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Managing Multiple Projects in Uncertain Contexts: A Case Study on the Application of a New Approach Based on the Critical Chain Method

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Abstract: Uncertainty and change are two features of modern project management. They strongly influence the project management needs to operate in such contexts. This is the case when a complete and accurate definition of the scope of a project is not available. Those situations require a project management approach capable of dealing with the special conditions that characterise said contexts. This study focuses on the application of the progressive elaboration approach and the Critical Chain method. We analysed the implementation process of the new procedure in a company that produces capital goods for the automotive industry. The work's main focus is on the effect of this change from the multi-project perspective. We found that the change had a larger impact than was expected by the company. Firstly, we found that the new approach provided an opportunity to improve the performance of the company. Besides, the new approach uncovered significant problems that previously were ignored, as well as problems and obstacles to the change. Based on the results and findings of this work, we conclude that shifting to this kind of approach requires a global managerial perspective, and strong support from the management.

Keywords: project management; progressive elaboration; critical chain; agile

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1. Introduction

Companies are disappearing six times faster than 40 years ago, regardless of size, age or sector, according to the results of a recent study [1] that analysed more than 30,000 firms. The authors also conclude, "Companies are dying younger because they are failing to adapt to the growing complexity of their environment." The current project contexts are a clear example of this fact [2]. Complexity and uncertainty are two of the main characteristics of any project [3]. The high levels of competitiveness and unpredictability that characterise project environments today are challenging traditional project management (PM) practices [4]. Under these conditions, the management of uncertainty—an inherent aspect of projects—arises as a crucial factor for project success.

It is widely recognised in the literature that uncertainty is inherent to projects, and a key issue when it comes to the methods of a project [5]. Although uncertainty has been studied in different disciplines related to organization theory, most of them are independent of PM [6]. Furthermore, in this context, there is not a universally accepted approach or definition of uncertainty. For instance, some authors agree that ambiguity and volatility are two key factors for uncertainty, which can be considered as the entire complexity of the project [5,7]. Other authors declare that the level of uncertainty a team faces is dependent on the organization's stock of experience and problem-solving capacity [6]. In line with this view, several authors recommend a practical perspective to deal with uncertainty in project management contexts [8,9].

Companies that operate in highly competitive environments must offer some kind of differential for their subsistence. Logistical improvements are of special interest, as they are more difficult to achieve than other kinds of improvements and, therefore, are more likely to be sustained [10]. Thus, organisations capable of developing and exploiting a competitive advantage are more likely to remain in the market. A number of authors highlight the growing impact of logistical success factors, such as lead time, service level and delivery due-date reliability, stating that they lead to a positive differentiation from competitors [11–13]. On the other hand, an increasing number of companies recognise that project cycle time reduction is essential to warrant a suitable response to the market today and that new, execution-oriented methods are required [14].

Some authors state that companies often fail to understand the holistic approach needed to perform in entrepreneurial contexts [13,15]. A multi-project environment is defined as "the formation of a network of projects of varying sizes and importance that depend on the same set of resources and are characterized by high uncertainty and high complexity" [16]. Uncertainty is one of the two main factors for a comprehensive multi-project environment [17], wherein constant changes occur throughout the project life cycle. The efficiency of critical chain project management (CCPM) when dealing with multi-project contexts is widely reported in the literature [18–20].

In line with these perspectives, several alternatives have been developed in recent years aiming to improve project performance [21,22]. The CCPM method in particular has proven effective for multi-project contexts [19], and it is characterised by high uncertainty and high complexity [20]. Several success stories related to CCPM have been reported in the literature since its appearance [18]. Some of these case studies not only describe the results, but also show the evolution of the method, which has progressively integrated additional concepts and functionalities [23,24].

The CCPM method is based on the theory of constraints (TOC) [25]. Consequently, it involves a systemic approach, and it aims to improve the overall performance of organisations. CCPM pays special attention to the human side, preventing the impact of Parkinson's law, the student's syndrome and multitasking [22,24]. Given the inherent uncertainty in projects, CCPM offers a specific approach to manage projects based on its own logic, including single project planning, multi-project planning and execution management. In addition, it uses buffers as decoupling mechanisms within projects, which provide both protection against uncertainty and visibility of the actual project status [22,26].

