		5.37	1.24	
Q15 The company's products portfolio possesses an adequate balance of projects (appropriate number of projects of high and low technological innovation degree, high and low risks, short and long deadlines and for different market segments)		4.72	1.59	
Q16 The allocation of resources with product projects reflects the strategic planning deliberations		4.84	1.60	
Total for the factor		5.25	1.05	
Factor: NPD program results				
Q17 The NPD programs are reaching the strategic objectives of the company	Dangelico *et al.* (2013), Kleinschmidt *et al.* (2007)	5.35	1.24	0.8084
Q18 The NPD programs are reaching the profitability objectives of the company		4.92	4.84	
Q19 The profitability of the NPD programs of your company is superior to that of the competitors		4.84	1.45	
Total for the factor		5.04	1.16	