A DFX ATTRIBUTION METHOD APPLIED TO INTEGRATED PRODUCT DEVELOPMENT WITHIN THE AEROSPACE DOMAIN

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Abstract: *The aerospace industry constantly seeks to optimize its product development processes 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 for the companies to address the appropriate ones for each project. Success in DFX application, keeping product development 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 project portfolio or project phase. Considering this scenario, the motivation of this work is to perform a mapping of the technological areas of the DFX, given the decision-making problem of selecting the most appropriate for each kind of project. The objective is to evaluate, according to the point of view of the engineering team, 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, and considering special characteristics in each phase of a project lifecycle. 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 product development engineers from a real aerospace company. Then, quantitative results are gathered through the Likert scale, which allows to draw a hierarchization analysis based on the multicriteria Analytic Hierarchy Process (AHP). A method to indicate the initial choice for the DFX area is presented, which is deemed to be suitable to help project managers and engineers during design of complex products*.

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

1. INTRODUCTION

Integrated product development (IPD) is a collaborative approach that coordinates people, processes, and systems from the initial stages of product conception through to its final production to overcome the challenges faced by complex product development processes (PDPs). It is intended to facilitate concurrent engineering, where tasks are performed in parallel, reducing the product development cost and improving quality (Ulrich & Eppinger, 2019). Design For X (DFX) is an IPD framework aimed at defining clear product requirements, balancing stakeholder expectations, and considering various factors impacted by the evolving customer demands on complex systems (Smith and Johnson, 2020).

In aerospace industry, for instance, managing advanced technologies, materials, testing, and certification impels a strong dependency among these aspects, making DFX approach an indispensable resource to deal with complexity (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). Notwithstanding, applying DFX methods and tools often requires investments in new technologies, tools, or even expensive training programs, so that companies must carefully consider the return on the investment to implement DFX techniques (Gupta and Sharma, 2016).

Integrating DFX methods into the PDP of complex evolving technologies while ensuring compatibility with existing systems can be complex and resource-intensive (Wang and Zhang, 2019). On the one hand, the aerospace industry operates under tight schedules, and 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). On the other hand, the aerospace industry is highly regulated, with strict safety standards and certifications, subjecting companies' PDPs to regulatory frameworks that cover a broad range of aspects such as safety, performance, emissions, and noise, which may be missed in case of lack of integrated thinking. Even so, incorporating DFX techniques to comply with regulations can be challenging due to the need to change established design practices (Williams and Davis, 2019). Therefore, companies must ensure 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 difficult of bridging the skills from design, manufacturing, materials, and regulation, as DFX practice requires a holistic understanding of the product lifecycle and company's project portfolio (Pessôa and Trabasso, 2017).

A theoretical company's project portfolio may comprise, for instance, the following kinds of projects: Competitiveness, Operational Continuity, Cost Reduction, Customer Request, and Product Reliability & Correction. Each of them comprises some set of characteristics that can require a specific kind of DFX approach. The regular PDP lifecycle follows some well-known phases, such as -, but not restricted to - Pre-Development Conceptual Study (PDEC); Pre-Development Studies (PDS); Informational Design (ID); Conceptual Design (CD); Detailed Design (DD); Certification Tests and Analysis (CTA); Production Preparation (PP); Launch and Production (LP). Each phase attains specific goals, tasks, and deliverables that contribute to the overall PDP output (Cooper, 2020). In the daily practice of an aerospace manufacturer, DFX method attribution and selection is equally based on the design needs, PDP performance, and project portfolio and phases. Giving this context, companies should endeavor in-depth analyses to properly consider the portfolio of projects and PDP lifecycle phases, which hardly ever are static.

Considering this scenario, the problem addressed in this work is the determination of the suitable DFX technological areas and methods that can help companies to successfully address the needs of each project type and phase. The main goal herein stated is to perform a preliminary mapping of the technological areas of the DFX, according to the point of view of the engineering experts. Then, a general approach to guide project managers is proposed to help in selecting the main technological areas of the DFX, having a typical aerospace organization project portfolio as the main boundary condition.

To provide an overview on the relevance of this research, a short summary of the main recent contributions in this line in literature is presented in Table 1**Erro! Fonte de referência não encontrada.**.

