Product Development Cost Management in Aerospace SMEs

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Abstract: Product development in the aerospace industry involves a complex environment that demands a high level of integration to ensure that the final product cost adheres to the business plan. However, in the initial development phases, the work scope is immature and cannot be completely defined a priori. In this context, cost management is a real challenge, particularly for small and medium-sized enterprises (SMEs) that have smaller margins for errors when defining their products' pricing. This paper proposes a framework to manage costs during product development using a method based on the design structure matrix associated with the design to cost methodology. The analysis is based on the literature and the case study method, which is applied in an aerospace SME. The results indicate positive prospects for the application of the method, which can provide a holistic perspective of the development process while promoting better control of costs.

Keywords: product development; cost management; design structure matrix (DSM); conceptual design to cost (CDTC); product change management; project management; recurring costs; complex system; case study; small and medium-sized enterprise (SME); product breakdown structure (PBS); method

1 Introduction

In a product development project approximately 70% to 80% of total product cost is determined during the development phase (Cao et al., 2011; Clark and Fujimoto, 1991; Kovacic and Filzmoser, 2014). However, during this phase, the scope of work is not yet mature and cannot be completely defined or planned a priori because continuous modifications are generated by stakeholders' requirements, technology evolution, the organization itself and changes in product knowledge (Karniel and Reich, 2013).

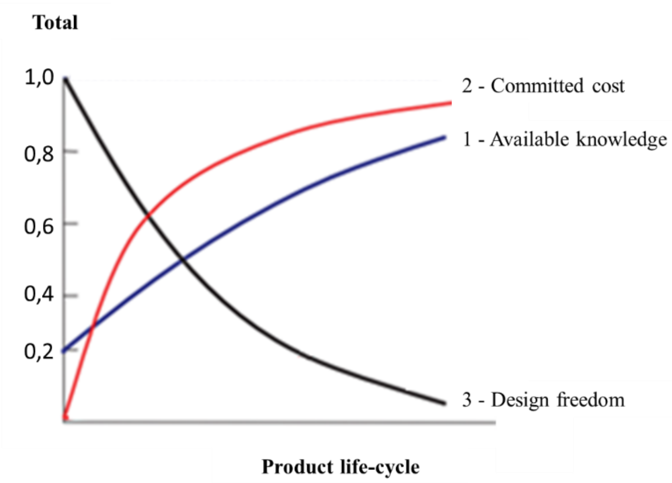
Product development management is even more challenging for aerospace products. Such products are complex and include many interconnected components and technologies, thus involving multiple departments within a company and numerous suppliers located all over the world (Cagli et al., 2012). In addition, aerospace product development projects follow strict requirements regarding quality and airworthiness regulations, while they must also meet cost and development cycle reduction targets. In summary, aerospace product development is a dynamic, highly regulated process that requires a high level of efficiency, integration, and alignment.

Product changes are expected in the development phase. As the process evolves, new information becomes available, which may lead to the rework of previously performed activities and to product changes (Maier et al., 2014). Even though the development phase is characterized by low levels of product knowledge and maturity (Pereira, 2015), to achieve rapid product time-to-market, companies usually rely on executing the engineering activities concurrently, which may also lead to product changes.

Another characteristic of the development phase is that because the technical documentation and product details are not frozen, design teams have much more flexibility to implement changes. Nevertheless, if not well managed, such flexibility can lead to unforeseen consequences for product costs by the end of the project. The design team normally focuses on technical matters, not on costs or financial indicators. This team is the source of product conception, and the team's design activity should be executed in a manner that ensures that the final cost of the product does not diverge from the financial targets (Marion and Meyer, 2011).

Figure 1 illustrates this scenario, described as the *product design paradox*, which indicates that the level of available knowledge is low when the product's development begins (curve 1, Figure 1), although that phase is when most of the critical decisions are made and a substantial portion of the cost is committed (curve 2, Figure 1). In addition, Figure 1 shows that there is much more design freedom at the beginning of the development phase, as depicted in curve 3, indicating that future decisions should be based on past decisions as to the project advances (Karniel and Reich, 2013).

Figure 1. Product development (adapted from Karniel and Reich, 2013).



Therefore, it is of paramount importance to establish a structured cost management process that is linked to the product change process during the development phase. Such a process should be flexible enough not to jeopardize the development cycle and to assure that the real costs incurred as a result of the modifications during product development adhere to the financial parameters initially projected by the company. In this study, the authors are particularly interested in managing recurring product costs during the development phase.

Additionally, the scenario analyzed in this study refers to small and medium-sized enterprises (SMEs),[1] which are characterized by a simple and centralized structure in which the owner/manager, frequently involved in all operations, including sales, development, accounting, production and human resources, is responsible for most of the decisions. Because SMEs frequently struggle to optimize scarce resources in terms of manpower and information technology (IT) management tools (Estrin et al., 2003) and face growing pressure from larger companies within the supply chain to be more and more competitive and to offer attractive prices (Dostaler, 2013), it is of paramount importance that SMEs manage their product development costs well to secure their financial margins.

In such a scenario in which SMEs must cope with the challenges of aerospace product development in a dynamic environment, with constraints in terms of lead time, regulations and costs, it seems reasonable to explore the conceptual design to cost (CDTC) methodology presented by Hari et al. (2008). However, as these authors focus on the initial phase of development, they do not detail the product modification process and cost evolution. As a contribution, the present study seeks to develop a way to manage recurring costs in all stages of product development by evaluating a new method that combines CDTC with change propagation in complex projects, using the design structure matrix (DSM) tool presented by Clarkson et al. (2004).

In this paper, this new method is termed 'product development cost management' (PDCM). This approach seems promising in terms of enabling SMEs to obtain an integrated view of product changes throughout the product development phase by determining the impact of a modification in one component on other interconnected components. PDCM shall also provide project managers with a more holistic view of a modification extension, thus contributing to the decision-making process and affording better control of the associated costs.

Thus, the following research question arises based on the preceding discussion:

> **Is it feasible to manage costs during product development using the PDCM method, which is based on a combination of the DSM tool (for change propagation management) and the CDTC methodology, for SMEs in the aerospace sector?**

Considering that the CDTC methodology does not address product changes or cost evolution, the contribution of this study is that it provides a method that covers a broader cost management process during product development. Moreover, no previous study that specifically discusses the application of the DSM to the management of a product's recurring cost was found. Most of the identified references concern non-recurring costs related to engineering development activities that have been optimized by the use of the DSM.

For the purpose of clarity, a non-recurring cost is defined as an "unusual charge, expense, or loss that is unlikely to occur again in the normal course of business. Such a cost type includes write-offs such as design, development, and investment costs, and fire or theft losses, lawsuit payments, losses on sale of assets, and moving expenses" (Business Dictionary, 2016a), while a recurring cost is a "regular cost incurred repeatedly, or for each item produced or each service performed" (Business Dictionary, 2016b).

In summary, the contribution of this paper lies in the analysis and combination of the existing literature applied to a scenario not extensively explored in the aerospace industry, which is that of SMEs, in order to adapt and modify some of the existing tools and combine them into a simpler and more useful framework that can help these companies to better manage their recurring costs during all stages of product development.

The study is organized as follows. The first section describes the scenario and motivation for the study. The second section presents the initial theoretical framework, including the use of the DSM and CDTC methodology as tools to support cost management. The third section defines the methodology used for a case study on a Canadian aerospace SME. The fourth section presents the results of the case study, and the fifth section offers the discussion. The sixth section presents the implications of the study, and finally, the seventh section describes the limitations of the study and possible future research paths and opportunities.