A number of authors have recently highlighted the positive impact of the CCPM approach in regard to its use of critical resources [3,17], which is considered a strength of the method. Other studies report case studies on improved versions of CCPM based on continuous improvement and supported by new software capabilities. This evolution has also brought about new ways of using CCPM, tending towards easier and friendlier approaches [27]. The basis for these improvements is the consistent integration of additional elements, such as the use of a suitable project life cycle approach or the full-kit (FK) concept [24]. Assisted by specific software, these turn CCPM into a more powerful method. The additional components suggested by this method are described below.

- When dealing with project environments characterised by uncertainty, it is essential to define suitable project frameworks capable of adapting to the changing needs of the contexts [4]. In other words, the definition of an appropriate project life cycle becomes crucial.
- 'On-demand' scheduling, one of the emerging practices for project scheduling, is considered useful for this purpose [4]. The Kanban system falls within this category, as it is based on the TOC and it aims to maximise the system's throughput based on work in process (WIP) control and flow enhancement [4,28]. It is therefore aligned with the CCPM approach. Both approaches are highly execution-oriented and agree that cycle time reduction is essential to achieve the on-time delivery of projects. Moreover, by shortening the project cycle time, additional capacity may be released, thereby giving the chance for producing 'extra' revenue. In other words, an increase in the project-delivery speed (i.e., cycle time reduction) may have a significant impact on profit [29].
- Decoupling points are specific points that disconnect one entity from another to prevent the propagation of variability on system flow [30]. By isolating said entities, the system is protected

against uncertainty downstream, as decoupling points avoid or mitigate the potential transmission of uncertainty between entities. They are typically used in supply chains to create independence between supply and use of materials when dealing with the 'bullwhip effect'. Given the uncertain nature of projects, we suggest inserting decoupling points between phases of the project life cycle.

- The kitting process has been previously used in manufacturing. However, the FK concept is more stringent [23]. It is defined as "a task that has a full-kit date and that includes a list of items which need to be completed by the FK date" [27], and it has already been applied to CCPM contexts [24]. According to this perspective, work is released only when the conditions to undertake the next phase are fulfilled. This approach contributes by significantly reducing the number of second actions to complete a single stage [23], thereby enabling better control of the WIP. Furthermore, it enables the smooth execution of tasks and projects, thereby contributing to both flow enhancement and the efficient use of resources.

Finally, it is also important to consider the concerns and warnings expressed by some authors regarding the human side of a CCPM implementation. Budd and Cooper state that without the necessary behavioural changes, CCPM will not achieve improvement and, even worse, performance may erode [29]. Similarly, Izmailov, Korneva and Kozhemiakin [19] emphasised that despite the fact that the underlying concepts of CCPM are easy to understand, it is difficult to change existing patterns and inertia. They concluded that the support of senior management is imperative to reach effective change.

The present article is in line with the future research suggested by Ghaffari and Emsley [18], who recommend more implementation cases focused on improvements of the CCPM method. Thus, we conducted a case study on the design department of an engineer to order company. The remainder of the article is organised as follows: we firstly present the objectives and the research method; the results of the case study are presented in section three; finally, the results are discussed and interpreted in section four, including the limitations and the future research suggested.

2. Materials and Methods

The present research is a real-world case study. Action research (AR) is an adequate methodological approach for this purpose, as it can contribute to both academic research and to solving practical problems [31,32]. Furthermore, AR is a variant of case study research in which researchers are actively involved in the process of change. AR is frequently used in operations management research to describe and explore areas without a theory having been previously proposed [32].

The ongoing research–reflection process that characterised AR means that learning is gained in action [31,32]. In AR, the planning–action–observation–evaluation cycle occurs several times [33], resulting in both action and research [31]. That is, the theory arises when applying AR and it "emerges through the development of a series of events as the problem is faced and the members of the organization try to solve it with the help of the researcher in action" [31].

The purpose of this research work is to analyse in detail the impact of the suggested method in a company located in the Basque Country (Spain), where there was a huge growth potential for the future. Nevertheless, the managers were aware that it would be impossible to improve the results significantly with the then-current practices and performance levels. The researchers carried out the fieldwork between May 2018 and January 2019 in two stages, according to the implementation schedule. The first stage was a pilot project aimed at testing the method in the real context, and it was developed between May and June 2018. The scope was limited to the design works, involving mainly engineering resources. The second stage, the expansion of the implementation to the rest of the company, was conducted between July and December 2018.

