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MAPPING THE STRATEGIC TECHNOLOGICAL AREAS OF THE DESIGN FOR EXCELLENCE (DFX) IN THE AEROSPACE DOMAIN

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Abstract. *The aerospace industry constantly seeks to optimize its product development processes (PDP) to stay competitive in the market. Design for Excellence (DFX) with its various technological areas, tools and methods play an essential role to allow meeting customer expectations while respecting organizational capabilities. However, the quantity and diversity of DFX technological areas and methods make sometimes difficult to the companies to address the appropriate ones for each project. Success in DFX application, keeping product development (PD) within scope, time, cost, and quality while not overloading it by applying, monitoring, and managing too many areas, is sometimes very context dependent, being influenced by the experience of the engineering team as well as the kind of portfolio project. Considering this scenario, the motivation of this work is to perform a first mapping of the technological areas of the DFX, given the problem of the suitable addressing for each kind of project. The objective is to evaluate, according to the point of view of the engineering team itself, if it is possible to define a general approach to guide, at least initially, project managers in selecting the main technological areas of the DFX, given a typical aerospace organization project portfolio as the boundary condition. Departing from the literature review of the main technological areas of DFX used in the aerospace domain, the research is performed by means of a survey with senior engineers and product development managers from a real aerospace company. Then, quantitative results are gathered through the Likert scale, which allows to draw a hierarchization analysis based on the Analytic Hierarchy Process (AHP) method. The representative example portfolio used in this research comprises the following types of projects: Competitiveness, Operational Continuity, Cost Reduction, Customer Request and Product Reliability & Correction. Results evinced that scope, time, cost and quality have the same weight for the organization whereas Design for Testability (DFT), Manufacturing (DFM), and Reliability (DFR) should be the initial choices for both Operational Continuity and Competitiveness project types.*

Keywords: *Design for Excellence (DFX), Integrated Product Development (IPD), Product Development Processes (PDP), Analytical Hierarchy Process (AHP)*

1. INTRODUCTION

Design For X (DFX) is an integrated product development (IPD) framework aimed at helping to overcome the challenges faced by complex product development processes (PDP). DFX provides a structured approach to optimize PDP, by defining clear product requirements, balancing stakeholder expectations and considering various factors impacted by the evolving customer demands (Smith and Johnson, 2020). Considering the aerospace industry faces challenges managing advanced technologies, materials, testing and certification to comply with regulatory standards, DFX methodology is still one of the main approaches to deal with complex systems development (Gupta and Sharma, 2016; Chua and Goh, 2020). It helps to identify potential issues and conflicting requirements early in the design phase, yielding improved product performance while mitigating rework and uncertainty in the PDP (Cooper and Kleinschmidt, 2016; Pinto and Slevin, 2016; Anderson and Thompson, 2018).

However, despite its vitalness to aerospace companies, applying DFX methods and tools often requires investments in new technologies, tools and training programs, so that companies must carefully consider the return on the investment to implement DFX techniques. Integrating DFX methods into the PDP of evolving technologies and ensuring compatibility with existing systems can be complex and resource-intensive (Gupta and Sharma, 2016). In addition, the aerospace industry operates under tight schedules, and delays can have serious consequences. Wrong or inappropriate application of the DFX methods may impact project schedules, as it requires detailed analysis and implementation of design changes, which may impact delivery dates (Chen and Wang, 2017).

Furthermore, the aerospace industry is highly regulated, with strict standards and certifications. The companies are subject to regulatory framework, such as those imposed by FAA and EASA, which cover a broad range of aspects such as safety, performance, emissions, and noise. Incorporating DFX techniques to comply with these regulations can be challenging due to the potential conflicts and the need to change established design practices (Williams and Davis, 2019). Therefore, companies must ensure that their design decisions meet regulatory requirements without compromising the overall performance and quality of their PDP.

A successful DFX implementation also requires the collaboration of various stakeholders, including designers, manufacturing experts, suppliers and regulators. Since it requires expertise in multiple areas, communication gaps, differing priorities, and lack of coordination among these stakeholders can pose significant challenges (Kim and Lee, 2018). The aerospace industry itself faces the challenge of bridging the skills from design, manufacturing, materials, and regulation, as DFX practice requires a holistic understanding of the product lifecycle and interdisciplinary collaboration (Brown and Collins, 2017).

Furthermore, although not less important, implementing DFX tools often requires the use of advanced tools to support the design and manufacturing. The incorporation of such tools and methods is challenged by the industry's complex product structure and long development cycles, which impair the effective adaption of new PDP strategies. The industry may also have difficulties in integrating these technologies due to factors such as high cost or even extensive training needs (Wang and Zhang, 2019). Giving this context, companies should invest not only in training programs, knowledge-sharing platforms, and collaborative initiatives, but also endeavor in-deep and time-to-time analyses to properly upskill their workforce, considering their portfolio of projects, which hardly ever are static, as an important boundary condition.

Therefore, the problem addressed in this work is the quantity and diversity of DFX technological areas and methods, which sometimes make it difficult for companies to determine the appropriate ones for each project. Considering these aspects, the main goal of this is to perform a preliminary mapping of the technological areas of the DFX, according to the point of view of the engineering team itself. As a result, it is proposed a general approach to guide project managers for selecting the main technological areas of the DFX. The general guide is applied in a typical aerospace organization project portfolio as the boundary condition addressing for each type of project. (Competitiveness, Operational Continuity, Cost Reduction, Customer Request, and Product Reliability & Correction).

To provide a view on the relevance of such approach, a short overview summary of main recent contributions in this line is presented in Table 1.

Table 1 - Literature Review: recent selected works on DFX technological areas prioritization.

