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INTEGRATED POSTPONEMENT AND CONCURRENT ENGINEERING APPLIED TO THE AEROSPACE INDUSTRY

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Abstract:
This paper aims to develop, demonstrate and justify a quantitative method that evaluates if the postponement strategy is worth applying for an aerospace company and determine the best time to make the main decisions during the product development project. This method also intends to identify the best kind and optimal level of postponement that should be adopted to promote production cost reduction, improving customer service, offering short times of delivery and increasing the overall program profit.
Keywords: Postponement; Concurrent Engineering; Competitiveness.

1 Introduction

Nowadays companies must adopt strategies to address new global market needs. This work deals specifically with the aerospace market, where the competition is very high and the customers want customized products, short delivery times and low price. These combined with high uncertainty scenario makes the demand forecast a very hard task (AME Info, 2004).

If a company makes a bad demand forecast, this often will generate changes in the schedule of customer orders, and it will cause discontinuities in the assembly line to reconfigure aircrafts, affecting the planning capacity (IYER *et al.*, 2002) and increasing production costs. On the other hand, if the company offers a high level of product customization, the cost with reconfigurations increases.

Therefore, to keep itself competitive at the global market, the company must avoid the occurrence of aircraft's reconfigurations, adopting a strategy to make its customization process more flexible, postponing the product configuration to as late as possible in the production phase (CUNHA, 2002). This reduces production costs, improves customer service as delivery time is shortened and increases the overall program profit. This strategy is named postponement: an operational concept that consists of delaying the product configuration until the actual customer demand is known (SAMPAIO *et al.*, 2003).

Rarely, authors mention the relationship between postponement and concurrent engineering; however this is an important requirement for the implementation of this strategy. The strategy addresses the following issues:

- integration among different technical areas such as Product Engineering, Process Engineering, Logistics and Sales Department;
- main factors that affect the customer needs (PRATS *et al.*, 2003): 1) the aircraft's operational cost, 2) the number of optional items offered to the customer and 3) the aircraft's delivery time.
- some factors affecting costs: 1) inventory levels may change (LEMBKE *et al.*, 2004 and GRAMAN, 2002), 2) high value added items may be installed earlier or 3) design solutions may affect the product cost.

Considering these characteristics, a company may create many alternatives of product design and manufacturing processes to implement postponement (SM Thacker and Associates, 2000), for example: applying design modularization (BULLOCK, 2002); constraining the number of optional items (WALLER *et al.*, 2000); employing buffers for the component bottlenecks or reorganizing manufacturing processes to install the parts that configure the product as late as possible.

The work described herein has identified some concurrent engineering tools that may help to make decisions at the right time and choose the best product alternative: these are: Design to Cost (DTC), Quality Function Deployment (QFD), Decision Trees (BECKMAN, 2000 and RAIFFA, 1970), Multi-criteria Systems, Design Structure Matrix

(DSM) and Critical Path Method (CPM). This paper proposes a quantitative postponement method that makes an adapted and systematic use of those tools, provides an example of application and discusses the effect of such method on cost reduction and customer satisfaction.

2 Method

Figure 1 provides an overview of the method proposed and demonstrated in this paper. This section details each box in Figure 1.