The company analysed herein is a cooperative, which employs over 200 workers. They manufacture machines and tools for the automotive, power generation, aeronautics and agricultural industries. Their key strengths are their knowledge of the industry, the quality of their products and their capability to adapt to customer needs. This study will focus on the machinery business, an engineer to order context. The attainment of the objectives in this kind of environment is reliant on the flow of relevant information, materials and services [34]. The business includes two parts: machinery manufacturing and retrofitting. Both of these parts share the same resources. The majority of projects are related to machinery manufacturing, which includes design, assembly and the start-up phase of customised machines. This is done mainly for the automotive industry. In addition, they retrofit obsolete machines to adapt them to current needs and requirements.

The market in which this process operates features high levels of uncertainty, fierce competitiveness and strict requirements regarding agreed-upon delivery dates, with penalties if delayed. The market success achieved by the company in previous years allowed growth both in sales and in expanding resources. However, the work carried out was too heavily focused on reacting to short-term needs, rather than focusing on the long term, which was proving unsustainable. Despite this, the company's growth expectations continued to be high. The company was aware, however, that it would be impossible to achieve such results with their then-current practices. To solve this, an analysis was developed that helped to identify the weak points of the organisation. The weaknesses identified were related to the industry, the strategy of the company, and aspects related to the organizational model, the methodology and the support means (mainly software). The problems derived from the diagnosis are very diverse and affect different levels of the organization. The main problems identified are listed below:

- Industry: changes in the market, issues related to customers, (delays in the definition of the project, changes of scope, changes of acceptance dates), issues related to suppliers (delays in the supplies, product quality, lack of compliant suppliers).
- Strategy: unclear strategy regarding market and product targets, lack of priorities.
- Organizational: low PM maturity level, unclear roles and responsibilities, delays in acquisitions, internal management of materials, lack of qualified resources (as a consequence of the ever-growing trend).
- Method: lack of a suitable PM approach (which was not properly implemented and uniformly used), lack of suitable plans, inefficient project tracking, delays in designs.
- Support: lack of suitable PM tools, lack of a tool for document management.

Given the situation, it was decided to apply the practical perspective of De Meyer, Loch and Pich [9]. According to them, one of the four types of uncertainty (i.e., variation, foreseen uncertainty, unforeseen uncertainty and chaos) is dominant in every project, and the PM approach must be based on it. The problems identified in the case study showed that the more suitable uncertainty profile was "variation", as most of the problems were related to issues related to the organizational model, the methodology and the support means. The rest of the problems were also considered. For instance, the findings related to the industry served to know aspects external to the organization, which directly affect it. Although in general, the company cannot influence them, this information allowed determining how they affect them. In this way, it was possible to identify some keys to modify the operation and improve the resilience of the organization. Similarly, because of the findings related to the strategy, the strategy was reoriented, prioritizing objectives on which to focus efforts. However, the project and this study are mainly related to the scope of the last three categories (i.e., Organizational, Method and Support), which are mutually dependent due to their very nature. Consequently, it was determined that it was essential to consider them simultaneously when developing any improvement action.

As a result of the analysis, a number of actions were suggested to address the shortcomings, with the main one being the implementation of the CCPM method. This will be the focus of this study. CCPM is the basis of the proposed method, and it acts as integrator of the rest of the components. Table 1 summarises the main components of the method and their expected contributions.

Table 1. Components of the Suggested Method and Expected Contributions.

Concept	Main Contribution
Project Life Cycle	Project overall view, phase lay out, FK and decoupling insertion points
Decoupling	Protection against uncertainty between phases
CCPM	Systemic perspective, bottleneck management, visibility, protection against uncertainty, WIP control and flow enhancement
Kanban	Short-term resource management, WIP control and flow enhancement
Full-kit	Protection against uncertainty and visibility in preparation tasks, WIP control and flow enhancement

The main driver for single project planning is project flow. Uncertainty causes a progressive increase in variability downstream in the project (see Figure 1a). Thus, it is essential to create a project structure capable of dealing with uncertainty, while enabling the integration of the project strategy with the management of the resources available in the company. This structure is built using the decomposition technique with a suitable project life cycle approach, resulting in a set of phases that can be sequential and/or overlapped (Figure 1b).