Summary	References
To improve operational efficiency, this study highlights the integration of DFX areas such as design for manufacturability, assembly, and cost to optimize resource allocation during PDP.	Smith et al (2019).
This work proposes a strategic approach for selecting DFXs to optimize resource allocation in new product development.	Chen and Wu (2020).
The article addresses the integration of agile product development with DFX, considering DFX areas such as design for flexibility, scalability, and modularity to enhance resource efficiency in dynamic development environments.	Gupta et al (2021).
This work presents a framework for resource optimization in product development using DFX principles, emphasizing design for sustainability, reliability, and serviceability to achieve effective resource utilization.	Wang et al (2019).
This work examines the maximization of resource utilization through DFX integration in a case study in the electronics industry.	Garcia et al (2018).

The research design advocated in this work is a useful approach to guide, at least initially, project managers in the aerospace domain to select the main technological areas of the DFX, given their typical organization project portfolio. This approach departs from the literature review of the main technological areas of DFX used in the aerospace domain, followed by a contextual survey carried with senior engineers and product development managers from the aerospace sector. Quantitative results are gathered by means of a treatment based on the classical Likert scale (Likert, 1932), which then allow to draw a hierarchization analysis based on the Analytic Hierarchy Process (AHP) method (Saaty, 1990; 2004; 2005; 2008). Both techniques have been widely accepted in the scientific community to perform, respectively, subjective human-based and decision-making research. To the best extent of the knowledge of the authors, this can be considered an innovative contribution that can help to pave the comprehension about managing decision criteria to prioritize strategic technological areas of the DFX in the aerospace domain.

2. MATERIALS AND METHODS

In this section, the techniques, resources, methods and diligences stablished to carry out this work are reviewed, giving emphasis on the revision of a typical aerospace organization project portfolio and of the main DFX technological areas used in the aerospace domain. Then, the methods used along the investigations are briefly reviewed, advocating the assumptions to define questionnaires and the Likert scale for the survey as well as the AHP method steps. The general approach of this work is depicted in
Figure 1.

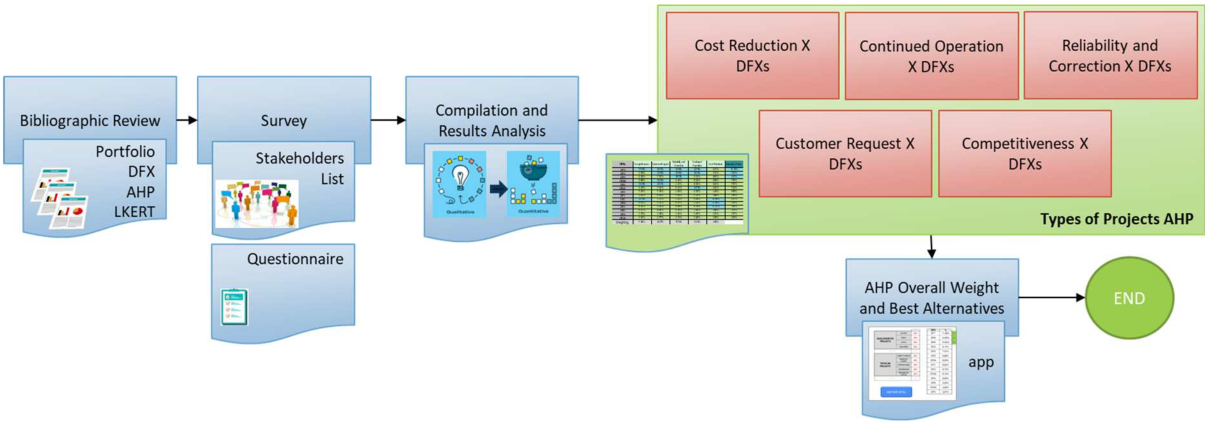

Figure 1. Research approach: it finishes with the preliminary recommendation of the DFXs for each project in portfolio.

2.1 Portfolio Classification

Portfolio classification is of utmost importance in the development and modification of aircrafts for efficient and strategic management in the aerospace industry (Williams and Davis, 2019). By identifying and grouping projects based on their specific objectives and characteristics, companies can gain a comprehensive view of their portfolio and make informed management decisions. Moustafaev (2019) provides insights into portfolio management in various sectors, including aerospace, through specific case studies. Portfolio classification is a critical aspect of strategic and operational management in the aerospace industry, points out the author. By categorizing projects based on their objectives and characteristics, companies can effectively prioritize and manage their portfolios. These are the basic steps used to organize and define the representative example portfolio of projects:

1) **Identification of classification criteria**: The first phase involves identifying classification criteria that helps to evaluate each project. Criteria may include factors such as financial return, strategic alignment, risk, complexity, development time, among others.
2) **Evaluation of projects**: The second phase evaluates each project based on the classification criteria identified in the first phase. This usually involves gathering information about each project, including financial, market, and competition information.
3) **Project classification**: The third phase classifies projects based on the evaluation conducted in the previous phase. Projects are usually grouped into categories such as "high priority," "medium priority," and "low priority."
4) **Review and update**: The last phase reviews and updates periodically the project portfolio classification. As market conditions and strategic priorities change, it is important to regularly review and update the classification to ensure that the selected projects align with the organization's objectives.

According to Moustafaev (2019), company´s management ought to observe the following points in order to classify their respective portfolios, among others: (i) develop new product families; (ii) develop attractive products; (iii) increase revenue and profitability by developing new product families; (iv) increase market share in new markets; (v) expand the product family; (vi) expand into new geographic markets; (vii) enable higher revenue growth. and (viii) implement a rigorous project portfolio management system to prioritize projects and cut low-priority ventures.