1.1 Theoretical Framework

A number of researchers have proposed the use of the DSM for different industrial applications and organizations, such as Ford, Xerox, Johnson & Johnson, and Westland. The DSM tool refers to the use of a square matrix to determine, initially, the interface and relationship among (a) the components of a product, (b) the activities involved in a process and/or (c) the communication among departments or teams in an organization to facilitate the analysis and improvement of the object that is being studied (Eppinger and Browning, 2012).

It is known that technical definitions may change during product development. As project advances, more information becomes available to those who are involved in the project. In consequence, the technical teams must update previous decisions (Maier et al., 2014; Yang et al., 2012). Clarkson et al. (2004) use the DSM to evaluate the impact of technical definition changes in complex designs. In that study, a risk analysis matrix that considers the probability and impact level of a design change is created based on the product components' DSM. In this context, the DSM is used as a predictive tool that is expected to support the decision-making process during the design phase.

Previous studies have proposed ways to indirectly control design costs during product development by using the DSM (Forbes et al., 2003; Maier et al., 2014; Shekar et al., 2011; Yang et al., 2012). They suggest using the DSM to reorganize the task sequence during product development with the aim of reducing the rework activities typically associated with the effects of technical redefinitions and shortening the design cycle, consequently reducing the costs related to working hours. Similarly, Browning and Eppinger (2002) analyze the cascading effects of process rework and activity sequencing and their impact on factors such as duration and cost to provide alternative process architectures to support the decision-making process. Karniel and Reich (2013) present a multilevel approach for modeling the product development process while considering its dynamic aspects. The simulation results presented different development durations and consequently different costs, which allowed the decision-makers to identify potential conceptual changes in the product design, architecture, and management that would lead to better performance. However, although these studies refer to costs resulting from design development activities, they do not specifically address recurring cost management.

For such purposes, Braun et al. (2008) present a solution in which the product design cost management of a new mechatronic device is supported by multiple-domain and DSM matrices that consider function, components and processes to determine the target and estimated costs of a product's components. However, the process of product evolution and change is not detailed in this study.

In addition, Hari et al. (2008) present solutions that can help designers make technical decisions without neglecting product component target costs. They propose the CDTC methodology, which combines the design to cost methodology, the Pareto principle, and a company's expert knowledge. It consists of 6 phases in which activities such as target costs definition, cost model methods selection, cost factors identification, assembly, and test charts elaboration, cost breakdown evaluations and analyses of results are performed. Basically, by following the Pareto approach (80/20), the most significant cost-driven factors can be identified that represent 80% of the total cost. The ideal number of components to be detailed in terms of cost for each system should be a maximum of 9, not including the values for assembly and testing. The remaining 20% are considered to be 'all the rest' and are expressed in one line of the cost breakdown table. The CDTC methodology aims to assist designers in achieving cost targets during the preliminary product development phase. However, in their cost management methodology, these authors did not analyze the product cost evolution related to design changes.

Therefore, an opportunity identified by this literature review is that the CDTC methodology does not cover product changes during product development, and the DSM has not been employed in studies related to a product's recurring costs. Thus, this study proposes and evaluates a framework to manage the product development costs of aerospace SMEs by considering the CDTC methodology jointly with the DSM to evaluate change propagation in complex projects (Clarkson et al., 2004). Figure 2 presents the initial theoretical framework.

Figure 2. Initial theoretical framework.

Therefore, proposition P1 is stated as follows for further investigation.

P1 – It is feasible to manage costs during product development using the PDCM method, which is based on a combination of the DSM tool and the CDTC methodology, for SMEs in the aerospace sector.

2 Methodology

In this empirical investigation, the case study method (Yin, 2014) is applied to examine one Canadian aeronautical SME with 18 employees and 10 years of expertise to test and refine the initial theoretical framework.

For this purpose, the development of an airborne system is analyzed .[2] This case is selected because the airborne system's cost is significant (i.e., millions of U.S. dollars) and because of data available concerning the development of such a complex system, which is characterized by a large number of interconnected components. In this type of product, a change made to any component will probably impact other components as a result of fit, form and/or function changes (Jarratt et al., 2011). Therefore, the analyzed product provides a meaningful scenario regarding cost variation resulting from changes, which justifies the application of the PDCM method.

This study uses a single-case design to obtain a maximum amount of information and identify specific characteristics to establish an average scenario regarding cost management during product development in SMEs. First, an explanatory assessment is performed to test the implementation in an SME of the initial theoretical framework, which is composed of the two methods presented in the literature review (i.e., the DSM and CDTC). Then, an exploratory approach is used during several meetings with the SME's experts. This approach adopts a critical case study design based on the results of the case study explanatory phase and in-depth interviews to obtain empirical data. The data are used to refine and enhance the initial theoretical framework (Wiebe et al., 2010). Thereafter, other tools and methods are identified as important for the full development of the PDCM method. Finally, the steps required to accomplish cost management are described in the Results section.

Regarding the data collection strategy, face-to-face meetings are conducted with the SME's specialists. Focus groups, brainstorming, and simulations are used to guide the meetings and to extract empirical data to facilitate the completion of the DSM and the cost tables based on similar product drawings and cost histories and to evaluate the impacts of the changes. Finally, a semi-structured questionnaire is administered to obtain feedback on the use of the PDCM method.

As part of the data collection process, the reactions of the specialists regarding the practicality of using PDCM in each of the steps are observed during the meetings. In addition, regarding data analysis, the collected information is compared with the initial theoretical framework. As the outcome, the final description of the framework is elaborated.

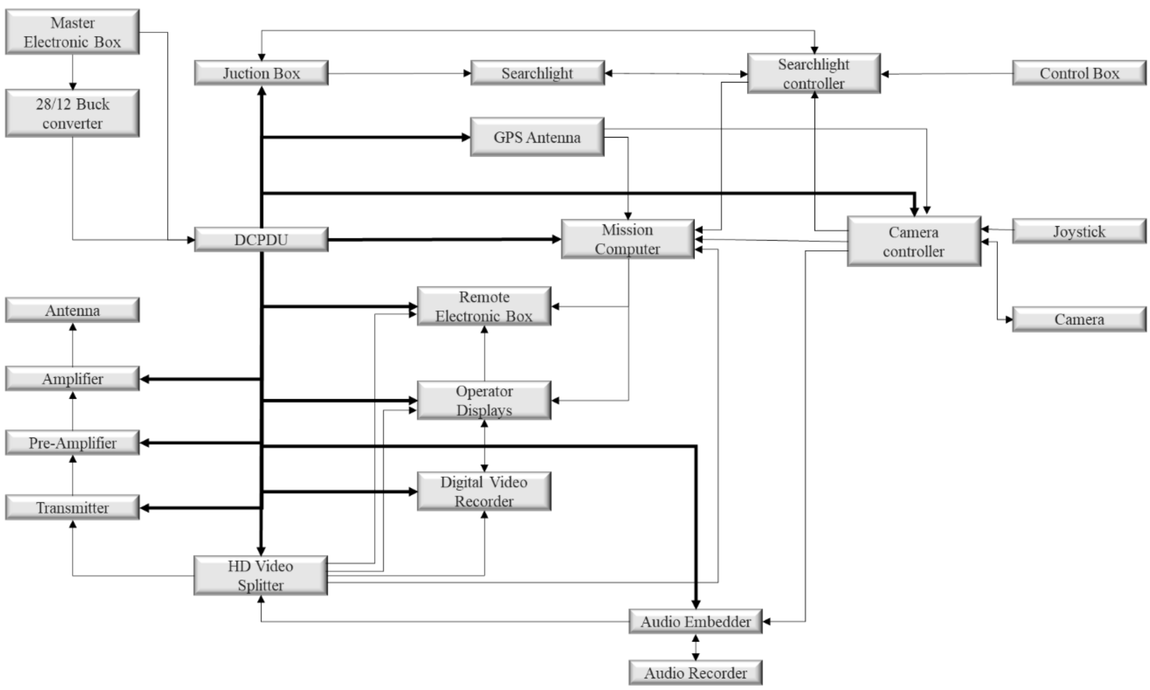
3 Results

From the discussions with the SME's specialists, it was possible to establish the steps required to manage costs during product development, considering the application of the CDTC methodology and the DSM for product change management. However, additional management tools were required to complete the process. Thus, the following steps were established, which henceforward compose the PDCM method.