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).

One can see from these very recent results that research effort has been put on evaluating suitability and proposition of novel DFX areas to different ways of addressing optimized PDP results. Chen and Wu (2020), for instance, proposes a strategic approach for selecting DFXs to optimize resource allocation in new product development, but they did not relate typical project portfolio and design phases.

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 during the PDP in the aerospace domain.

2. MATERIALS AND METHODS

The resources stablished to carry out this work are reviewed in this section, emphasizing the revision of a typical aerospace organization project portfolio, project development phases, project quality criteria and the main DFX technological areas used in the aerospace domain. The methods used along the investigations are briefly reviewed, advocating the assumptions to define questionnaires and the Likert scale for the surveys as well as the AHP method steps. Departing from a base of knowledge built upon these concepts and, in addition, a relevant internal stakeholder's list and project record database of a given aerospace company, the general research approach followed in this work is depicted in Figure 1**Erro! Fonte de referência não encontrada.**. The core of our research approach showed in Figure 1 is the definition of the multicriteria AHP matrix that allows extracting implicit knowledge evoked by expert opinions (collected by means of two specific surveys) considering the individual clustered criteria from: Project Quality AHP; Types of Projects AHP; and Project Phases AHP. In the end, they are also crossed with the AHP Overall Weight method which allows to design an *App* that issues general initial decisions on DFX selection. In the end, to verify the method, perform a *Retrospective Analysis* considering previous selected records of real projects has been carried out.

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. By categorizing projects based on their goals and characteristics, companies can effectively prioritize and manage 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.