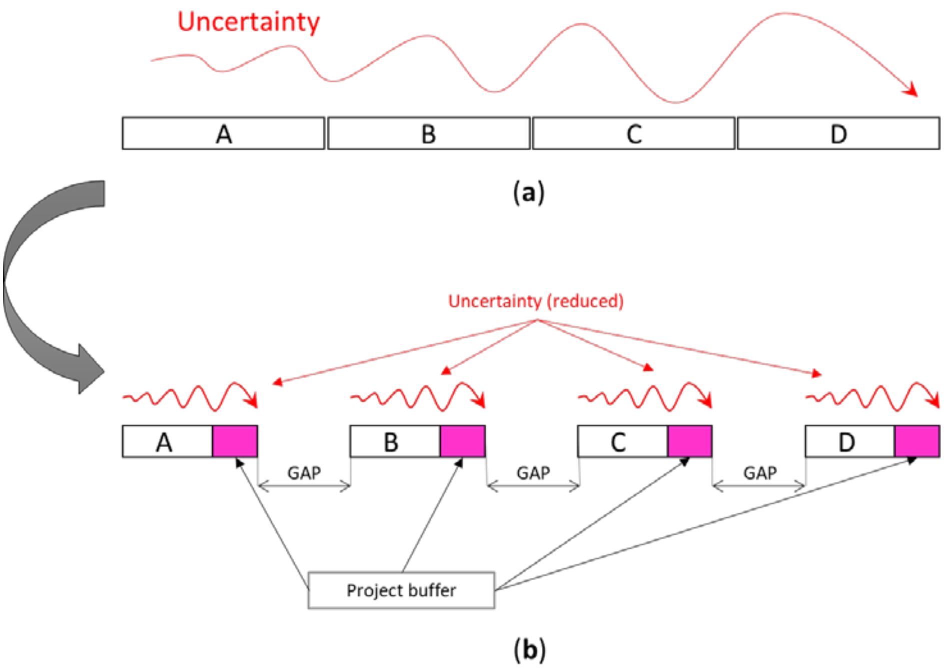


Figure 1. High-level Perspective of the Single-project Approach of the Method. (**a**) Single-phase life cycle, comprised of longer cycle times and an easy spread of uncertainty. (**b**) Multi-phase life cycle, comprised of reduced cycle times and protection against uncertainty (decoupling, buffers).

Phases must be properly protected against uncertainty. For this purpose, both decoupling points and buffers are used. The insertion of decoupling points between phases opens gaps between phases, which act as a firewall, preventing or mitigating the transmission of uncertainty. Similarly, the buffers provide protection against uncertainty at the operational (task) level. In addition, project buffers also provide visibility regarding the current situation of the phase.

The decomposition technique is also used to define the tasks that make up the phases. The tasks will be managed according to the Kanban principles. Thus, resource concentration and WIP control are critical to create a suitable, flow-oriented plan. The decomposition of tasks into two levels is recommended, as it provides simplicity of use and visibility. Specific software (we used Concerto software v 5.10) enables the easy integration of CCPM and Kanban. The task managers are responsible for level 1 tasks, and they coordinate and supervise the subtasks (level 2 tasks) in collaboration with those responsible for the subtasks. Thus, the task manager estimates the overall progress of the task and reports it to the system. Based on this information, the software updates the situation of the project phase.

In the case of the company analysed, the similarity of the projects warranted the use of a unique high-level outline in all cases (see Figure 2). The three levels of CCPM (i.e., single project planning, multi-project planning and execution management), combined with the rest of the components, are described below. However, adaptation to the specific characteristics of each project must be carried out at an operational level. The generic phases identified are Design, Assembly, Preliminary acceptance and Final acceptance, as explained below.