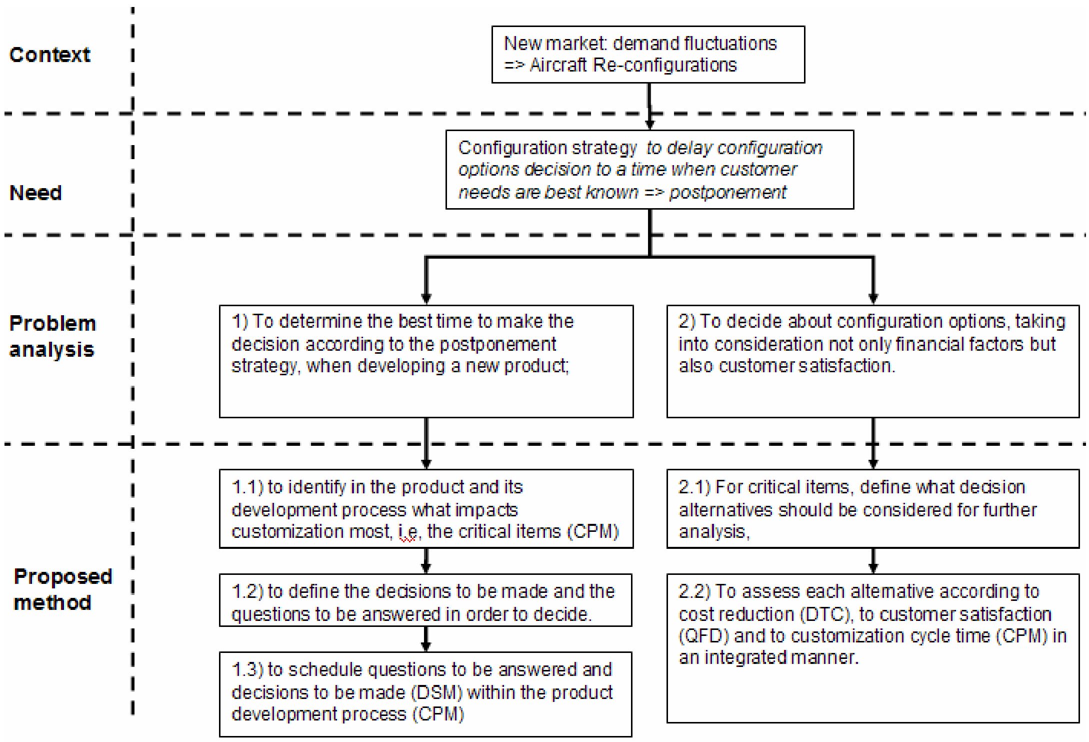

Figure 1: An overview of the proposed method.

The problem to be tackled can be divided into two parts. The first is related to the accomplishment of an important milestone in an aircraft development process: to use or not the postponement strategy to produce an aircraft. The second part consists in supporting the decision made, through the choice of the best design alternative, which presents lower cost, while keeping focus on customer needs. The present work focuses on the first part of the problem.

There are three kinds of elements in a decision making process: milestones, decisions and questions, and they relate to each other as following (NASA, 2005):

- The milestones accomplishments depend on the decisions made;
- Decisions depend on the answer of some questions;
- Also, milestones may depend on other milestones, decisions may depend on other decisions and questions may affect each other.

As shown in Box 1.1 of Figure 1, CPM will be used in the aircraft manufacturing network to identify the most critical items that contribute to increase the customization cycle time. After that, questions and decisions related with these items design and manufacturing will be formulated.

The numerical DSM activity-based tool can be used to create the relationships among these elements and rank them according to a priority criterion. In this work, a DSM adaptation is required to define each activity time length, instead of priority relationships (HOFFMEISTER, 2003). The CPM was selected to determine the best time each element takes place in a new aircraft development project (PERALTA, 2002). CPM can be used because the statistical variance of the activity durations is insignificant (DARCI, 2004). The Primavera Project Planner (P3) has been used to implement CPM (Primavera Project Planner manual, 1997). As shown in Box 1.3 of Figure 1, the Numerical-DSM is used and its results are input to P3 to generate the project activities programming (PERALTA *et al.*, 2003). After this precedence network is calculated, it is related with a product development plan to determine the ideal schedule to answer each question, to make the decisions and to accomplish the milestones, without affecting the program end date. Thus, the architecture to solve the first part of the problem is ready.

The second part of the problem (see Box 2 of Figure 1) integrates CPM, QFD, DTC and the Total Probability Theorem.