3.1 First Step: Block Diagram

The first step was to prepare a block diagram of the airborne system. A block diagram is a schematic that can verify the relationships among the components of the system. The principle is to use arrows to connect the components, which are represented as square boxes in Figure 3.

Figure 3. Airborne system block diagram.



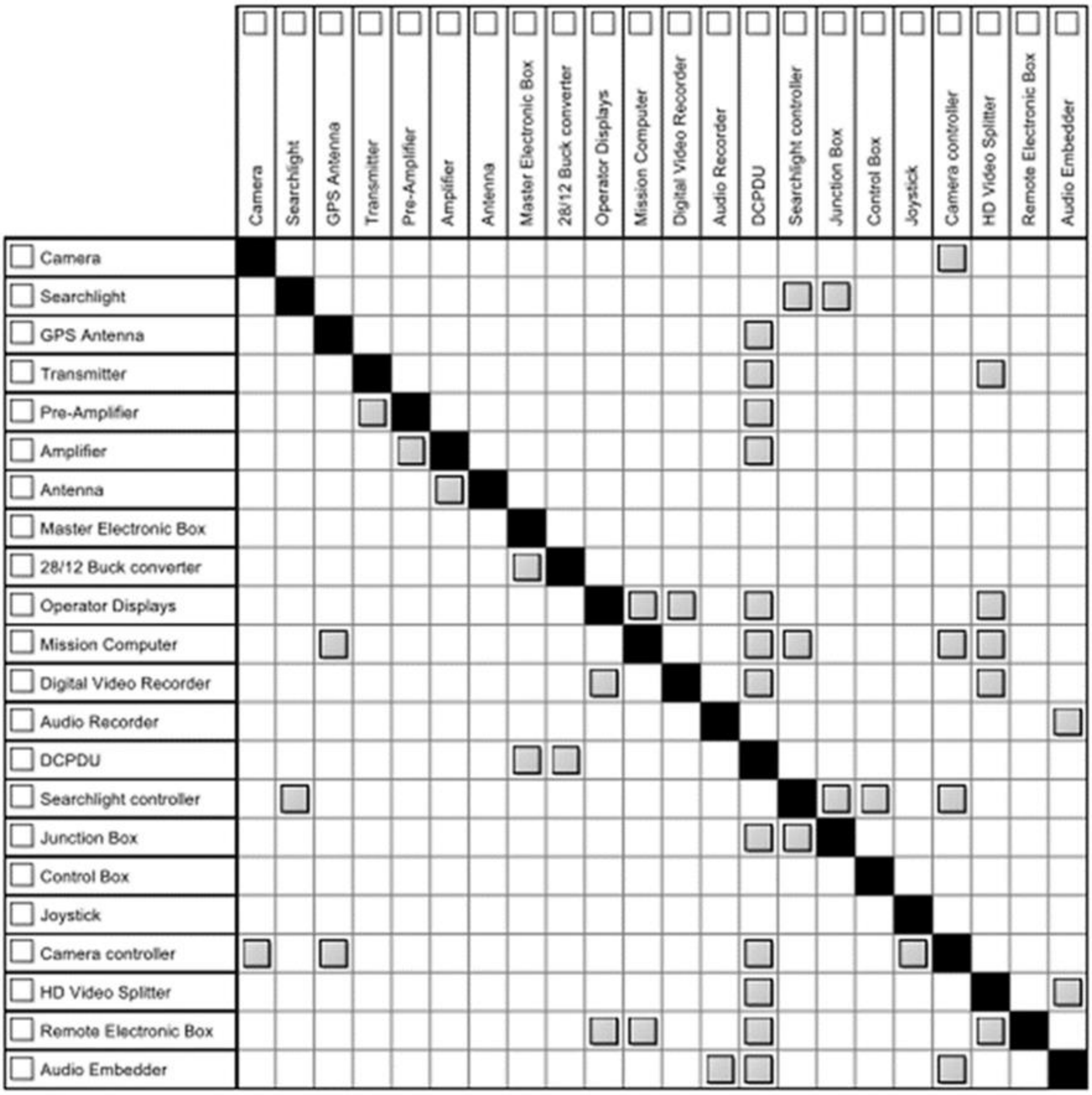
The direction in which the arrow points represents whether the component is an input (arrowhead) or output for another component. For example, the joystick is an input for the camera controller; thus, the camera controller is an output of the joystick. The arrows that have arrowheads at both ends indicate that the component is an input and an output for the other component, such as the relation between the camera and the camera controller, in which they exchange information both ways.

Figure 3 depicts the block diagram of the airborne system for this case study, which consisted of 22 elements, with each element having at least one input or one output to another component of the system. The professionals who established these relationships were the engineer(s) responsible for the concept and the architecture of the system.

3.2 Second Step: DSM

An analysis of the interdependency of the system's parts was performed to generate the DSM presented in Figure 4. The DSM is a square matrix that summarizes the components' interfaces such that the components' names and descriptions are indicated on the left side of the matrix and in the same order above the matrix. Additionally, a mark (□) in any cell off the diagonal refers to the existence of a relationship between two elements, indicating that in regard to one specific component, the row determines its inputs and the columns its outputs. The relationships among the system's parts are the same as previously presented in the block diagram. Consequently, as found by Browning (2016), the DSM provided a holistic visualization of the system that facilitated the identification of impacts due to any modification and improved the overall management process.

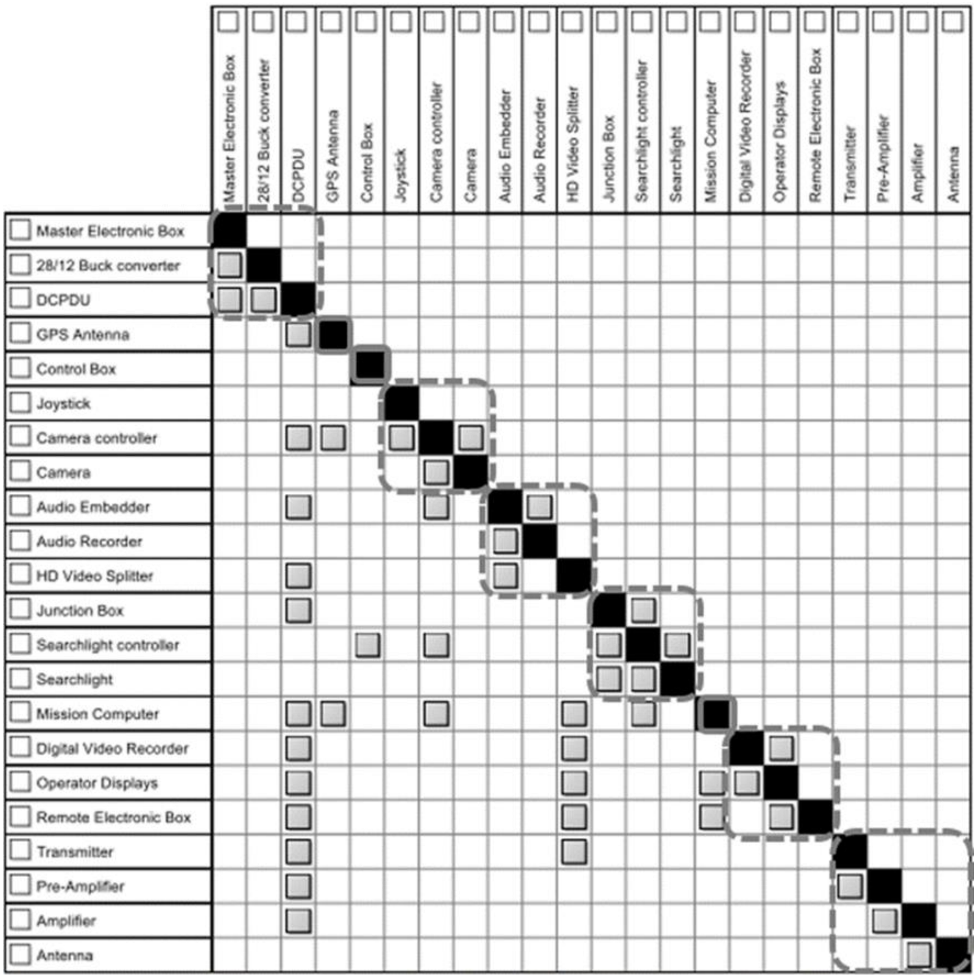
Figure 4. System DSM.