Based upon technical conversations with Boeing´s representatives, the authors of this work received the information that the company uses a project classification system known as "Programs and Development Projects". This classification is based on the development stages of aircraft and the key objectives of each project, yielding their main project classification: Program Development Projects (developing new aircraft programs); Program Enhancement Projects (continuous improvements in Boeing's existing aircraft families to enhance the competitiveness and efficiency of aircraft already in production); Modernization and Conversion Projects (modernization and conversion of old or existing aircraft to meet specific customer requirements); Sustainment and Support Projects (ongoing sustainment and support of operational aircraft). Therefore, departing from the Boeing's experience and from the main points analyzed in Moustafaev's book (2019), the portfolio classification used in this paper is summarized in Table 2.

Table 2 - Representative example portfolio used in this study.

Types of Projects	Brief Description
Competitiveness Projects	Improve a company's competitive position in the aerospace industry, involving research and development initiatives to enhance aircraft efficiency, increase performance or introduce new technologies (Raymer, 2012).
Customer Request Projects	Driven by the specific needs of a customer or group of customers, these projects involve customized modifications to existing aircraft (Patel, 2009).
Reliability and Correction Projects	Ensuring aircraft reliability and safety, monitoring activities, performance data analysis, identification and correction of technical issues, and implementation of improvements to increase reliability and reduce failures (Cardoso, 2007).
Cost Reduction Projects	Identify and implement cost reduction opportunities throughout the aircraft lifecycle, involving optimizing production processes, implementing maintenance and repair improvements (Levine, 2014).
Continued Operation Projects	Maintaining the operation and sustainability of in-service aircraft. They may involve regulatory updates, modifications to extend the aircraft's lifespan, and obsolescence management (Shtub et al., 2005).

This project classification for the aerospace industry should allow companies in the sector to have a strategic view of their portfolio, facilitating project prioritization, planning, and execution. Thus, the proposed portfolio is used as the basis for the survey phase of the research, according to the steps detailed as follows.

2.2 DFXs in the Aerospace Domain: an oriented review

Almost any technological area involved in the PDP of a complex system in an aerospace company (Hall, 2019) could give rise to an DFX approach, with its own methods, tools, and guidelines (Gupta and Sharma, 2016). This should at least be circumscribed to those areas or competences that claims for some measure of improvement or quality (Huang, 1996). Table 3 summarizes some pre-selected DFX techniques within aerospace PDPs, and thus they figure in the survey.

Table 3 – Main strategic areas of the DFX considered in the aerospace domain.

DFX Area	Brief Description	Main References
DFT (Design for Testability)	Design a product to be easily tested during the manufacturing/maintenance, playing a critical role in the Verification (VER) and Series (SE) development phases.	Cooper, (1993); Pahl and Beitz, (2013)
DFM (Design for Manufacturing)	Design a product in a way that facilitates and optimizes the manufacturing process. Considered in from the Conceptual Studies (EC) to the Series (SE) development phases.	Pahl and Beitz, (2013); Ulrich and Eppinger, (2015)
DFR (Design for Reliability)	Design a product that is reliable and has an appropriate lifespan. Studies indicate that DFR is particularly important in the Initial Definition (DI) and Detailing (DET) phases.	Pahl and Beitz, (2013); Ulrich and Eppinger, (2015)
DFE (Design for Environment)	Considers minimizing environmental impacts throughout the product's lifecycle, being of great importance in the Preliminary Studies (EP) and Joint Definition (DC) phases.	Pahl and Beitz, (2013); Ulrich and Eppinger, (2015)
DFS (Design for Sustainability)	Incorporates of sustainable practices in product and development. Relevant in the Conceptual Studies (EC) and Pre-Operation (POP) development phases.	Pahl and Beitz, (2013); Ulrich and Eppinger, (2015).
DFDA (Design for Disassembly)	Design a product that is easy to disassembly, being relevant in the Joint Definition (DC) and Detailing (DET) development phases.	Pahl and Beitz, (2013); Ulrich and Eppinger, (2015).
DFSS (Design for Six Sigma)	Apply Six Sigma principles and methods in product design. Interesting in the Verification (VER) development phase.	Antony, (2014); Pahl and Beitz, (2013)
DFQ (Design for Quality)	Design products incorporating quality characteristics, being highly relevant in all development phases, especially in the Initial Definition (DI) and Verification (VER) phases.	Pahl and Beitz, (2013); Ulrich and Eppinger, (2015).

DFA (Design for Assembly)	Design a product that is easy to assembly, being in almost all the development phases.	Boothroyd et al., (2010); Pahl and Beitz, (2013).
DFN (Design for Network)	Considers the interoperability and connectivity interactions of the product in communication networks. It is relevant in the Joint Definition (DC) and Verification (VER) phases.	Pahl and Beitz, (2013); Ulrich and Eppinger, (2015).
DTC (Design to Cost)	Design a product emphasizing strictly the importance of controlling and optimizing costs throughout the entire development process.	Pahl and Beitz, (2013); Ulrich and Eppinger, (2015).
DFMt (Design for Maintainability)	Design a product easy for maintenance and repair, being particularly relevant in the Verification (VER) and Series (SE) development phases, minimizing product downtime.	Pahl and Beitz, (2013); Ulrich and Eppinger, (2015).
DFO (Design for Operation)	Design a product considering its operational efficiency and effectiveness, being indicated in the Initial Definition (DI) and Pre-Operation (POP) development phases.	Pahl and Beitz, (2013); Ulrich and Eppinger, (2015).
DFB (Design for Business)	Design a product considering commercial and strategic aspects, mainly to strictly align the development with business objectives and market needs.	Pahl and Beitz, (2013); Ulrich and Eppinger, (2015).

Although not all the DFX technological areas presented above could encounter immediate resonance to manager engineers, Pahl & Beitz (2013) highlights the interesting aspect of their affinity with the phases of the product development lifecycle. Table 3 gives rise to a good scenario for the survey carried in the first phase of this present paper, as it is detailed in the following.