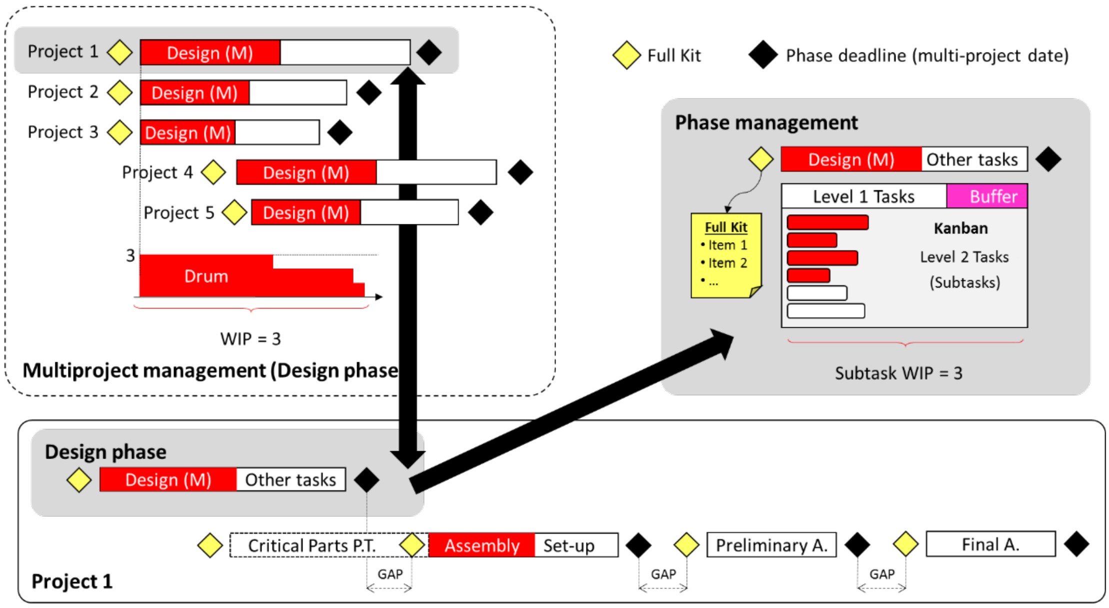
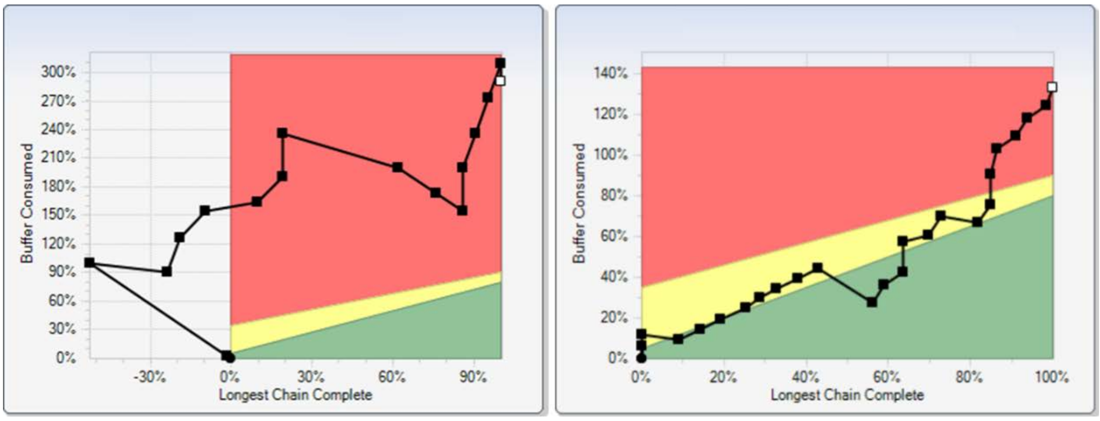


Figure 2. Application of the Method to the Projects of the Company.

- Design phase: involves gathering the mechanical and electrical jobs required to complete the design of the machine. A FK determines the beginning of the phase.
- Assembly phase: includes purchasing, assembly and set-up tasks. The "critical parts purchasing task" aim to enable better control of those parts with long delivery times, and a FK defines the conditions to start the task. Similarly, a second FK for non-critical parts and the completion of the purchasing task define the conditions to start the assembly task.
- Preliminary acceptance phase: the aim is to achieve the preliminary acceptance of the customer, and it strongly depends on the assembly phase. Typically, it is a short phase (1–2 weeks) during which time issues are identified. It is done in the facilities of the company and is a part of the completion of the FK, requiring the customer to be present.
- Final acceptance phase: similar to the preliminary acceptance phase, except the aim is the definitive, formal acceptance and it is done at the customer's facilities.

Regarding multi-project planning, the drum (bottleneck) of each phase and its capacity are first defined consistently with the TOC perspective. This determines the WIP of each phase. This way, the managers launch the projects consistently with both the global priorities and with the capacity available. This is an iterative process performed by the master scheduler, and it may require certain adjustments to reconcile the project strategy, the capacity available and the required deadlines, thereby meeting the definitive deadlines for each project phase. Figure 2 shows how the Design subproject launch is paced by the mechanical design resource, the drum of the design phase, which limits the project WIP to three units (i.e., three projects in progress simultaneously).