3.3 *Third Step: Partitioned DSM*

The next step consisted of partitioning the DSM by reordering the matrix's rows and columns to bring the related parts closer to one another. For this purpose, Cambridge advanced modeler (CAM) software (Cambridge University, 2016) was used to generate a partitioned DSM. The outcome of this process is presented in Figure 5. The marks that remain above the diagonal represent the components that exchange information in both directions, for example, the camera and the camera controller, which means that they are an input and an output for one another. This relationship is depicted in Figure 5 by the mark above the diagonal and in Figure 3 by the arrow (with an arrowhead at both ends) that links these components.

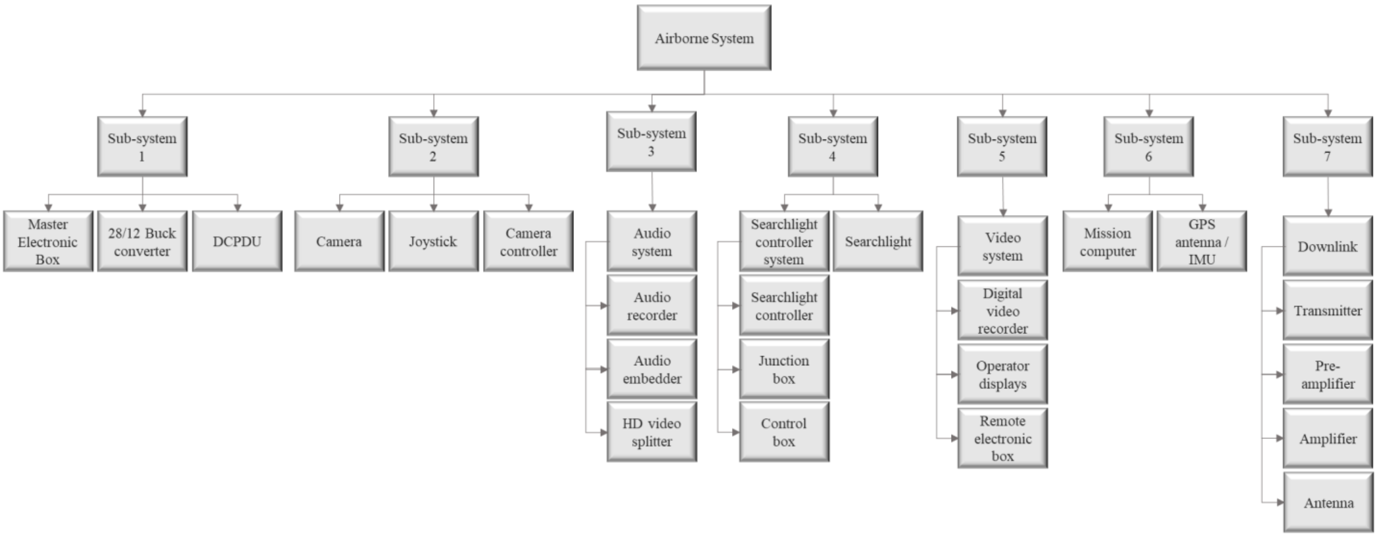
Figure 5. Partitioned DSM.



3.4 Fourth Step: Product Breakdown Structure (PBS)

The PBS was generated based on the partitioned DSM (indicated by dotted grey squares in Figure 5) and is presented in Figure 6. The PBS was divided into 7 subsystems: subsystem 1 was related to the electrical power sources; subsystem 2 contained the main components of the camera assembly; subsystem 3 included the audio devices; subsystem 4 contained the searchlight controller and searchlight components; subsystem 5 was related to the video devices; subsystem 6 contained the mission computer and GPS antenna; and subsystem 7 included the downlink components.

Figure 6. Airborne system PBS.



3.5 *Fifth Step: Cost Estimation*

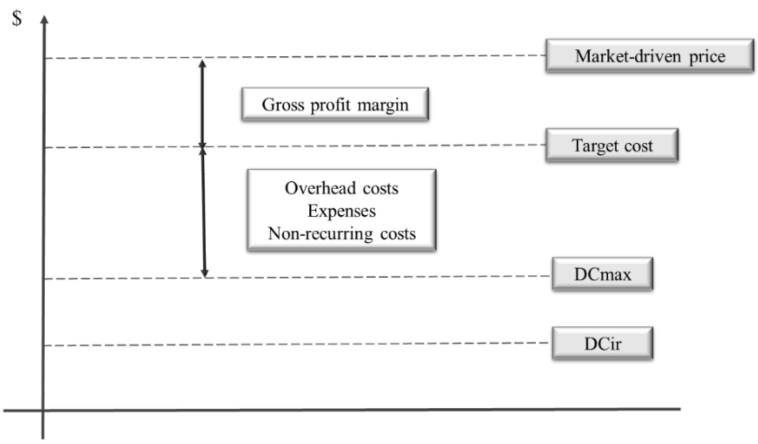
In the aerospace industry, it is common to present both recurring and non-recurring costs in product quotes (Curran et al., 2004). However, because the focus of this study was on recurring costs, the cost references presented herein only refer to this category of costs and more specifically to its direct portion, which means direct materials and direct labor, also known as direct or prime costs (Hansen and Mowen, 2009; Horngren et al., 2015). The direct costs are hereinafter designated as DC.

To manage the evolution of the DC during the product development phase, it was necessary to establish cost references such as, the direct cost maximum acceptable value (DCmax) and the initial reference (DCir), which were defined in alignment with the expected financial targets.

The DCmax value was obtained based on the target-costing concept, which, in turn, was determined by the price of the product accepted by the market (Accounting Tools, 2016). According to Ward and Graves (2004), the target cost is obtained by subtracting the gross profit margin from the market-driven price. Provided that the focus of the analysis was on the recurring direct costs, the DCmax reference was obtained by subtracting the estimated overhead costs, expenses and non-recurring costs from the target cost.[3]

For the DCir definition, the CDTC methodology was used (Hari et al., 2008). Although it was not feasible to precisely determine the total product cost, by using such methodology it was possible to obtain a rough order of magnitude or a reasonable estimation for proceeding with the development. Figure 7 illustrates the aforementioned cost references.

Figure 7. Cost references.



Thus, following the CDTC approach, the most significant cost-driven factors, representing 80% of the total direct costs, were determined for each of the 7 subsystems according to PBS. The cost breakdown for each subsystem was completed per the template presented in Figure 8.