With CPM, the precedence network of the aircraft manufacturing and assembly processes is developed (SOUZA, 2000) as depicted in Figure 2. The level of postponement is calculated based on:

$$C_{custom} = C_{cm} + C_{ca} \quad (1)$$

where,

C_{custom} = aircraft customization cycle time [days]

C_{cm} = customization cycle time for manufacturing [days]

C_{ca} = customization cycle time for assembly [days]

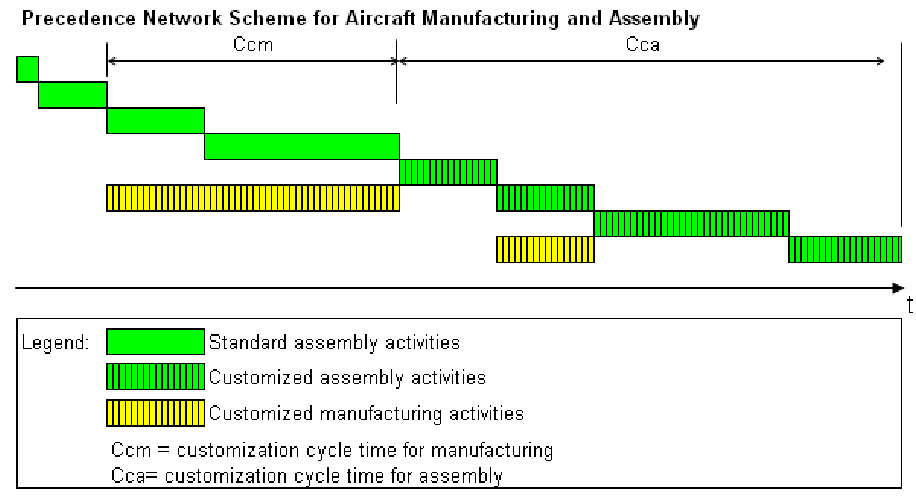

Figure 2: Aircraft's customization cycle time.

The Total Probability Theorem (BECKMAN, 2000) helps to define the optional kits for the aircraft and the QFD and DTC tools will help to determine the best aircraft design and manufacturing alternative according to cost constraints and customer needs.

3 Case Study

Applying CPM to the aircraft manufacturing and assembly process, allows the definition of the most critical aircraft components, which increases the value of C_{custom} (PINEDO, 2002). They are: main hardness, furnishings (interiors) and electronics equipments (such as avionics, entertainment options) - see Table 1. After the identification of these items, some questions and decisions are formulated about how the design and manufacturing of these components can contribute to reduce C_{custom}. The answers for these questions and the decisions made define the level of postponement is used to produce the aircraft. Table 1 lists those questions and decisions.

Table 1: Questions and decisions list.

Code	Description	Technical Area
D1	**Hardness: Standard; customized; standard in cockpit and customized in fuselage.**	
Q1	Is it technically possible? (Weight, fabrication, assembly)	System Eng, Weight, Manufacturing
Q2	Is it profitable? (Trade-off)	Process Eng and Supply
Q3	Do the customization cycle time reduce?	Process Engineering
Q4	Is the customer needs affected? (Positive, negative, how much?)	Market and Sales Department
Q5	Is the fabrication lead time so far?	Process Eng and Supply
D2	**Interiors: Standard; customized; standard cockpit and customized PAX cabin.**	
Q1	Is it technically possible? (Weight, fabrication, assembly)	System Eng, Weight, Manufacturing
Q2	Is it profitable? (Trade-off)	Process Eng and Supply
Q3	Do the customization cycle time reduce?	Process Engineering
Q4	Is the customer needs affected? (Positive, negative, how much?)	Market and Sales Department
Q5	Is the fabrication lead time so far?	Process Eng and Supply
D3	**Number of optional items: constrained or not constrained.**	
Q6	How many optional items?	System Eng and Market Dep.
Q7	Which optional items will be offered?	System Eng and Market Dep.
Q8	How to determine? (Total Probability Theorem)	Process Engineering and Market
Q9	Is the customer needs affected? (Positive, negative, how much?)	Market Department
Q10	Will the kits be created?	Process Engineering and Market
D4	**Production buffers: to use or not?**	
Q5	Is the fabrication lead time so far?	Process Engineering
Q11	Is it profitable? (Trade-off)	Process Engineering

Next, DSM is used to determine the relationships among questions and decisions. The first configuration of DSM elements generated a lot of interactions that usually increase cycle time and project cost. To optimize the DSM elements sequence, the Partitioning Algorithm (MIT and UIUC DSM Research Teams, 2003) has been used. The resulting Numerical DSM, with activity durations (in weeks) in the matrix main diagonal, is presented in Table 2.