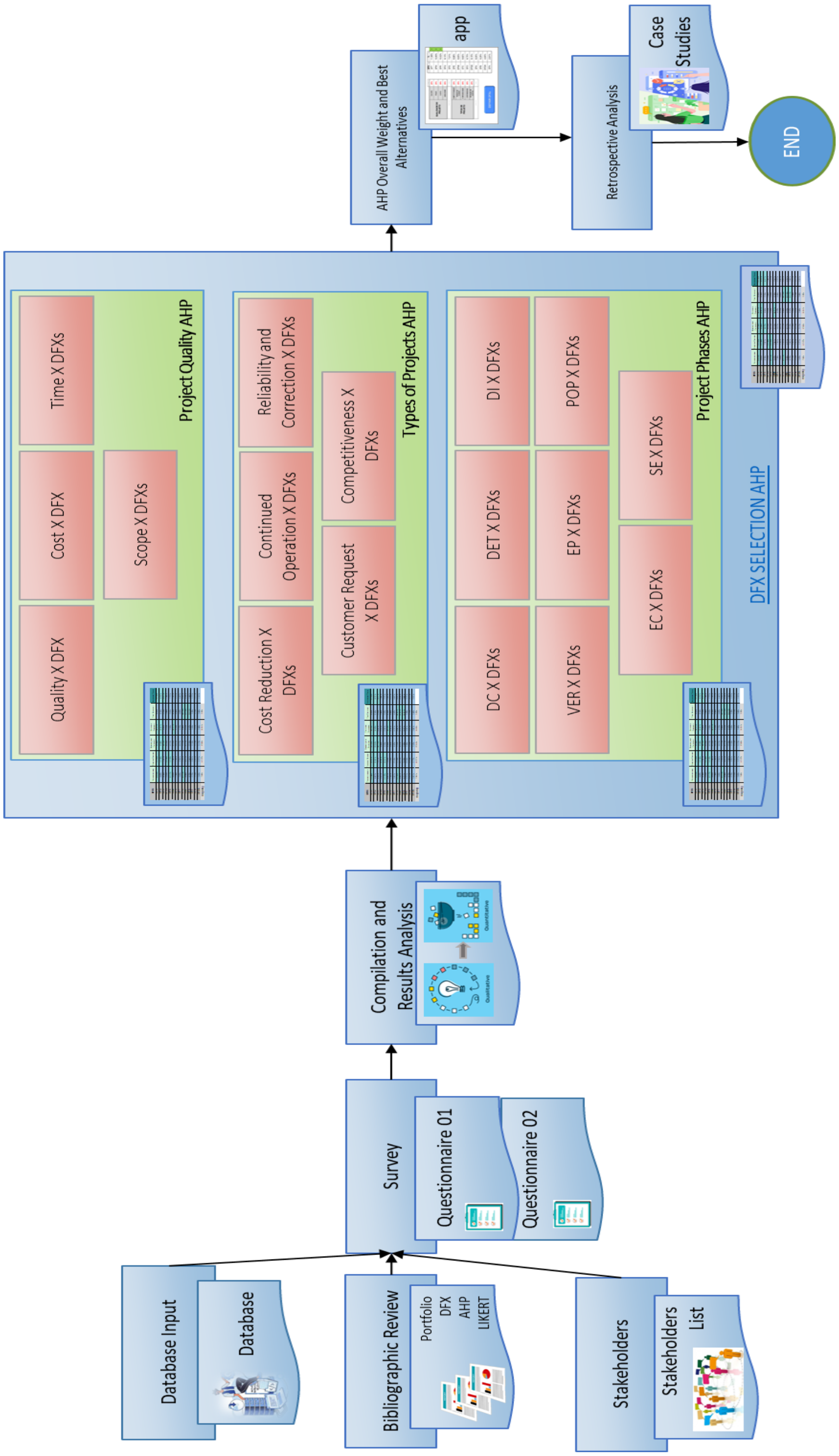


Figure 1. Research approach: it finishes with the recommendation of the DFXs.

In addition, according to Moustafaev (2019), company´s management ought to observe the following points in order to classify their respective portfolios: (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.

Aerospace companies usually adopt a project classification system known as “programs” (set of projects) or specific “development projects”. They base this classification on the development stages of an aircraft and the key objectives of each project. Departing from this “aerospace commonplace knowledge” and from the main recommendations analyzed in Moustafaev's work (2019), the portfolio classification used in this paper is summarized in Table 2, with the indication of a reference where it can be consulted in detail.

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 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 Project Development Phases

In the dynamic realm of PDP, the journey from a nascent idea to a fully operational product involves a series of intricate phases, each marked by specific milestones and evaluations. This process is particularly nuanced in sectors like aerospace, where products are not only highly complex but also subject to stringent safety and quality standards. Figure 2 shows the theoretical sequence of design phases in a common PDP considered in this paper.

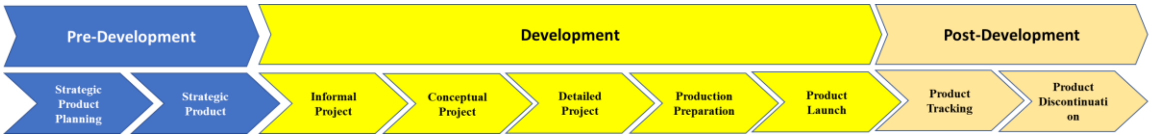


Figure 2. Product Development Phases Process, (Adapted from Rozenfeld *et al.* (2006)).

The product development lifecycle commences with Pre-Development Conceptual Study (PDEC) where market intelligence synergizes with advanced design principles to sow the seeds for innovative products, laying the groundwork for future phases. Pre-Development Studies (PDS) follow, focusing on the critical assessment of a product's technical and economic feasibilities. As the concept solidifies, the Informational Design (ID) takes over, setting concrete goals, objectives, and detailed plans, pivotal for the transition from idea to tangible design. Subsequently, the Conceptual Design (CD) and Detailed Design (DD) further refine the product through collaborative efforts, leading to the creation of prototypes and rigorous design reviews. Post-design, the Certification Tests and Analysis (CTA) stands as the crucible wherein the product is tested against the highest standards, affirming its readiness for real-world application. Table 3 summarizes some of the product development phases considered within this research.

Table 3 – Product development phases considered in this work.