Figure 8. Breakdown table of product direct costs (adapted from Hari et al., 2008).

Product Direct Costs										
Item	Quantity	Unit Price	Material Price (Local Purchase)	Material Price (Outsource)	Labour (hours)		Labour Costs (Rate 1)	Labour Costs (Rate 2)	Other Costs	Total
					Rate 1	Rate 2				
Searchlight Controller										
Junction Box										
Control Box										
Searchlight										
Harnesses										
Assembly										
Testing										
All the rest										
Total Net			$0.00	$0.00			$0.00	$0.00	$0.00	$0.00

Once the cost of the 7 subsystems was determined, it was possible to estimate the DC. The first DC value was the DCir per formula (1):

$$DCir = DCSS1 + DCSS2 + DCSS3 + DCSS4 + DCSS5 + DCSS6 + DCSS7 \quad (1)$$

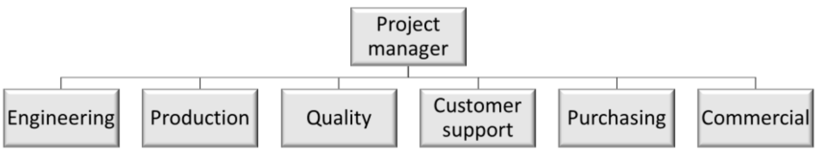
where SS1 is subsystem 1, SS2 is subsystem 2, SS3 is subsystem 3, SS4 is subsystem 4, SS5 is subsystem 5, SS6 is subsystem 6, and SS7 is subsystem 7.

3.6 Sixth Step: Change

This step considered the changes that occurred during the product development phase and also addressed the cost incurred from the changes. In the PDCM method, practices included in the agile method regarding regular meetings seemed to be suitable for managing changes during the product development phase. Such suitability stems from the fact that this method favors team integration and reduces risk. In addition, the agile method fit the dynamic and flexible nature of an SME (Smith and Smith, 2007) and the simultaneous engineering environment.

Key resources, who can initiate changes or be impacted by changes, must participate in both meetings. They are members of teams, such as project management, engineering (i.e., airworthiness, certification, technical documentation, system architecture, design, methods and process), production, quality, customer support, purchasing, and sales. This approach is compatible with the principles of simultaneous engineering to improve integration, mitigate risk and promote team awareness regarding the evolving development (Goswami and Tiwari, 2014). Figure 9 presents the breakdown structure of the key resources that are expected to be part of the meetings.

Figure 9. Key resources for change meetings.



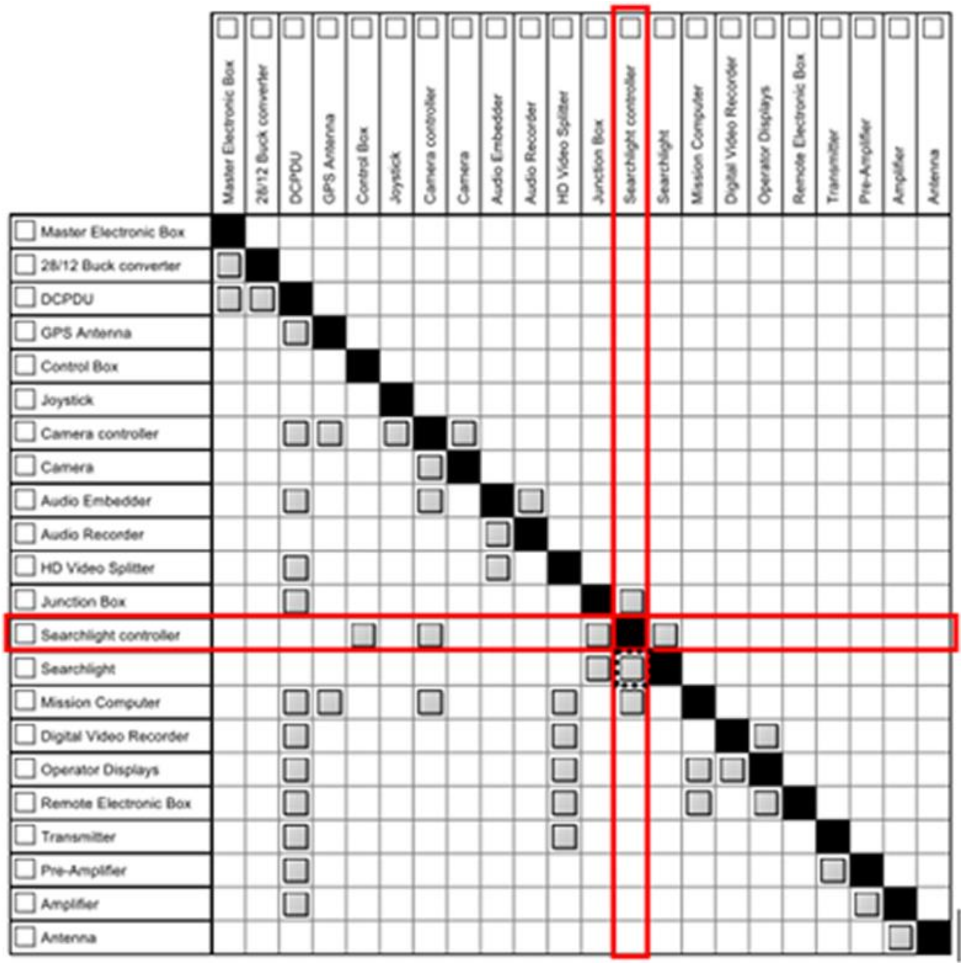
The agile approach proposes 15-minute (maximum) daily meetings and longer meetings every two to four weeks (Levitt, 2011). The longer meetings' frequency and length should be neither so considerable that they disrupt daily activities nor so minimal that there is a risk of losing control of the development and its associated costs. In the PDCM method, the longer meetings were named cost review meetings. The objectives of the daily and cost review meetings were to promote, respectively, the change impact analysis and the management of the DC value. Both meetings are further discussed below.

3.6.1 Daily Meetings

In the daily meetings, the participation of the key resources is essential in case any relevant change related to product development is presented. During the daily meeting, the partitioned DSM (Figure 5) is used to enable preliminary change impact analysis as well as change propagation analysis.

In this case study, a change to the searchlight controller was presented during one of the daily meetings. The partitioned DSM was used to facilitate the visualization of the possible pathways through which such a change might propagate and to identify other system components that interfaced directly with the searchlight controller. These components were referred to as first-level interface components (e.g., the junction box, searchlight, mission computer), as highlighted in Figure 10.

Figure 10. First-level interface components. In this case, the searchlight was the component directly affected by the change.



The key resources identified that the only component directly affected by this change was the searchlight. Still supported by the partitioned DSM (Figure 5), the key resources also noticed that the initial change propagated to the second level affecting the junction box (Figure 11).

Figure 11. Second-level interface components. In this case, the junction box was the component indirectly affected by the change.