Table 2: Final DSM after Partition Algorithm applying and times attribution.

	Q1	Q2	Q3	Q5	Q8	Q4	Q6	Q7	Q9	Q10	Q11	D1	D2	D3	D4
Q1	10														
Q2		5													
Q3			4												
Q5				6											
Q8					7										
Q4			X			8									
Q6					X		10								
Q7							X	7							
Q9					X		X	X	5	X					
Q10					X		X	X	X	2					
Q11					X		X	X			6				
D1	X	X	X	X		X						8			
D2	X	X	X	X		X							4		
D3					X		X	X	X	X				1	
D4	X			X			X	X		X	X	X	X	X	4

After that, the DSM data is transferred to the P3 software, to calculate the precedence network and incorporate it into the product development plan. The best time for the questions and postponement decisions to happen is, therefore, determined. Figure 3 shows the Gantt chart for the questions, decisions and the product development phases. Figure 3, does not present numerical values to preserve the company's confidential information.

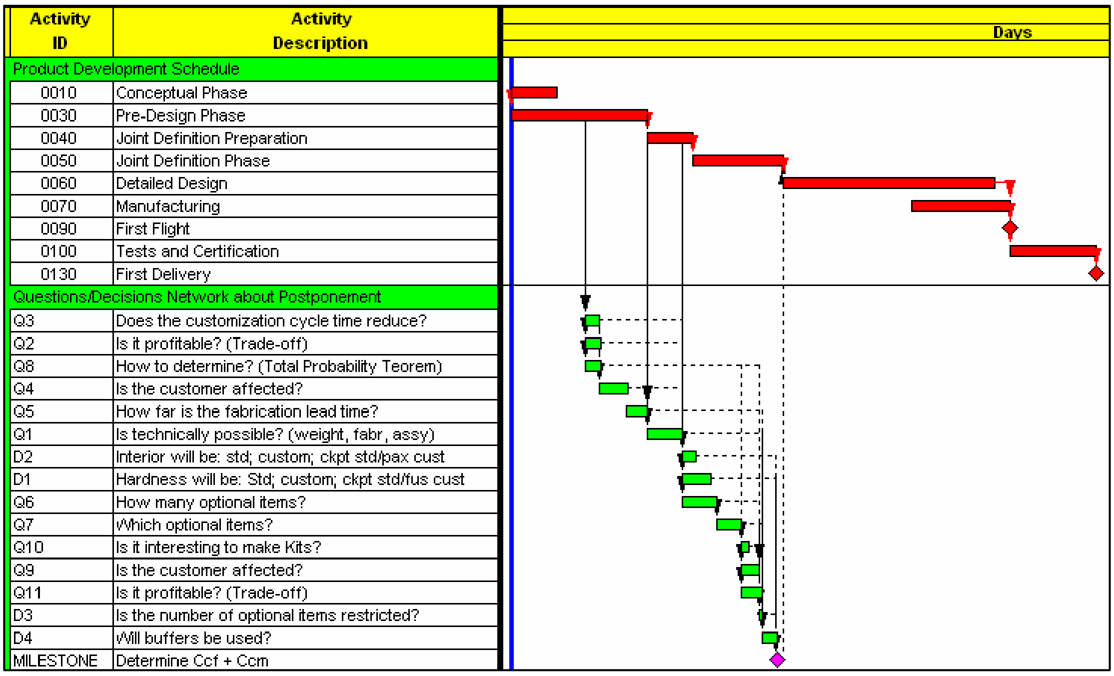

Figure 3: Network for questions, decisions and product development

The questions shall be answered considering the program cost constraints and customer needs. To do that, techniques such as QFD and DTC will be used.