Phase	Description	Key References
Pre-Development Conceptual Study (PDEC)	Identification of new product opportunities; activities include market research, competitive analysis, trend tracking, and brainstorming.	Cooper (1994), Ulrich & Eppinger (2015)
Pre-Development Studies (PDS)	Assessment of technical and economic viability; activities include feasibility studies, cost evaluation, risk assessment, and market studies.	Blank (2013), Pahl & Beitz (2013)
Informational Design (ID)	Submission of business plan for approval; activities include goal setting, requirements definition, in-depth analyses, and conceptual modeling.	Project Management Institute (2017), Pugh (1991)
Conceptual Design (CD)	Detailed project definition: activities include creating product structures, computational models, prototypes, and conducting Preliminary Design Reviews.	Clarkson et al. (2004), NASA (2007)
Detailed Design (DD)	Transformation of designs into components; activities include Critical Design Reviews and initiation of part fabrication.	U.S. Department of Defense (2001)
Certification Tests and Analysis (CTA)	Product testing to meet requirements; activities include in-flight tests, ground assessments, system rig testing, and qualification trials.	Federal Aviation Administration (2011)
Production Preparation (PP)	Preparation for operational debut; activities include finalizing customer support services, crew training, and maintenance.	Aerospace Industries Association (2013)
Launch and Production (LP)	Commencement of large-scale production; activities include addressing customer demands, component obsolescence, regulatory compliance, and engineering modifications.	Trott (2008), Pyzdek & Keller (2009)

As the product approaches completion, the Production Preparation (PP) ensures that all ancillary systems, training, and support structures are operational, paving the way for a smooth Entry into Service (EIS). Finally, the lifecycle culminates with the Launch and Production (LP), marking the commencement of large-scale production, with continual adaptations and improvements in response to evolving customer needs, market trends, and regulatory standards.

This comprehensive framework underscores the multifaceted nature of the PDP, highlighting the need for meticulous planning, cross-functional collaboration, and unwavering commitment to quality and innovation at every stage. A general review of quality criteria to evaluate the PDP output is presented as follows.

2.3 Project Quality (Performance Criteria)

In the contemporary landscape of product development and project management, the quest for optimizing project outcomes necessitates a nuanced understanding of performance criteria. This paper delves into the pivotal role of Design for Excellence (DFX) practices in augmenting project quality across four cardinal dimensions: Scope, Schedule, Cost, and Quality. These dimensions are instrumental in evaluating a project's effectiveness and its alignment with the Product Development Process (PDP).

These practices are integral to optimizing products and processes across various performance criteria, effectively preempting challenges throughout the product development cycle (Brissaud, 2013). Through this discourse, this paper explores how DFX practices contribute to mitigating challenges in these areas, drawing insights from scholarly literature and real-world case studies.

In the challenging field of project management, particularly within product development, the quality of the output is directly influenced by a multitude of performance criteria. To address the intricacies of managing these criteria effectively, Design for Excellence (DFX) practices have been implemented with growing frequency across various industries. DFX encompasses a series of strategies aimed at enhancing various aspects of product development such as manufacturability, testability, reliability, and quality. This integration of DFX practices into project management is not only strategic but also pragmatic in overcoming common obstacles that may hinder a project's success.

Scope pertains to the comprehensiveness of work and specifications required for a product, embodying the challenges that may necessitate rework. Schedule addresses the temporal aspects of product delivery, where complexity necessitates adept coordination across teams. Cost considerations highlight the financial implications of early-stage design decisions, while Quality focuses on fulfilling or surpassing stakeholder expectations. The integration of DFX practices offers a strategic methodology to preemptively mitigate challenges across these dimensions, ensuring project success.

Table 4presents a synthesized view of key performance criteria within project quality management. Each criterion is paired with a description that outlines common challenges faced during project execution. Furthermore, the table identifies specific DFX practices that are effectively utilized to address these challenges, supported by scholarly references that provide deeper insights into these methodologies. This alignment of challenges with DFX practices and supportive literature creates a comprehensive framework for understanding the impact of DFX on project quality. Table 4 synthesizes some insights, presenting a clear linkage between specific DFX practices and the performance criteria they predominantly influence.

Table 4 – Project Quality (Performance Criteria).