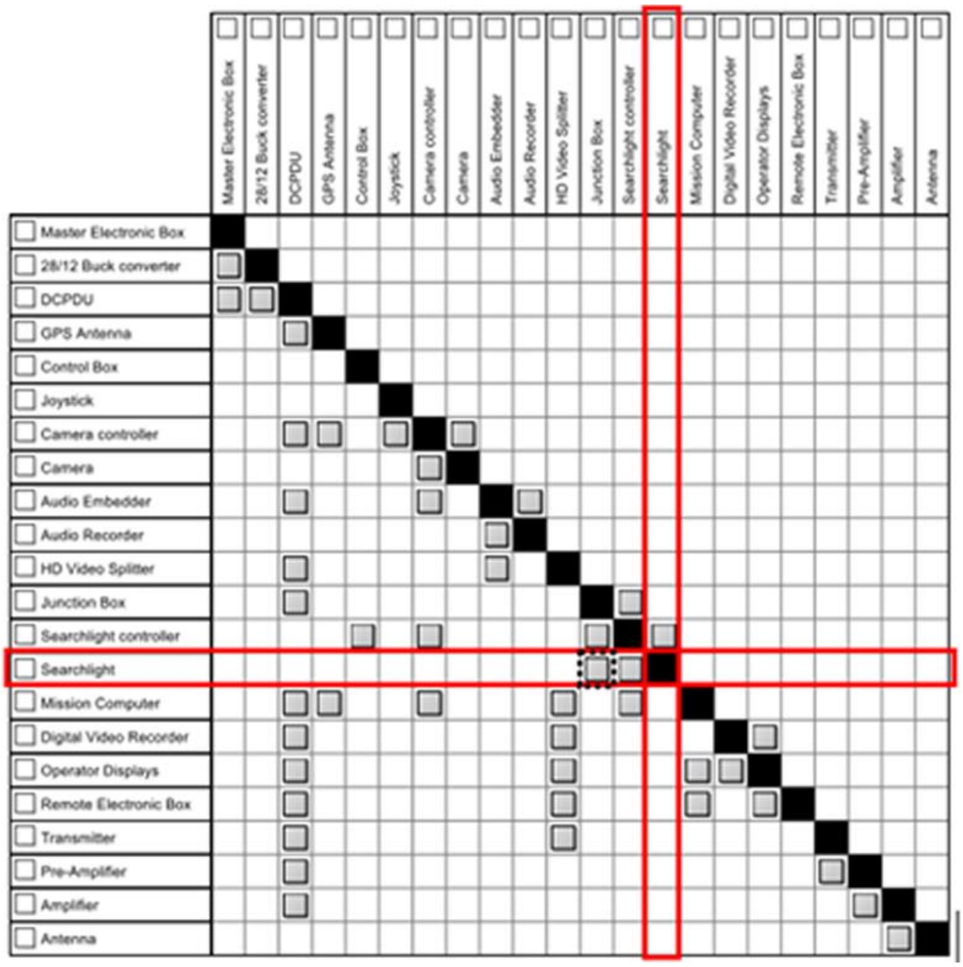
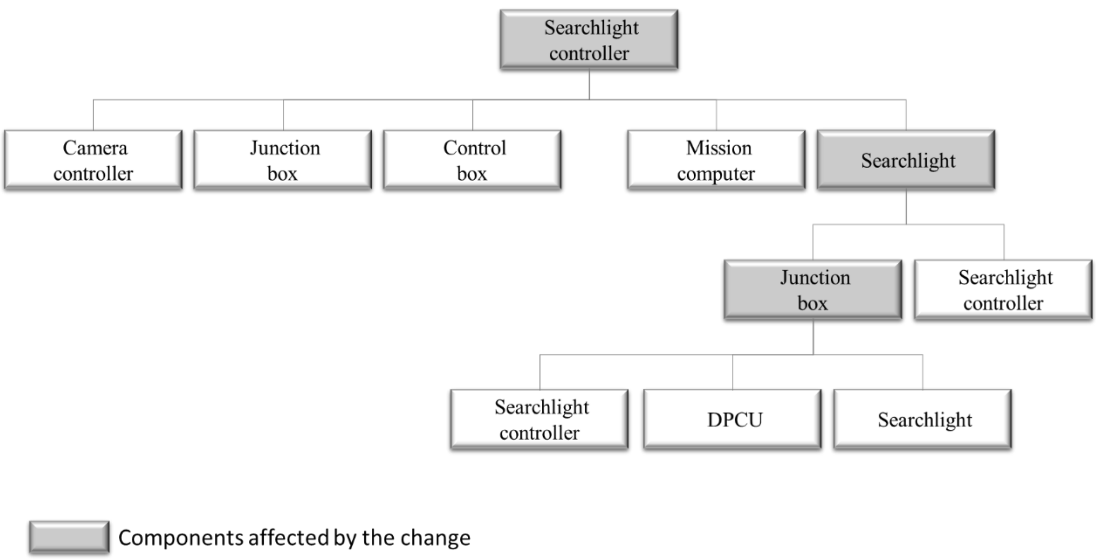


Figure 12 presents the entire propagation path of the change in the case study.

Figure 12. Change propagation.



As a result of the daily meetings, when relevant changes were presented, the key resources could refine the preliminary change impact analysis. Once the affected components were identified, their cost impact could be evaluated and estimated. This information was used during the cost review meeting to determine the new DC.

3.6.2 Cost Review Meetings

The cost review (CR) meetings are dedicated to addressing the changes and managing the DC value. During the cost review meeting, the key resources collaborate with the project manager to identify the impact of several changes, compiling the information previously discussed in the daily meetings. The advantage is that the key resources can share different perspectives, which may also favor the rise of an optimal and integrated change solution.

As an outcome of the cost review meetings, the cost breakdown tables were updated. Then, the new DC(n) was determined by the sum of all seven subsystems' costs, as recalculated after the evaluation of the changes discussed in the cost review meeting, as presented in equation (2), where (n) is the index associated to the cost review meetings.

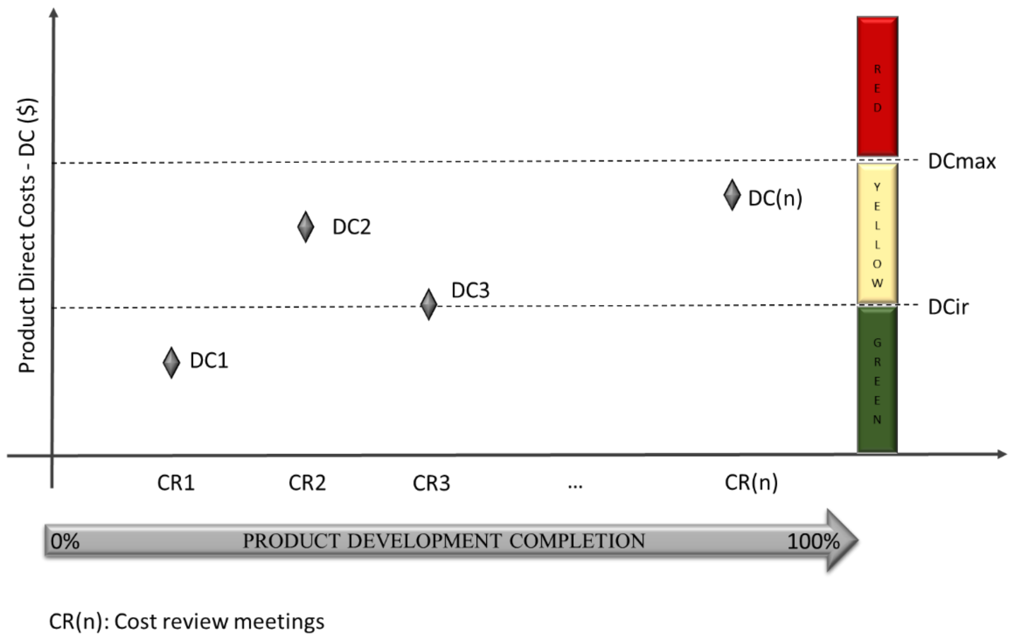
$$DC(n) = DCSS1(n) + DCSS2(n) + DCSS3(n) + DCSS4(n) + DCSS5(n) + DCSS6(n) + DCSS7(n) \qquad (2)$$

In the upcoming cost review meetings (CR1, CR2, CR3, etc.), the same procedure was performed, enabling the project manager to evaluate whether the cost variations due to various product changes were within acceptable limits for the expected financial margins.