As can be observed in Figure 4, the first QFD matrix relates the aircraft design and manufacturing requirements (System Requirements) with the Customer Needs; the second QFD matrix, the design and manufacturing characteristics of the critical components (Parts Characteristics), with the System Requirements. Finally, the DTC matrix helps to make the System Requirements cost estimation from Parts Characteristics. Then, this estimated cost is compared with the program target cost, weighted according to how customer values their needs accomplishments. Therefore, it is possible to choose the best design alternative according to costs constraints and customer requirements.

QFD Matriz 1

Customer Requirements	System Requirements: Light weight aircraft	Wide scale production	Flexible assembly line	Low n° of components	Standard assemblies
Low operational cost	9				
Short delivery times		9	9		3
High offer of optional items	3	1	3	1	1
Simple maintenance				3	
Simple inspection	1	1		9	1
Quality	1	1	1	3	9
PA_{RS}	2,36	3,64	3,85	1,54	2,97
PR_{RS}	16,43%	25,37%	26,78%	10,71%	20,71%

QFD Matriz 2

System Requirements	Parts Characteristics: Custom. Hardness	Custom structure at Structural Completion	Custom interior at Final Assy	No interior stock	No optional equip. stock
Light weight aircraft	9	3			
Wide scale production			1		
Flexible assembly line		1			
Low n° of components	3	1	1		
Standard assemblies		1			
G	5	3	4	4	4
PA_{CP}	9,00	3,22	1,44	0,00	0,00
PR_{CP}	65,85%	23,59%	10,56%	0,00%	0,00%

DTC Matriz

System Requirements	Parts Characteristics: Custom. Hardness		Custom structure at Structural Completion		Custom interior at Final Assy		No interior stock		No optional equip. stock	
Light weight aircraft	1	75144	1	352825	0	0	0	0	0	0
	0,6		0,5				0			
Wide scale production	0	0	0	0	1	98868	0	0	0	0
	0		0		0,2					
Flexible assembly line	0	0	0	0	0	0	0	0	0	0
	0									
Low n° of components	1	50096	1	352825	1	148302	0	0	0	0
	0,4		0,5		0,3					
Standard assemblies	0	0	0	0	1	247170	0	0	0	0
	0		0		0,5					

Figure 4: QFD and DTC matrices scheme.

Combining the options of decisions (listed in Table 1), a lot of design alternatives can be generated for the product and its manufacturing process. This study evaluates only 2 design alternatives. Basically, the set of decisions made for Alternative 1 does not contribute to postponement usage. On the other hand, the set of decisions made for Alternative 2 enable the postponement utilization to produce an aircraft. The alternatives characteristics are shown in Table 3.

Table 3. Characteristics of design alternatives.

ALTERNATIVE 1	ALTERNATIVE 2
Customized hardness	Standard hardness in cockpit and installed during Pre-equipage phase and customized in the fuselage installed during the Final Assembly Phase
Structural customization during the Structural Complementation Phase (best time technically)	Standard fuselage structure
Optional items limits unconstrained	Offered 4 Kits of optional items.
No optional items stock.	Optional items stocked

Table 3. Characteristics of design alternatives. (continuation)

ALTERNATIVE 1	ALTERNATIVE 2
Customized interior and installed during Final Assembly Phase.	Stock for 4 kinds of hardness
No interior items stock.	Standard interior in cockpit and customized in PAX cabin (less optional items => reduced stock)
	Pre-equipage of forward fuselage (to facilitate access to cockpit and to reduce customization cycle time)

According to the precedence network of aircraft manufacturing, related to Alternative 1, the value of $C_{custom\ 1}$ is:

$C_{cm} = C_{cm\ 1}$ [days]
$C_{ca} = C_{ca\ 1}$ [days]
$C_{custom\ 1} = (C_{cm\ 1} + C_{ca\ 1})$

Alternative 1 does not adopt any kind of production buffers to the optional items, then the manufacturing lead times are included in the customization cycle time, significantly increasing it.