Criteria	Description	Key DFX Practices	References
Scope	Challenges in project scope lead to rework. DFX practices mitigate these issues.	DFM, DFT, DFR, DFQ	Haque (2017), Kusiak (2013), Boothroyd et al. (2002)
Schedule	Product development complexity requires multi-team coordination, risking delays. DFX practices help keep projects on schedule.	DFM, DFQ	Azzi & Hansen (2015), Anderson (2014)
Cost	Cost overruns are common due to early-stage design flaws. DFX practices help control costs.	DFM, DFR	Rea & Schmid (2014), Smith & Bliesner (2006)
Quality	Quality affects satisfaction and costs. DFX practices ensure high standards.	DFQ, DFM	Swink et al. (2017), Chowdhury (2002)

The paper further articulates an analysis of each performance criterion, revealing the nuanced impact of DFX practices:

Scope Management: Emphasizes the reduction of rework and delays through early consideration of manufacturability, testability, reliability, and quality. DFM emerges as the most significant practice, followed by DFQ, DFR, and DFT, based on their potential to preempt scope-related challenges.

Schedule Adherence: Illuminates the importance of DFX in maintaining project timelines, with DFM and DFQ identified as critical in mitigating delays through improvements in manufacturability and quality.

Cost Control: Explores how DFX practices, particularly DFM and DFR, play crucial roles in curbing cost overruns by incorporating cost considerations early in the design phase, thus addressing design flaws that could escalate expenses.

Quality Assurance: Underscores the paramount importance of DFQ and DFM in fostering high-quality standards and reducing the likelihood of rework, thereby directly influencing customer satisfaction and project costs.

In conclusion, this paper posits that the meticulous integration of DFX practices into the product development lifecycle can substantially mitigate risks associated with scope, schedule, cost, and quality. Such an integrated approach not only streamlines the product development process but also enhances overall project outcomes, underscoring the indispensability of DFX methodologies in achieving excellence in project management and product development. Through a collaborative and interdisciplinary approach, organizations can harness the full potential of DFX practices to navigate the complexities of modern product development, thereby securing a competitive advantage in the rapidly evolving technological landscape.

2.4 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 a 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 5 summarizes some pre-selected DFX techniques within aerospace PDPs, which will figure in our research in the Survey Phase (refer to Figure 1.)

Table 5 – 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 Certification Tests and Analysis (CTA) and Launch and Production (LP) 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 Pre-Development Conceptual Study (PDEC) to the Launch and Production (LP) 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 Informational Design (ID) and Detailed Design (DD) 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 Pre-Development Studies (PDS) and Conceptual Design (CD) phases.	Pahl and Beitz, (2013); Ulrich and Eppinger, (2015)
DFS (Design for Sustainability)	Incorporates of sustainable practices in product and development. Relevant in the Pre-Development Conceptual Study (PDEC) and Production Preparation (PP) 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 Conceptual Design (CD) and Detailed Design (DD) 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 Certification Tests and Analysis (CTA) 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 Informational Design (ID) and Certification Tests and Analysis (CTA) 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 Conceptual Design (CD) and Certification Tests and Analysis (CTA) 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 Certification Tests and Analysis (CTA) and Launch and Production (LP) 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 Informational Design (ID) and Production Preparation (PP) 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, which is especially important to our research goal. **Erro! Fonte de referência não encontrada.**Table 5 gives rise to a good scenario for the survey carried in the Survey Phase of this work, as it is detailed as following.

2.5 Resources – Database Input (background analysis)

Following the approach depicted in Figure 1, the first step is the definition of a relevant database in which a comprehensive analysis of project performance within the illustrative organizational portfolio defined in Figure 4 is performed, leveraging a set encompassing 346 distinct projects. The evaluation metrics are predicated on four critical dimensions: Quality, Scope, Time, and Costs, with an aggregated status indicator termed "ALL OK?" to signify overall project health. Figure 3 summarizes this initial evaluation on the database.

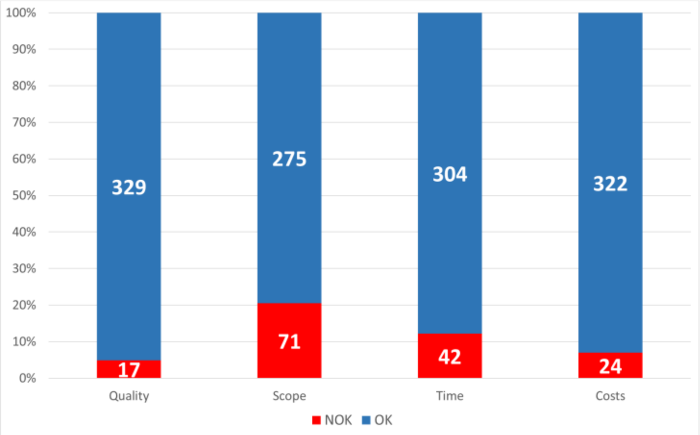


Figure 3 - Overview of background considering the evaluation of each Performance Criteria. If a project is “OK” in a given criteria Scope, Schedule, Cost and Quality, it will figure in the blue count.