3. METHODS

3.1 Survey structure: Likert-based questionnaries

The assumptions to define questionnaires and the Likert scale used in the survey carried out with experts from the aerospace industry are detailed as follows. The first step is set a consulting research based on a questionnaire to relate the project portfolio to the DFX technological areas. This is to achieve the first goal of this paper, i.e., providing expert knowledge on the suitability of each method in each situation. It was applied using Google® Forms to a sample of professionals. The mapping is guided asking the participants to relate each of the 5 predefined project types (Table 2) with each of the 14 preselected technological area(s) of the DFX (Table 3) in terms of suitability. A sample of a question like "Considering Design for X (DFX), indicate the suitability for each Project Type", as depicted in Figure 2.


Considerando o DFT (Design for TESTABILITY), indique para cada Tipo de Projeto sua respectiva adequabilidade. *

	Não Recomend...	Pouco Recome...	Recomendado	Muito Recomen...	Extremamente ...
Competitividade	○	○	○	○	○
Pedido de Cliente	○	○	○	○	○
Confiabilidade	○	○	○	○	○
Continuidade da...	○	○	○	○	○
Redução de Cu...	○	○	○	○	○

Figure 2. Sample of the questionnaire used in the survey with experts from the aerospace industry.

The sample consists of a selective and chosen audience composed solely of experienced aerospace professionals, such as senior engineers, program managers, product development managers, quality managers and manufacturing managers. The average time to reach a senior design engineer or manager position in the aerospace industry depends on the company policies and candidate's experience and skills. This position typically requires approximately 10-15 years of engineering experience. Some companies may even require certification in certain areas. The questionnaire was submitted to 150 professional seniors: out of them, 50 respondents fully answered the form.

To bring the survey from the qualitative to a quantitative basis derating subjectivity, it is used the Likert Scale (1932). It consists of classical psychological grading scale widely recognized as a beginner, though effective, measurement technique for evaluating attitudes, opinions, and perceptions, capturing the intensity and direction of participants' opinions on the topic being researched. The scale comprises a series of statements in which participants are asked to rate on a continuum of responses ranging from "strongly disagree" to "strongly agree". In this paper, it is adapted a five-level o Likert Scale, such as summarized in Table 4.

Table 4 – Likert scale used in to quantize expert opinions in the survey.

LIKERT SCALE		PAPER SCALE	
Strongly disagree	1	Not Recommended	0
Disagree	2	Slightly Recommended	1
Neutral	3	Recommended	2
Agree	4	Highly Recommended	3
Strongly agree	5	Extremely Recommended	4

To reach the goal of capturing the intensity and direction of participants' opinions about the DFX technological area vs project type, the overall sum of the related grades issued by the participants is carried out. Because of that, one can notice the use of the grade 0 (and not 1) to convert the "not recommended" answer, valuing the important knowledge of the expert recording its absolute deterrence on the use of that DFX method in that given specific context.

3.2 Analytic Hierarchy Process (AHP)

The AHP (Analytic Hierarchy Process) method is used to make complex decisions that involve multiple criteria and alternatives. It is used in this paper to take advantage of the expert knowledge obtained from the survey detailed in subsection 3.1 to build a generic decision workflow that allows to hierarchize strategic DFX technological areas according to the type of project. It was developed by Thomas L. Saaty and is widely applied in various fields such as management, engineering, economics, and operations research (Saaty, 1990; 2004; 2005; 2008; Saaty and Vargas, 1990; 2012).

In this method, a simple hierarchical model consists of goal, criteria and alternatives. AHP is composed of several previously existing but unassociated concepts and techniques, such as hierarchical structuring, pair-wise comparisons, the eigen-vector method for deriving weights and consistency considerations. Basically, according to Saaty (1990; 2004; 2005; 2008), AHP has three main phases:

1) **Decomposing**: the elements of decision problem are arranged in form of hierarchy. The top elements of hierarchy are overall goal, the next level is the criteria which impact the goal directly, the next level is the operational sub-criteria, against which the decision alternatives of the lowest level of hierarchy can be evaluated and all the elements of a given level are assumed to be mutually independent.
2) **Comparative Judgements**: elements of one level of a hierarchy are compared pairwise as to the strength of their influence on an element of the next higher level. Saaty has suggested a scale of 1 to 15 when comparing two elements, with a score of 1 representing indifference between the two elements and 15 representing the overwhelming dominance of that element over the other. These comparisons lead to dominance matrices which are called pair-wise comparison matrices.
3) **Synthesizing**: The next phase is to synthesize the priorities, the simple hierarchical model which evaluates alternatives with respects to criteria and sub-criteria of overall goal. The priorities of all alternatives with respect to each criterion are calculated. The overall priorities weights are calculated from pair-wise comparison matrix.

Figure 3 summarizes in a *Flow Chart* how the AHP steps are used in this paper. After these steps are used using quantized data from the survey, the consistency of the analysis is to be checked by means of a metric called *Consistency Ratio* (**CR**). The value of all pair-wise comparison matrix should be lower than 0.1, indicating that the expert's judgements/weights allotted are reasonable. To calculate the consistency ratio, first determine the *degree of consistency* (**CI**) which can be estimated from the eigen-value λ_max obtained from the comparison matrices, and N is the order of the matrix.