If the new DC value is lower than the previous one, it represents a cost reduction, and if it is higher, it represents a cost increase. However, the new DC value should always be lower than the DCmax. Otherwise, the project manager must seek an alternative solution to achieve project targets.

Figure 13 represents the DC evolution.

Figure 13. System cost evolution.



Finally, the process resulting from the case study is summarized in Figure 14.

Figure 14. Product design cost management.

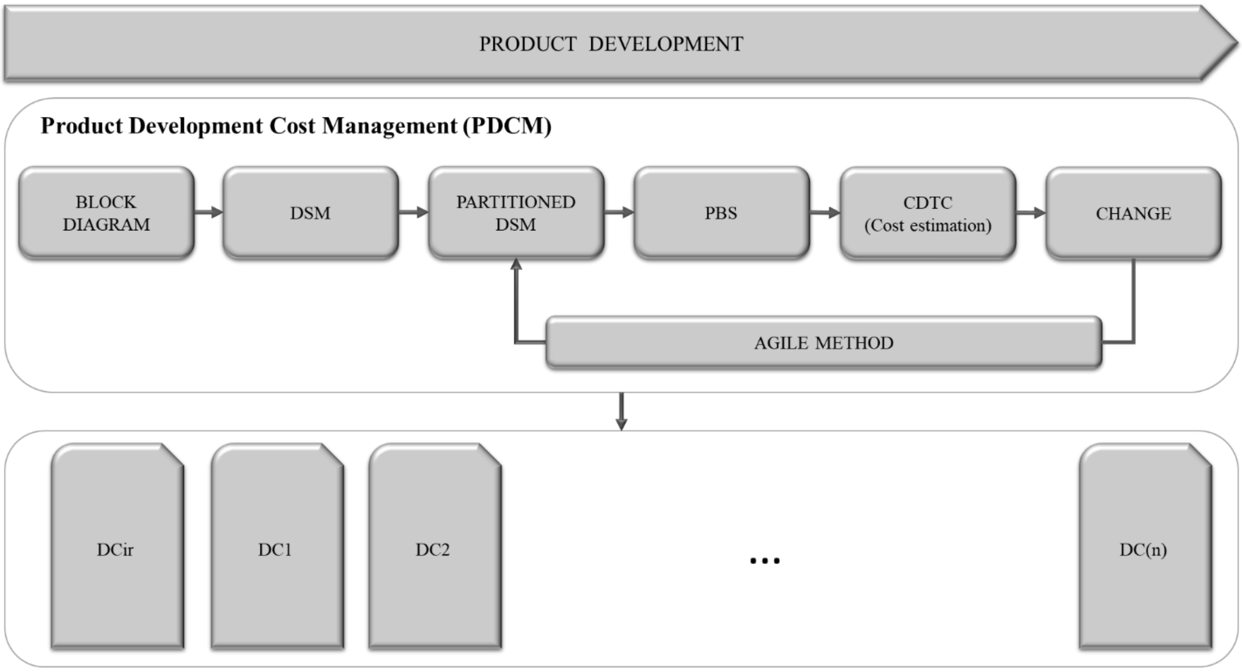


Figure 14 describes the PDCM method. From a block diagram, the system DSM was generated and then partitioned to better organize the interrelated components and allow the elaboration of the PBS. Once the subsystems were defined, their preliminary cost was determined using the CDTC methodology, and consequently, the DC was estimated by summing up all the costs. When a change in one system component was proposed, its propagation was evaluated by using the partitioned DSM, and the process was reinitiated, leading to a new DC. Additionally, the agile approach was used to optimize the meetings related to the product change evaluation process.

4 Discussion

The proposed PDCM method aims to provide a global perspective on product development by improving visibility regarding cost-target adherence. It also provides visibility concerning project feasibility from the beginning of the project to facilitate the decision-making process (Go/No Go) and to act as an indicator for managers if costs deviate from the target.

It was noticed that some characteristics are relevant to the implementation of the process, as indicated by Clarkson et al. (2004) with regard to implementing the DSM, such as the need for an organizational culture that foments and empowers the use of the tool; team expertise and maturity; the employment of different points of view to analyze the system and impacts; and the availability of product history and/or a similar product to support the elaboration of the assumptions.

Additional factors that affect the implementation of the PDCM method were identified by the specialists.

- The daily meetings are revealed to be important. However, it is not easy to motivate employees to attend the meetings because they have numerous other demands on their attention. In addition, mobilizing several resources is expensive for the company. Therefore, it is imperative to start and end the meetings punctually and to respect the 15-minute duration limit. Thus, participants should arrive on time, and the project manager should be able to control the meeting scope while concentrating on the changes that may impact product development costs.
- The design engineers are the key resource that is likely to trigger the change process, as they are responsible for the concept of the system and are best able to evaluate whether changes are sufficiently

relevant to be communicated to the project manager and other key resources to guarantee product development cost follow-up during the daily meetings.

- A change criteria definition is required to determine which changes will be presented in the daily and weekly meetings. This point was mentioned as the key to the success of the cost management method. Addressing all modifications would make the process extremely bureaucratic and ineffective. Thus, it is important to define criteria for capturing only those changes that will substantially affect costs and that cannot be neglected. Each project and product has characteristics that suggest the adoption of particular criteria. As evaluated in the case study, this definition is possible only through the support of experienced members of the project team.
- A business-oriented and cost-related approach is not frequently the goal of design engineers. However, the development of such a culture is important to reinforce the idea that inputs from the engineering team regarding the commercial effects caused by product changes must be noted at the appropriate time to avoid unpleasant surprises at the end of the project. This concept is also supported by Marion and Meyer (2011).
- The simultaneous engineering approach favors a close relationship between the engineering and purchasing teams. It was observed that these teams can become isolated from one another, which creates disruptions in product development. The PDCM method seeks to integrate areas, improve communication between them and search for a common product development financial target that considers the perspectives of key resources. Benefits regarding cost minimization due to collaboration among multi-functional teams have also been observed by Sánchez and Pérez (2003).
- Although DSM fulfillment is relatively subjective, its importance was recognized with regard to the better organization of the parts interface data to facilitate visualization of product change propagation. The technical specialists also acknowledged the DSM's contribution, highlighting that the parts most related were closer to one another in the partitioned DSM after the parts were reordered. This outcome led to simplifying the PBS construction.
- The study participants indicated that using the partitioned DSM to analyze the change propagation (Figure 5) was a practical and useful way to reduce rework regarding the product development life cycle. In the daily meetings, key resources can discuss how the change may impact them, thus favoring the analysis of alternatives that can optimize resource use when considering the product development life cycle.
- An important remark was made regarding the 'all the rest' components in the cost breakdown table. Although the CDTC methodology (Hari et al., 2008) suggests considering the value of such 'all the rest' parts as 20% of the DC, the recommendation made by the technical specialists was to consider, from the first estimation, that this value may vary up to 20% depending on the degree of knowledge regarding the product and the product's maturity. Thus, instead of starting with 20% and decreasing the percentage as the project evolves, a smaller value may be proposed depending on the initial analysis and degree of uncertainty. Such adjustments may make the commercial proposal more accurate and competitive. Thus, the implementation of the following categories is proposed (Table 1):