An initial appraisal of the dataset reveals a bifurcation in project performance outcomes. A majority, constituting 228 projects, have met the predefined criteria across all dimensions, as indicated by an "OK" status in the "ALL OK?" proposition. Conversely, 118 projects exhibit deficiencies in one or more dimensions, necessitating further scrutiny to identify and address underlying issues.

From Figure 3, a deeper dive into individual performance categories elucidates that Scope is the predominant area of concern, with 71 instances of non-compliance ("NOK"). This is followed by Time, with 42 instances, suggesting a pervasive challenge in adhering to project timelines. The Cost dimension, with 24 instances, and Quality, with 17 instances, reflect comparatively fewer occurrences of non-conformance, though they warrant continuous monitoring and improvement efforts.

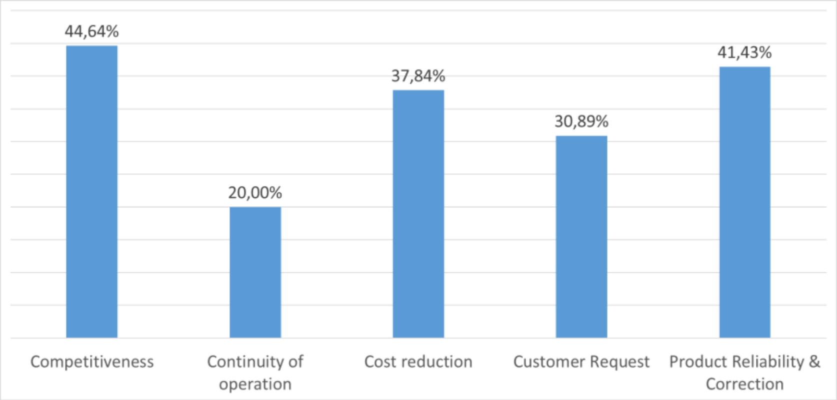


Figure 4 - Overview of background considering the evaluation of each Project Type considered “NOK”

Data shown in Figure 4 reveals that "Competitiveness" challenges are most prevalent, affecting 44.64% of projects. This high incidence rate underscores the imperative for organizations to continually innovate and enhance their product offerings to maintain a competitive edge in the market. It suggests a dynamic environment where the pace of technological advancement and customer expectations necessitates agile and responsive project management strategies.

Following closely, "Product Reliability & Correction" issues impact 41.43% of projects, pointing to the criticality of robust design and quality assurance processes. This statistic highlights the importance of integrating reliability considerations into the product development lifecycle, thereby preempting potential defects and ensuring product integrity.

"Cost reduction" challenges are encountered in 37.84% of projects, reflecting the ongoing pressure to optimize resource allocation and efficiency. This dimension emphasizes the need for strategic cost management practices that do not compromise product quality or customer satisfaction, underpinning the delicate balance between cost-effectiveness and performance excellence.

"Customer Request" related challenges are noted in 30.89% of projects, illustrating the significance of aligning project deliverables with client expectations. This finding reinforces the necessity for effective communication channels and flexible project scopes that can accommodate evolving customer needs.

Lastly, "Continuity of operation" challenges are observed in 20.00% of projects, which although the least frequent, still represent a substantial area of concern. This aspect underscores the importance of ensuring operational resilience and the ability to sustain business functions amidst unforeseen disruptions.

The exploratory investigation into potential correlations suggests that deficiencies in project scope may exert a cascading effect on other dimensions, particularly Time/Schedule. This correlation indicates that inadequate scope definition not only jeopardizes the project's timeline but also influences its competitiveness, reliability, cost-effectiveness, and responsiveness to customer requests. Such interdependencies highlight the interconnected nature of project challenges and the importance of a holistic approach to project management that considers the interplay between scope, schedule, cost, quality, and stakeholder expectations.