The degree of consistency (**CI**) is estimated as in Eq. (1).

$$CI = (\lambda\_max - N) / (N - 1) \quad (1)$$

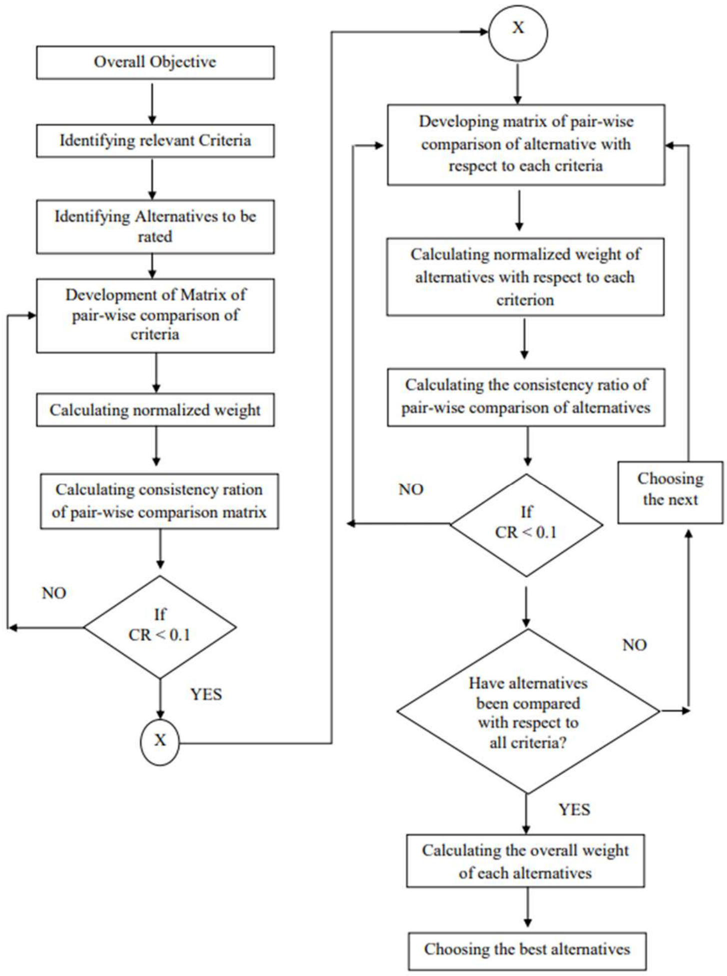

Figure 3.Flow Chart of the AHP method used in this paper.

Then, consistency ratio (CR) can be calculated from the relation of the consistency index (CI) and the *random consistency index* (**RI**), as in Eq. (2).

$$CR = CI / RI \tag{2}$$

Where the RI value is obtained from Table 5, which depends on the value of *N*, i.e., the number of alternatives being compared in the AHP context (in this work they comprehend the DFX technological areas). In this this study, since has 14 different DFX, the RI is 1,57.

Table 5. Random Consistency Index (RI) value according to the number of alternatives (*N*) (Saaty, 1991).

RI _ Randomic Index - SAATY (1991)														
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0,00	0,00	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49	1,51	1,48	1,46	1,57	1,59

4. RESULTS

The answers and grades gathered from the questionaries according to the procedure detailed in the section 3.1 were processed and converted taking the overall sum of the related grades issued by the participants. The research raw results then obtained are plotted in

Figure 4. This partial result shows that each Project type attains some DFXs to address a better methodology to work with. When analyzing the results using these values, one may notice interesting initial insights delivered by the survey step carried in this work: (i) "Competitiveness Projects" issues importance on DFB and DFO; (ii) “Customer Request Projects” issues emphasis on DFSS, DFQ and DFO; (iii) “Reliability and Correction Projects” attains importance to DFR, DFQ and DFT; (iv) “Continued Operation Projects” seams to put relevance on DFMt, DFO and DFQ; and (v) “Cost Reduction Projects” issues importance DTC, DFM and DFA, as an expert could expect at a glance.

Following the next step of research approach, using the obtained data to apply AHP, started creating the Pair-Wise Comparison of Alternatives (DFXs) per Project Type, as shown in Figure 5.

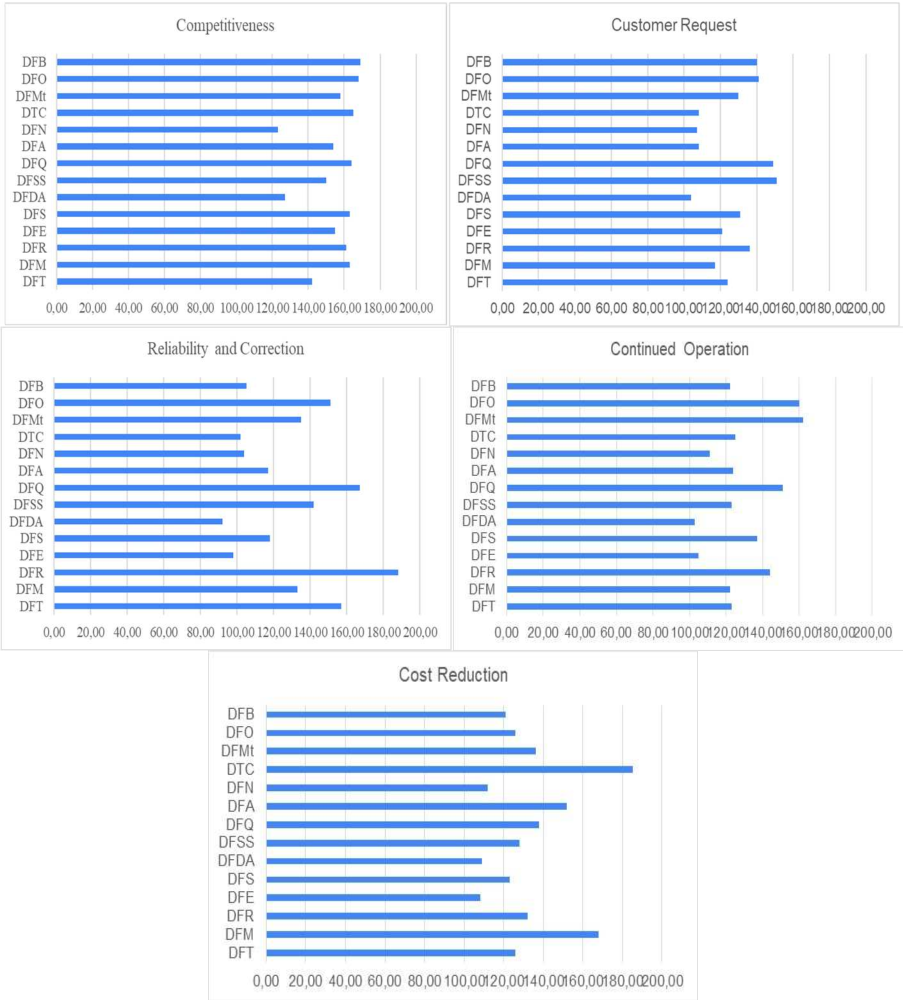

Figure 4.Questionnaire Raw Results per Project Type (sum of the grades rated by the participants).