The third level is execution management. The monitoring and control of the multi-project system is performed with the tools provided by the software, in line with CCPM. The software provides multiple views of the portfolio, multi-project, single project, task and resource levels among others, as well as metrics and tools for issue management (see Figures 3 and 4). All this information is based on the reporting, done by task and subtask managers.



(**a**) (**b**)

Figure 3. Progress of the Design and Assembly phases of a project (horizontal axis: % Longest Chain Complete; vertical axis: % Buffer Consumed): (**a**) Design phase. (**b**) Assembly phase.

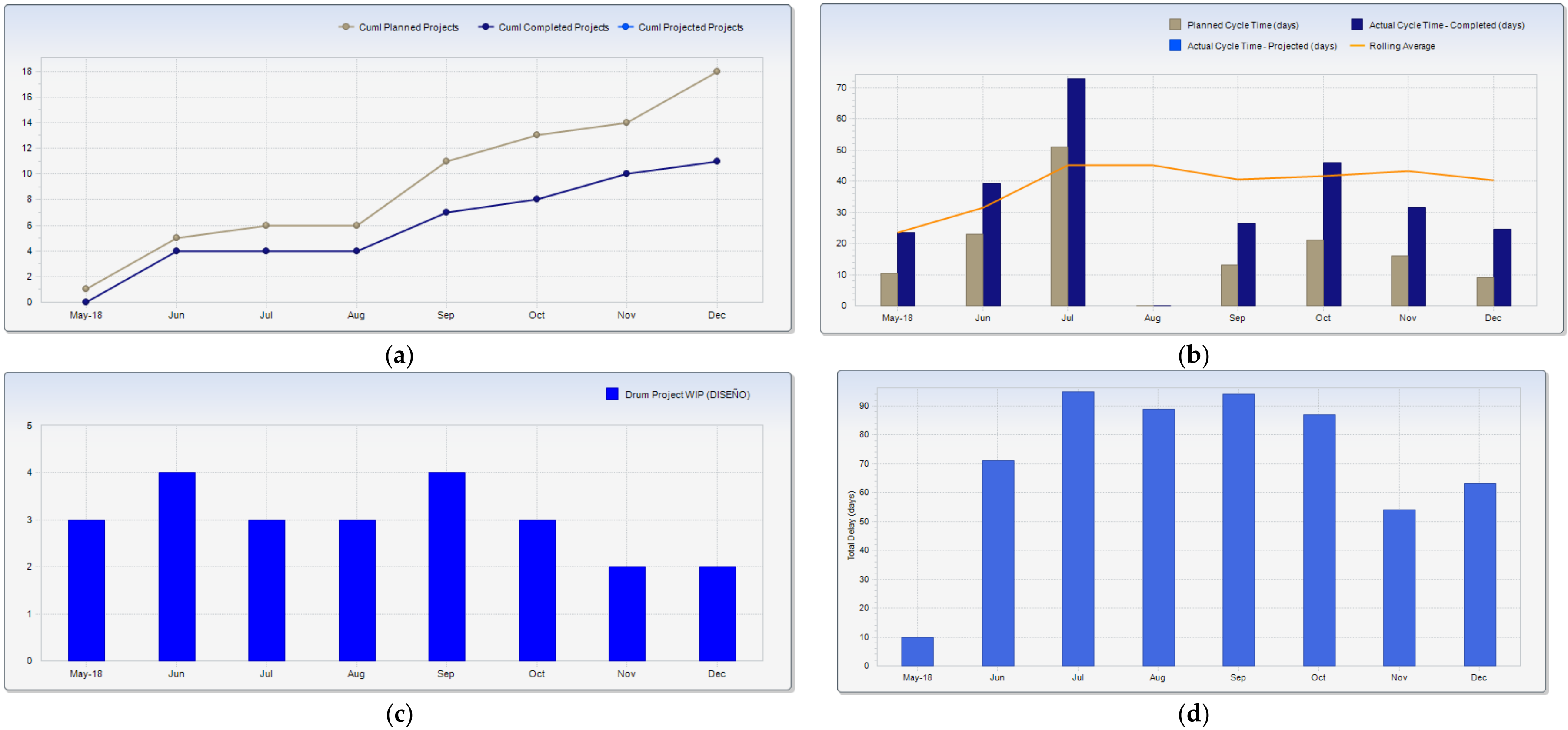


Figure 4. Outcomes (Design Phase): (**a**) Throughput: number of projects completed per period (planned vs actual). (**b**) Cycle time: number of days per project (expected vs actual. Each project data is allocated to the month corresponding to its deadline). (**c**) Drum Project WIP: number of projects in execution per period. (**d**) Total delay: days of delay corresponding to projects in execution.