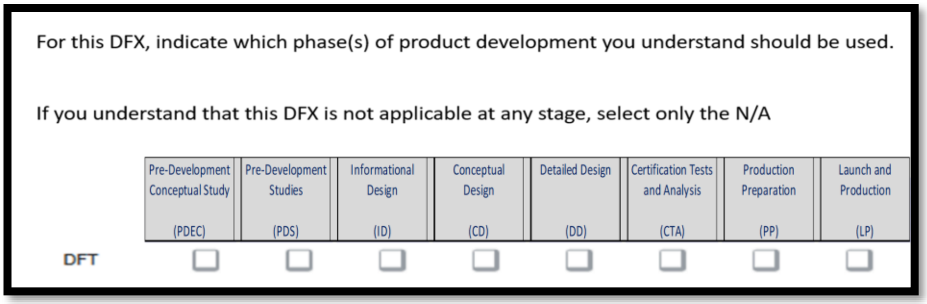
The analysis underscores the interconnected nature of project challenges and the imperative for a holistic management approach that addresses the intricate interplay between scope, schedule, cost, quality, and stakeholder expectations. It highlights the necessity of targeted interventions to address specific areas of concern, particularly in scope and time management, to avert the cascading effects on other project dimensions.

Furthermore, the prevalence of "Competitiveness" and "Product Reliability & Correction" issues accentuates the need for continuous innovation, effective communication channels, and the integration of robust quality assurance processes. Organizations must embrace agile and responsive project management strategies to navigate the dynamic technological landscape and meet evolving customer expectations.

In conclusion, this chapter has elucidated the critical challenges within project management and offers insights into potential strategies for enhancing project outcomes. By recognizing and addressing the root causes of deficiencies across the key dimensions of project performance, organizations can better position themselves for success in the competitive technology and management arena.

2.6 Research Methods – Survey and Likert Psichometric Scale

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 phases 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 by asking the participants to relate, in terms of suitability, each of the 8 predefined project phases (see Table 3) with each of the alternatives of the DFX given in Table 5. A sample of a question like "*For this DFX, indicate which phase(s) of product development you understand should be used*", as depicted in Figure 5



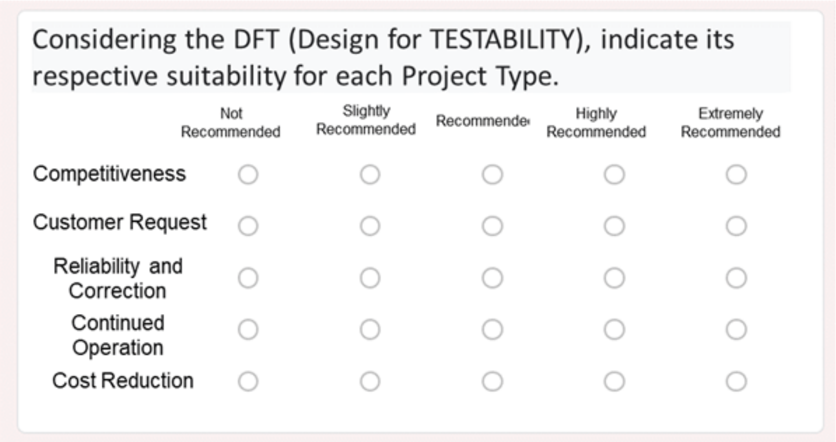
For this DFX, indicate which phase(s) of product development you understand should be used.

If you understand that this DFX is not applicable at any stage, select only the N/A

	Pre-Development Conceptual Study (PDEC)	Pre-Development Studies (PDS)	Informational Design (ID)	Conceptual Design (CD)	Detailed Design (DD)	Certification Tests and Analysis (CTA)	Production Preparation (PP)	Launch and Production (LP)
DFT	☐	☐	☐	☐	☐	☐	☐	☐

Figure 5. Questionnaire used in the survey 01/02 with experts from the aerospace industry to investigate DFX areas subjective importance according to project phases.