	Competitiveness													
	DFT	DFM	DFR	DFE	DFS	DFDA	DFSS	DFQ	DFA	DFN	DTC	DFMt	DFO	DFB
DFT	1	2/5	2/5	1/2	2/5	2	1/2	2/5	1/2	2	2/5	2/5	2/5	2/5
DFM	2 1/2	1	1	1	1	2 1/2	1	1/2	1	2 1/2	1/2	1	1/2	1/2
DFR	2 1/2	1	1	1	1/2	2 1/2	1	1/2	1	2 1/2	1/2	1	1/2	1/2
DFE	2	1	1	1	1/2	2	1	1/2	1	2 1/2	1/2	1/2	1/2	1/2
DFS	2 1/2	1	2	2	1	2 1/2	1	1/2	1	2 1/2	1/2	1	1/2	1/2
DFDA	1/2	2/5	2/5	1/2	2/5	1	2/5	1/3	2/5	1	1/3	2/5	1/3	1/3
DFSS	2	1	1	1	1	2 1/2	1	1/2	1/2	2	1/2	1/2	2/5	2/5
DFQ	2 1/2	2	2	2	2	3	2	1	1	2 1/2	1/2	1	1/2	1/2
DFA	2	1	1	1	1	1	2	1	1	2 1/2	1/2	1/2	1/2	1/2
DFN	1/2	2/5	2/5	2/5	2/5	2/5	1/2	2/5	2/5	1	1/3	1/3	1/3	1/3
DTC	2 1/2	2	2	2	2	2	2	2	2	3	1	1	1/2	1/2
DFMt	2 1/2	1	1	2	2	1	2	1	2	3	1	1	1/2	1/2
DFO	2 1/2	2	2	2	2	2	2 1/2	2	2	3	2	2	1	1/2
DFB	2 1/2	2	2	2	2	2	2 1/2	2	2	3	2	2	2	1
SUM	28,00	16,20	17,20	18,40	16,20	26,40	19,40	12,63	15,80	33,00	10,57	12,63	8,47	6,97

	Customer Request													
	DFT	DFM	DFR	DFE	DFS	DFDA	DFSS	DFQ	DFA	DFN	DTC	DFMt	DFO	DFB
DFT	1	1	1/2	1	1/2	2	2/5	2/5	2	2	2	1/2	2/5	2/5
DFM	1	1	2/5	1/2	2/5	2	1/3	1/3	1	1	1	1/2	2/5	2/5
DFR	2	2 1/2	1	2	1	2 1/2	1/2	1/2	2 1/2	2 1/2	2 1/2	1	1/2	1/2
DFE	1	2	1/2	1	1/2	2	2/5	2/5	2	2	2	1/2	2/5	2/5
DFS	2	2 1/2	1	2	1	2 1/2	2/5	2/5	2	2	2	1	1/2	1/2
DFDA	1/2	1/2	2/5	1/2	2/5	1	1/4	1/4	1/2	1/2	1/2	2/5	1/3	1/3
DFSS	2 1/2	3	2	2 1/2	2 1/2	4	1	1	2 1/2	2 1/2	2 1/2	2	1	1
DFQ	2 1/2	3	2	2 1/2	2 1/2	4	1	1	2 1/2	2 1/2	2 1/2	2	1	1
DFA	1/2	1	2/5	1/2	1/2	1/2	2/5	2/5	1	1	1	2/5	1/3	1/3
DFN	1/2	1	2/5	1/2	1/2	1/2	2/5	2/5	1	1	1/2	2/5	1/3	1/3
DTC	1/2	1	2/5	1/2	1/2	1/2	2/5	2/5	1	2	1	2/5	1/3	1/3
DFMt	2	2	1	2	2	1	1/2	1/2	2 1/2	2 1/2	2 1/2	1	1/2	1/2
DFO	2 1/2	2 1/2	2	2 1/2	2 1/2	2	1	1	3	3	3	2	1	1
DFB	2 1/2	2 1/2	2	2 1/2	2 1/2	2	1	1	3	3	3	2	1	1
SUM	21,00	25,50	14,00	20,50	17,30	26,50	7,98	7,98	26,50	27,50	26,00	14,10	8,03	8,03