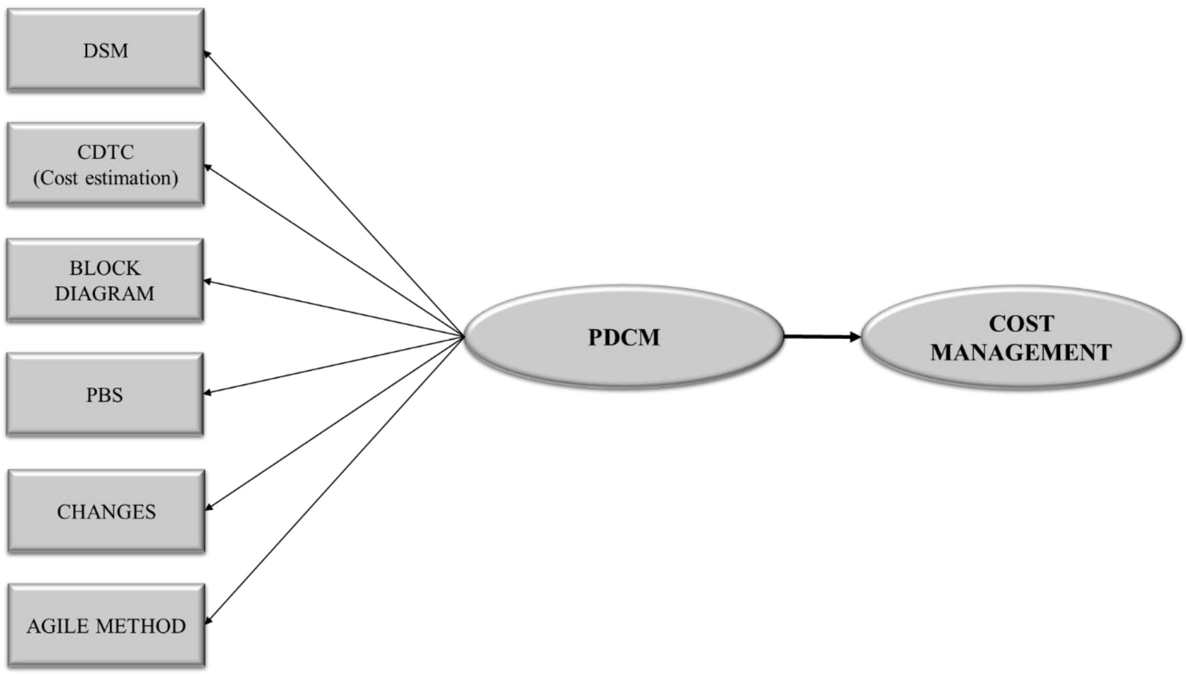
Table 1. 'All the rest' value depending on the degree of uncertainty.

Category	Criterion	% of total cost
Minor	High product knowledge	0% to 5%
Moderate	Medium product knowledge	5% to 10%
Major	Low product knowledge	10% to 20%

- The agile method for managing product changes seems pertinent to this type of company due to its flexibility, dynamism and reduced bureaucracy. However, even if a more informal and paperless approach is adopted, the necessary controls and documentation should be written down to comply with configuration management, product conformity and certification requirements.

Based on these comments and the findings presented in the Results section, the initial theoretical framework has been revised to reflect the necessary adjustments regarding the management tools and processes that have been added to the method: the block diagram, the PBS, change management and the agile approach. Figure 15 presents the final theoretical framework.

Figure 15. Final theoretical framework.



Thus, according to the case study results, proposition P1 was demonstrated to be partially valid, provided that the feasibility of managing costs during product development using PDCM for SMEs in the aerospace sector is confirmed. However, as described, the method had to be expanded to incorporate other tools and processes (Figure 15).

5 Conclusion

This paper evaluates a framework to manage costs during product development using the PDCM method, which is based on the DSM associated with the conceptual design to cost methodology for aerospace SMEs. The analysis was based on the literature and the case study method, which was applied in an empirical investigation of a Canadian aerospace SME.

Considering that the CDTC methodology does not address the product modification process and cost evolution, the PDCM method covers a broader cost management process during product development. In addition, no previous study that addresses the application of the DSM to the management of a product's recurring cost was found.

Proposition P1, which was developed to validate the initial theoretical framework, refers to the feasibility of using the PDCM method to manage costs during product development for SMEs in the aerospace sector. As a theoretical implication, the proposition was demonstrated to be partially valid, provided that the PDCM method was revised to incorporate other tools and processes, such as change management, the block diagram, the PBS and the agile method.

Regarding managerial implications, the case study results show that although the studied company has expertise in product development and substantial experience in the market, it recognized that a method to manage cost evolution during the product development phase would be a valuable asset.

The proposed method provides a systemic perspective on the product. This perspective results in better control of the project's cost evolution during the product development phase, which is characterized by little information available regarding the product. In addition, the PDCM method proposes a simpler approach to enable its implementation in SMEs because these companies cannot sustain complex, bureaucratic, and time- and resource-consuming processes.

All of the steps that the method involves and the factors relevant to its implementation have been described. Thus, the paper provides guidelines and directions for SME practitioners when managing costs related to product development.

Among the relevant findings of this study, the following are emphasized. (1) The PDCM method promotes integration among areas, improves communication and uses a common product development financial target. (2) The use of partitioned DSM to analyze change propagation is a practical way to reduce rework regarding the product development life cycle. (3) The agile method for managing product changes is pertinent to the SME environment because of its flexibility, dynamism and reduced bureaucracy.

Although the initial results suggest a promising pathway, they also present some limitations because the analysis was performed by considering only one company in the sector, and the long-term results have not yet been evaluated.

Nonetheless, this initial analysis sheds welcome light on a field to be explored; therefore, evaluations based on this method are recommended for a longer period to measure the accuracy of the estimated values against the actual values. It would also be useful to employ the method in other SMEs in the aerospace industry to obtain data from a more representative sample. Furthermore, the scope of analysis might be expanded by including aspects other than costs, such as weight and lead time. Moreover, once the method has been deeply analyzed and validated, the possibility of developing an IT tool to support this management process might be explored.

In conclusion, this study contributes a method for aerospace SMEs to better manage product costs during a dynamic and immature phase such as product development as they seek to achieve their projected financial results.

Notes

[1]SMEs are considered in this study to be formal companies with a maximum of 250 employees (Ayyagari et al., 2007).

[2]The airborne system is described in the Annex.

[3]Overhead and expenses are costs determined based on apportionment. They can be summed up to the DC to determine the product's total recurring cost. Non-recurring: these costs can be managed by applying the PDCM, following the same steps presented for the recurring costs. The non-recurring cost can be summed up to the total recurring cost to determine the product total cost.

Annex

The goal of the airborne system is to perform rescue, search, surveillance and pursuit missions. The main part of the system is a camera that also has night-vision capacity, depending on the model specifications.

Although the main part is the camera, other parts (components) and devices are included in the system to permit the full use of its functionalities. The technical specifications of the parts (components) and devices that should be purchased and assembled depending on the customer's requirements, which should be carefully analyzed. Even when the design team proceeds carefully, changes driven by factors such as stakeholders' requirements, technology evolution, the internal organization and changes in knowledge regarding the product can occur (Jarratt et al., 2011).

A brief description of the airborne system is as follows. The camera captures the images. If requested by the customer, a searchlight device can be part of the assembly, as it is useful for capturing images in restricted light conditions. Another device, the searchlight controller, synchronizes the camera movements and the searchlight. The commands for the camera movements are made by a joystick-controlled by a human user. Screens are required to see the images that are being captured by the camera, and the quantity of screens also depends on the customer's requirements. If the customer wants to record the images, a recorder device is required, and/or if the customer wants to transmit the images in real-time to another remote screen, a downlink device must be part of the assembly. All these devices are interconnected by electrical harnesses. The mechanical mounting should also be taken into consideration, primarily for the camera and the searchlight, which are large devices attached to the outside of the aircraft. Considering all these aspects, this airborne system meets the definition of a complex system.

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