3. Results

3.1. Qualitative Results

The project life cycle defined for the projects uncovered situations that previously were masked. Thus, the belief that the main problem of the assembly phase was the delay of supplies was proven false. The lack of materials is mainly caused by the delay in the design phase, which prevents carrying out the purchasing and supply tasks within the required deadlines. Furthermore, it has also been proven that the inability to close the designs on time generated the tendency to open new designs, while the designs in progress remained unfinished. This is the main reason why the WIP grew in the design phase, which, as a result, led to undesired consequences, such as increased multitasking, dispersion of resources and difficulty when monitoring the status of activities and projects. Being the first stage of a project, the design phase becomes a source of variability that increases downstream.

The use of CCPM has provided several improvements over the previous system:

- The individual planning of the projects is oriented towards on-time delivery. This approach progressively reduces the cycle times of the projects.
- Multi-project planning is done by combining the established WIP limit, which is given by the capacity of the limiting resource, and the global priorities. Consequently, the projects are staggered consistently with the available capacity of the system and aligned with the objectives of the organisation.
- Buffer management provides the necessary visibility to determine the project situation from the beginning, providing early warnings and future projections. In addition, it provides information for making decisions at the activity level. Combined with Kanban, the management of tasks and subtasks becomes easy.
- In addition, the analysis of the causes for buffer consumption uncovered the problems that were most influencing the projects. The company was surprised to know that the lack of resources and waiting time to solve technical issues, both strongly dependent on internal decisions and coordination, were two of the main buffer consumption causes reported. Other important problems were time spent waiting for customers and suppliers.

The use of the FK also has a remarkable impact on a deadline. The monitoring of preparation tasks allowed for better control of the process. Thus, projects now are launched in a better position, reducing interruptions caused by the lack of definition or information. Furthermore, the use of the FK helped to identify problems in advance, as well as to increase the flow of projects.

Another aspect of interest is the verification that using decoupling in the transition between phases is advisable. As stated above, the design phase is inherently uncertain. This, together with the dependence on suppliers, over which there is no total control, prevents defining realistic start-up dates for assembly immediately after the design. These are points where diverse conditions converge, as determined by the respective FKs. The non-compliance of any of these conditions can be highly detrimental to the projects. Therefore, it is essential to decouple the phases to avoid the spread of uncertainty downstream.

The first project managed with the proposed method is an example of all of the above (see Figure 3). The design phase was completed in a shorter period than usual. Despite this, it was a significant delay compared to the planned duration. However, the assembly phase was able to start in good conditions thanks to the cushioning effect of decoupling. The second phase evolved satisfactorily, and only certain problems prevented its completion within the target period. The decoupling again absorbed this small delay, and the remaining phases were completed within the customer deadline. Importantly, the customer congratulated the project manager, highlighting the way in which the project was managed.

3.2. Quantitative Results

Figure 4 summarises the evolution of the design projects throughout the two stages of the observation period. The throughput shows a positive trend as the number of projects completed per unit of time increases. The WIP reduction observed in the implementation period allowed for an improvement of the cycle time of the projects. In addition, the improvement of the flow of the projects positively influenced the cumulated average delay, which was considerably reduced. These results are in line with the initial expectations of the research. However, said results are still incipient. Thus, it is necessary to continue observing their evolution to confirm whether the trend sustains over time, as well as to ascertain the extent of the improvement.

4. Discussion

The main finding of this research is that the application of the suggested approach provides a real opportunity for improving multi-project management in uncertain contexts. As explained above, the results are in line with the initial expectations of the research, even if they are still incipient. Nevertheless, the results are not yet as good as the forecasts of the plans (see Figure 4). The throughput and cycle time curves indicate that the improvement achieved is not enough to follow the planned pace. The curve of the planned projects shows a gap that occurred at the beginning of September, from which it has not been possible to recover. The graph of the cycle time, on the other hand, shows that every month, there was a deviation between the time planned to complete the projects and the time actually used.