According to the precedence network of aircraft manufacturing, related to Alternative 2, the value of $C_{custom\ 2}$ is:

$C_{cm\ 2} = 0$ [day]
$C_{ca\ 2} = (C_{ca\ 1}).0{,}623$ [days]
$C_{custom\ 2} = C_{cm\ 2} + C_{ca\ 2} = 0 + (C_{ca\ 1}).0{,}623$
$C_{custom\ 2} = 0{,}623.(C_{ca\ 1})$ [days]

Alternative 2 proposes to offer optional kits to customer, as in the automotive industry. It was applied the Total Probability Theorem to determine the number of kits and its compositions (BECKMAN *et al.*, 2000).

Table 4: Unconditional probabilities of the optional items.

Optional Items	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13
Probability of a customer to choose the item	85%	11%	5%	12%	0%	50%	11%	5%	6%	10%	8%	79%	13%

Combining the optional items in assembly kits with three items, it was possible to identify the 4 combinations most demanded by the global market: B1B6B12, B1B12B13, B6B12B13 and B1B6B13. Due to the creation of 4 kinds of kits, it is necessary to keep 4 kinds of hardness in stock.

4 Discussion

In the first part of the problem, the DSM method, jointly with the CPM techniques help to determine the best schedule to make the decisions about postponement strategy usage to produce an aircraft, during the product development phase. The results show that the questions Q2, Q3 and Q8 should be answered at the end of the Pre-Design Phase. These questions should not be anticipated, because they depend on some technical information like market requirements, product and manufacturing requirements, defined earlier.

The first decision to be made is D2. This one will occur at the end of the Joint Definition Preparation Phase, because it is a successor of Q1 and depends on the basic information of furnishing supplier.

The other decisions shall be made during the Joint Definition Phase, when the product acquires a greater maturity and the suppliers have more detailed information.

The final milestone, of postponement strategy definition, shall occur until the end of the Joint Definition Phase, because the Detailed Design Phase needs to start with this definition.

In the second part of the problem, by observing the precedence network results for both design alternatives, alternative 2 presents 1413% of customization cycle time reduction if compared with alternative 1. The major part of this gain is due to the strategic buffers usage for the optional items. However, for alternative 2, these stocks are feasible just because the hardness and furnishing design was changed and the creation of optional kits after market statistic study. This action contributed to reduce the number of optional items, eliminating those ones with less demand. Then, the stock size was reduced, decreasing the inventory costs to acceptable levels.

The standard hardness design in cockpit and customized in fuselage, for alternative 2, did not affect the aircraft's weight significantly, because the standard hardness length in cockpit is short, thus the aircraft operational cost was not affected.

The standard cockpit hardness and furnishing design created opportunities to reduce installation times, because the learning curve tends to fall quickly considering that more repeated activities occur.

Alternative 1, although having lower material costs compared with alternative 2, derived a higher total cost, because the non-conformities costs (non standardized design) and aircraft reconfigurations (high customization cycle time) contribute to exceed the target cost.

5 Conclusions

The design alternative 2 revealed that the postponement strategy can be extremely profitable to the company, because it increases significantly its flexibility to meet the demand fluctuations of the global market, reducing high reconfigurations costs, without losing focus on customer needs.

These gains consider only one aircraft. So if considering a high monthly production rate, the gains will be in the order of tens of million dollars.

Conclusions are that the proposed method met the objectives fully. A postponement strategy was defined from the scheduling of decisions, questions and milestones by using DSM. It was integrated into the product development plan by using CPM. Also the best design alternative was determined, not only from a cost point of view, but also according to a customer value point of view by using QFD and DTC.

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