	Reliability and Correction													
	DFT	DFM	DFR	DFE	DFS	DFDA	DFSS	DFQ	DFA	DFN	DTC	DFMt	DFO	DFB
DFT	1	2	2/5	3	2 1/2	4	1	1/2	2 1/2	3	3	2	1	3
DFM	1/2	1	1/3	2 1/2	2	3	1/2	1/3	2	2 1/2	2 1/2	1/2	2/5	2 1/2
DFR	2 1/2	3	1	4	3	5	2 1/2	2	3	4	4	2 1/2	2	4
DFE	1/3	2/5	1/4	1	2/5	1	1/4	1/5	2/5	1/2	1/2	1/3	1/4	1/2
DFS	2/5	1/2	1/3	2 1/2	1	2 1/2	2/5	1/3	1	2	2	2/5	1/3	2
DFDA	1/4	1/3	1/5	1	2/5	1	1/4	1/5	1/3	2/5	1/2	1/4	1/4	2/5
DFSS	1	2	2/5	4	2 1/2	4	1	2/5	2	2 1/2	2 1/2	1	1/2	2 1/2
DFQ	2	3	1/2	5	3	5	2 1/2	1	2 1/2	3	3	2	1	3
DFA	2/5	1/2	1/3	2 1/2	2 1/2	1	1/2	2/5	1	2	2	2/5	1/3	2
DFN	1/3	2/5	1/4	2	2	1/2	2/5	1/3	1/2	1	1	1/3	1/4	1/2
DTC	1/3	2/5	1/4	2	2	1/2	2/5	1/3	1/2	1	1	1/3	1/4	1/2
DFMt	1/2	2	2/5	3	3	2 1/2	1	1/2	2 1/2	3	3	1	2/5	2 1/2
DFO	1	2 1/2	1/2	4	4	3	2	1	3	4	4	2 1/2	1	3
DFB	1/3	2/5	1/4	2	2	1/2	2/5	1/3	1/2	2	2	2/5	1/3	1
SUM	10,88	18,43	5,40	38,50	30,30	33,50	13,10	7,87	21,73	30,90	31,00	13,95	8,30	27,40

	Continued Operation													
	DFT	DFM	DFR	DFE	DFS	DFDA	DFSS	DFQ	DFA	DFN	DTC	DFMt	DFO	DFB
DFT	1	1	2/5	1	2/5	2	1	2/5	1/2	1	1/2	1/3	1/3	1
DFM	1	1	1/3	1	2/5	2	1/2	2/5	1/2	1	1/2	1/3	1/3	1
DFR	2 1/2	3	1	2 1/2	1	3	2	1	2	2 1/2	2	1/2	1/2	2 1/2
DFE	1	1	2/5	1	2/5	1	1/2	1/3	1/2	1	1/2	1/3	1/3	1/2
DFS	2 1/2	2 1/2	1	2 1/2	1	2 1/2	2	1/2	2	2 1/2	2	2/5	2/5	2
DFDA	1/2	1/2	1/3	1	2/5	1	2/5	1/4	2/5	1/2	2/5	1/4	1/4	2/5
DFSS	1	2	1/2	2	1/2	2 1/2	1	2/5	1/2	1	1/2	1/3	1/3	1
DFQ	2 1/2	2 1/2	1	3	2	4	2 1/2	1	2	2 1/2	2	1/2	1/2	2
DFA	2	2	1/2	2	2	1/2	2	1/2	1	2	1/2	1/3	1/3	1
DFN	1	1	2/5	1	1	2/5	1	2/5	1/2	1	2/5	1/4	1/4	1/2
DTC	2	2	1/2	2	2	1/2	2	1/2	2	2 1/2	1	1/3	1/3	1
DFMt	3	3	2	3	3	2 1/2	3	2	3	4	3	1	1	2 1/2
DFO	3	3	2	3	3	2 1/2	3	2	3	4	3	1	1	2 1/2
DFB	1	1	2/5	2	2	1/2	1	1/2	1	2	1	2/5	2/5	1
SUM	24,00	25,50	10,77	27,00	19,10	24,90	21,90	10,18	18,90	27,50	17,30	6,30	6,30	18,90

	Cost Reduction													
	DFT	DFM	DFR	DFE	DFS	DFDA	DFSS	DFQ	DFA	DFN	DTC	DFMt	DFO	DFB
DFT	1	1/3	1/2	2	1	2	1/2	1/2	2/5	2	1/4	1/2	1	1
DFM	3	1	2 1/2	3	2 1/2	3	2 1/2	2	1	3	1/2	2	2 1/2	2 1/2
DFR	2	2/5	1	2	1	2	1	1/2	2/5	2	1/3	1/2	1	1
DFE	1/2	1/3	1/2	1	2/5	1/2	2/5	1/3	1/3	1/2	1/5	1/3	2/5	2/5
DFS	1	2/5	1	2 1/2	1	2	1/2	2/5	2/5	1	1/4	1/2	1/2	1
DFDA	1/2	1/3	1/2	2	1/2	1	2/5	1/3	1/3	1/2	1/5	2/5	2/5	1/2
DFSS	2	2/5	1	2 1/2	2	2 1/2	1	1/2	2/5	2	1/4	1/2	1	1
DFQ	2	1/2	2	3	2 1/2	3	2	1	1/2	2	1/3	1	1	2
DFA	2 1/2	1	2 1/2	3	3	2 1/2	2 1/2	2	1	2 1/2	2/5	2	2	2 1/2
DFN	1/2	1/3	1/2	2	2	1	1/2	1/2	2/5	1	1/4	2/5	2/5	1/2
DTC	4	2	3	5	5	4	4	3	2 1/2	4	1	2 1/2	3	3
DFMt	2	1/2	2	3	3	2	2	1	1/2	2 1/2	2/5	1	1	2
DFO	1	2/5	1	2 1/2	2 1/2	2	1	1	1/2	2 1/2	1/3	1	1	1
DFB	1	2/5	1	2 1/2	2 1/2	1	1	1/2	2/5	2	1/3	1/2	1	1
SUM	23,00	8,33	19,00	36,00	28,90	28,50	19,30	13,57	9,07	27,50	5,03	13,13	16,20	19,40

Figure 5. AHP Pair-Wise Comparison of Alternatives per Project Type

It is important to highlight that the values depicted inside the matrices' cells in Figure 5 are based on estimate the ratios as numbers using the Fundamental Scale of the AHP by Saaty (1990) shown in Table 6. A judgment is made on a pair of elements with respect to a property they have in common. The smaller element is the unit and one estimates how many times more important, preferable, or likely, more generally "dominant", the other is by using a number from the Fundamental Scale.

Table 6. Fundamental Scale of the AHP

Intensity of Importance	*Definition*
1	Equal importance
2	Weak or slight
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong or demonstrated importance
8	Very, very strong
9	Extreme importance

The following the next steps to use AHP, it is calculated the *Normalized Weights* and check the analysis with the *Consistence Index* (CI). The results pertaining this latter aspect are summarized in Table 7.