We have identified two potential main causes for the abovementioned deviations: lack of experience in using the method, and too optimistic expectations. We have not observed any evidence that suggests that the estimates are optimistic. On the contrary, the deviations experienced are mainly due to the difficulties of certain people when applying the new method. Furthermore, the observations made have shown progressive improvement in the use of the new method. Everything seems to indicate that this improvement will continue, as the organization is still assimilating certain habits and guidelines. Thus, it is necessary to continue observing their evolution to confirm whether the trend sustains over time, as well as to ascertain the extent of the improvement.

On the other hand, the keys to enable the change are diverse, as explained in Table 1. CCPM is the basis on which the method is built, confirming the virtues reported in the literature. Additionally, the combination of the rest of the components that constitute this approach proved suitable, and each of the components contributes to strengthening the method in a complementary manner.

- The project life cycle reconciles the individual strategy of the projects, the required deadlines and the capacity of the system. This new perspective revealed problems that remained hidden for the company until then. The underlying logic of the project and the need for consistent links between phases when decomposing the entire project uncovered said problems.
- The combination of the multi-phase project life cycle approach with decoupling and FK contribute to reducing the amount of uncertainty in the system in different ways. FK management encourages effective task preparation, thereby reducing reworks and interruptions while enhancing project flow. Decoupling, in turn, impedes the propagation of uncertainty between phases, mitigating and even preventing its impact downstream. Furthermore, we found that the impact of decoupling in the early phases reduces the growth of the deviations caused by uncertainty downstream.
- The WIP control is another key component that promotes project flow. It keeps multitasking under control, preventing the dispersion of resources. Thus, resources remain focused on the most important activities. This increases resource efficiency from an overall perspective and facilitates the monitoring of the status of both activities and projects.
- Finally, Kanban provides agility and ease of use in the short term. This approach showed to be especially effective when dealing with multiple activities in the short term, at the operational level.

Its simplicity allows for easy management and reporting, which in turn contributes to maintaining the information updated.

Another aspect of relevance identified by the researchers is the utility demonstrated by the analysis of the causes of buffer consumption to identify the problems with the greatest impact on the result. The analysis of objective information provided by the software has shown that unproven beliefs were masking some of the main problems and asserting that the most relevant problems were different.

The main problem observed is the difficulty of the engineering department to adapt to the new approach. The inertia of years working individually, lacking clear priorities and exhaustive control is difficult to overcome. The concentration of resources that is now required also entails more coordination and communication, as well as leadership. In particular, we observed that the design engineers had difficulties performing the assignment and managing activities at the operational level. As a result, some capacity was lost due to lack of consistency in FK and closure completion. These findings are consistent with the statements of Budd and Cooper [29] in the sense that the potential of CCPM is conditioned by the degree of achievement of the necessary change in behaviour in the organisation.

In summary, the method offers a reliable chance to achieve high performance levels in this type of context. We highlight in particular its orientation towards deadline compliance, visibility, simplicity of use and effectiveness when dealing with uncertainty.

However, it is essential to understand that the adoption of this method entails an important organisational change. To perform properly, it is essential to create roles and responsibilities that are consistent with the underlying principles of the method, as well as with the specific characteristics of the context. The implementation of a method capable of dealing satisfactorily in this type of context requires certain doses of management. This not only means more dedication to organisational tasks, but also a certain level of management training. In addition, it is also indispensable to modify behaviour according to the needs of the new organisation, deterring old habits. It is expected that this will require a period of adaption. Thus, the commitment of people, and the management in particular, is the key to success.

Given the nature of AR, there are obvious limitations to this research. AR provides profound knowledge of the studied context, but it neither aims at nor allows generalisation [31]. The present study is mainly focused on the design phase, the first step of the project life cycle defined in this specific context. Additional research from an overall perspective, including the entire project life cycle, would be of interest. We suggest analysing the efficiency of the method regarding the mitigation of uncertainty concerning the overall result of projects, as well as its implications regarding the components of the method.

In addition, it is important to check the implications of our findings in other situations, even if we have not identified reasons to discard or discourage the use of the method in other contexts different from engineering to order. Therefore, we encourage researchers to develop additional case studies focused on improvements of the CCPM method and applied to different environments.

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