Table 7. Consistency check from the use of the AHP Method

	Consistency Check				
	Competitiveness	Customer Request	Reliability and Correction	Continued Operation	Cost Reduction
CI	0,016	0,007	0,039	0,034	0,026
RI	1,570	1,570	1,570	1,570	1,570
CR	1,64%	0,73%	3,92%	3,39%	2,59%
Conclusion	OK	OK	OK	OK	OK

From Table 7, the results of the Consistency Check conducted using the AHP method indicate a satisfactory level of consistency (CR < 0.1 in all the cases). This allows to proceed with the final steps of the AHP methodology, enabling a more in-depth analysis of the relationships between each DFX and the project types.

Next, and final step is to populate the last table with all the normalized values based on DFX and project type. After that, perform the last normalization calculation to obtain the final percentages corresponding to each DFX. This process enables to identify notable trends, as presented in Table 8, which showcases the AHP Overall Weight and Best Alternatives. When analyzing the "Competitiveness" column, it can be noticed that DFB has the highest percentage at 13.35%, closely followed by DFO at 11.99%. This may indicate that these two aspects are highly related to product competitiveness, and the guidelines of these DFX can better direct project managers and the entire team in product development. However, when examining the "Customer Request" column, DFSS and DFQ lead with 12.28%, while DFO and DFB appear in second place, both with 12.01%. These results agree with first analysis of raw data in Figure 4, although they provide a more in-depth view of relative importance between each DFX technological areas in each context.

Table 8. AHP Overall Weight and Best Alternatives.

DFXs	Competitiveness	Customer Request	Reliability and Correction	Continued Operation	Cost Reduction	Normalized Value
DFO	11,99%	12,01%	12,36%	14,70%	6,41%	10,15%
DFQ	8,95%	12,28%	12,98%	10,43%	8,14%	9,74%
DFR	6,26%	7,97%	16,70%	9,81%	5,51%	8,17%
DFSS	5,55%	12,28%	8,46%	5,02%	5,86%	7,99%
DFB	13,35%	12,01%	4,01%	5,54%	5,42%	7,72%
DFMt	8,45%	7,84%	8,14%	14,70%	8,24%	7,40%
DFS	7,28%	7,39%	4,92%	8,76%	4,46%	5,75%
DFT	3,82%	5,26%	9,83%	4,23%	4,65%	4,95%
DTC	10,15%	3,74%	3,32%	6,86%	18,59%	4,41%
DFM	6,48%	4,07%	6,37%	4,02%	12,06%	4,26%
DFA	6,32%	3,48%	5,06%	6,15%	11,41%	3,98%
DFE	5,72%	5,54%	2,39%	3,54%	2,56%	3,73%
DFN	2,75%	3,35%	3,32%	3,57%	3,73%	2,77%
DFDA	2,92%	2,77%	2,13%	2,68%	2,98%	2,20%
Weighting	7,68%	43,07%	17,84%	11,04%	3,59%	

Regarding "Reliability and Correction" projects, DFR stands out with a significant percentage of 16.70%, followed by DFQ with 12.98% and DFO with 12.36%. These results indicate that these three aspects play a crucial role in ensuring product reliability and correction, being DFR the most important. In relation to "Continued Operation" projects, DFMt stands out with 14.70%, followed by DFO with 14.70% and DFQ with 10.43%. These high values suggest that these three aspects are fundamental to ensuring the continuous and efficient operation of products. As for "Cost Reduction," DTC leads with 18.59%, followed by DFM with 12.06% and DFA with 11.41%. These percentages indicate that these three aspects are crucial for reducing costs associated with product development and production.

Finally, in the last column of Table 8, when normalizing all the values by considering all types of projects together, yields one of the most interesting results of this present investigation: DFO at 10.15%, followed by DFQ at 9.74%, and DFR at 8.17%. This represents a strong suggestion that, in general, at a glance, project managers in the aerospace domain could at least start their conceptual phase putting emphasis on the DFX technological areas of quality and operation. However, it should be emphasized again that different aspects of the PDP give rise to varying importance along the project lifecycle course, suggesting the specific weights discussed above to be considered afterwards.

5. CONCLUSIONS

The analysis of the results obtained through the AHP methodology provided a deeper understanding of the relationships between the DFXs and the different types of projects, providing valuable insights for project managers seeking improvements and enhancements. The analyses allowed to identify which aspects are most relevant in terms of competitiveness, customer request, reliability, continuous operation, and cost reduction. In special, it is interesting to observe the main DFX technological areas do not retains absolute but relative importance in each project type context.

For instance, while DTC attains the obvious greater relative importance to projects aimed at “Cost Reduction”, it is not always true for all the situations, attaining only the tertiary emphasis for projects aimed at “Competitiveness”, for instance. Notwithstanding, it is crucial to emphasize that the application of the AHP methodology was essential for a more precise and thorough analysis, enabling decision-making based on quantitative and objective data. For instance, in the last column of Table 8, normalized values by considering all types of projects together, the tendency to the broad direction in the very beginning phase of any project to select DFO (Operation), DFQ (Quality) and DR (Reliability), which evinced the culture of the aerospace domain industries that deals with critical-safety products and systems, which in general claim for high reliability and low tolerance to any kind of faults.

In summary, the conclusions derived from this in-depth analysis of DFXs and their relationship with project types provide a solid framework to guide project managers in the pursuit of better results, being however important to stress that each project and organization may present particularities that should be considered when adapting these guidelines.

This research opens doors for future analyses and practical applications that can further deepen the understanding of the relationships between DFXs and projects, such as discuss the importance of defining DFX (Design for Excellence) during the different phases of product development.

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7. RESPONSIBILITY NOTICE

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