The second step is set a consulting research based on a questionnaire to relate the project portfolio to the DFX. This is to achieve the second goal of this paper, i.e., providing expert knowledge on the suitability of each method for each project type. 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**Erro! Fonte de referência não encontrada.** with each of the 14 preselected technological area(s) of the DFX Table 5**Erro! Fonte de referência não encontrada.** in terms of suitability. A sample of a question like "Considering Design for X (DFX), indicate the suitability for each Project Type", is shown in Figure 6.



Considering the DFT (Design for TESTABILITY), indicate its respective suitability for each Project Type.

	Not Recommended	Slightly Recommended	Recommende	Highly Recommended	Extremely Recommended
Competitiveness	○	○	○	○	○
Customer Request	○	○	○	○	○
Reliability and Correction	○	○	○	○	○
Continued Operation	○	○	○	○	○
Cost Reduction	○	○	○	○	○

Figure 6. Questionnaire used in the survey 02/02 with experts from the aerospace industry to investigate DFX areas subjective importance according to project types.

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 questionnaire was submitted to 150 professional seniors: out of them, 50 respondents fully answered the forms. In addition, to concretize the step “Compilation and Results Analysis”, bringing the survey from the qualitative to a quantitative basis and 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 6.

Table 6 – Likert scale used in to quantize expert opinions in the survey.

LIKERT SCALE		**PAPER SCALE (LIKERT 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. RESEARCH METHODS - ANALYTIC HIERARCHY PROCESS (AHP)

The core of the approach presented in this paper is the AHP (Analytic Hierarchy Process) method, which 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 the previous subsection, to build a generic decision workflow that allows hierarchizing 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). Figure 7 summarizes in a *Flow Chart* how the AHP steps are used in this paper.

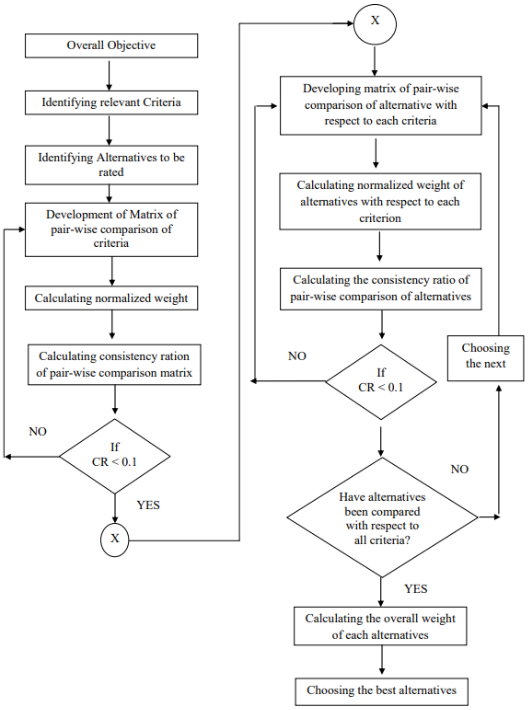


Figure 7. Flow Chart of the AHP method used in this paper.

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 that affect 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.

After these steps are performed 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).

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

Then, consistency ratio (CR) is 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 7, 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 work, since has 14 different DFX, the RI is 1,57.

Table 7. Random Consistency Index (RI) value according to the number of alternatives (N) (Saaty, 1991).

RI _ Average Random Index of AHP as a function of matrix size - 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

This section presents a discussion about the main results of the research, starting with an in-deep analysis of the answers and grades gathered from the survey, according to the procedure described in Section 2.6.

4.1 Raw Results from the Survey

The analyses are initiated by converting the subjective answers to the overall sum of the related grades issued by the participants, considering the Likert scale used in the paper (see Table 6). The raw results obtained are plotted in Figure 8 and Figure 9.

At a glance, one can notice from Figure 8 and Figure 9 that each Project type and Project phases attains some DFXs to be a better method to work with. From Figure 8, one may notice some initial insights delivered by the survey, such as: for Pre-Development Conceptual Study (PDEC), experts issued importance on DFB, DFE and DFS; for Conceptual Design (CD), experts seam to put relevance on DFM, DTC and DFS; and for Launch and Production (LP), experts issues importance to DFQ, DFMt and DFO. These first results are in agreement to what an expert project manager could expect at first.

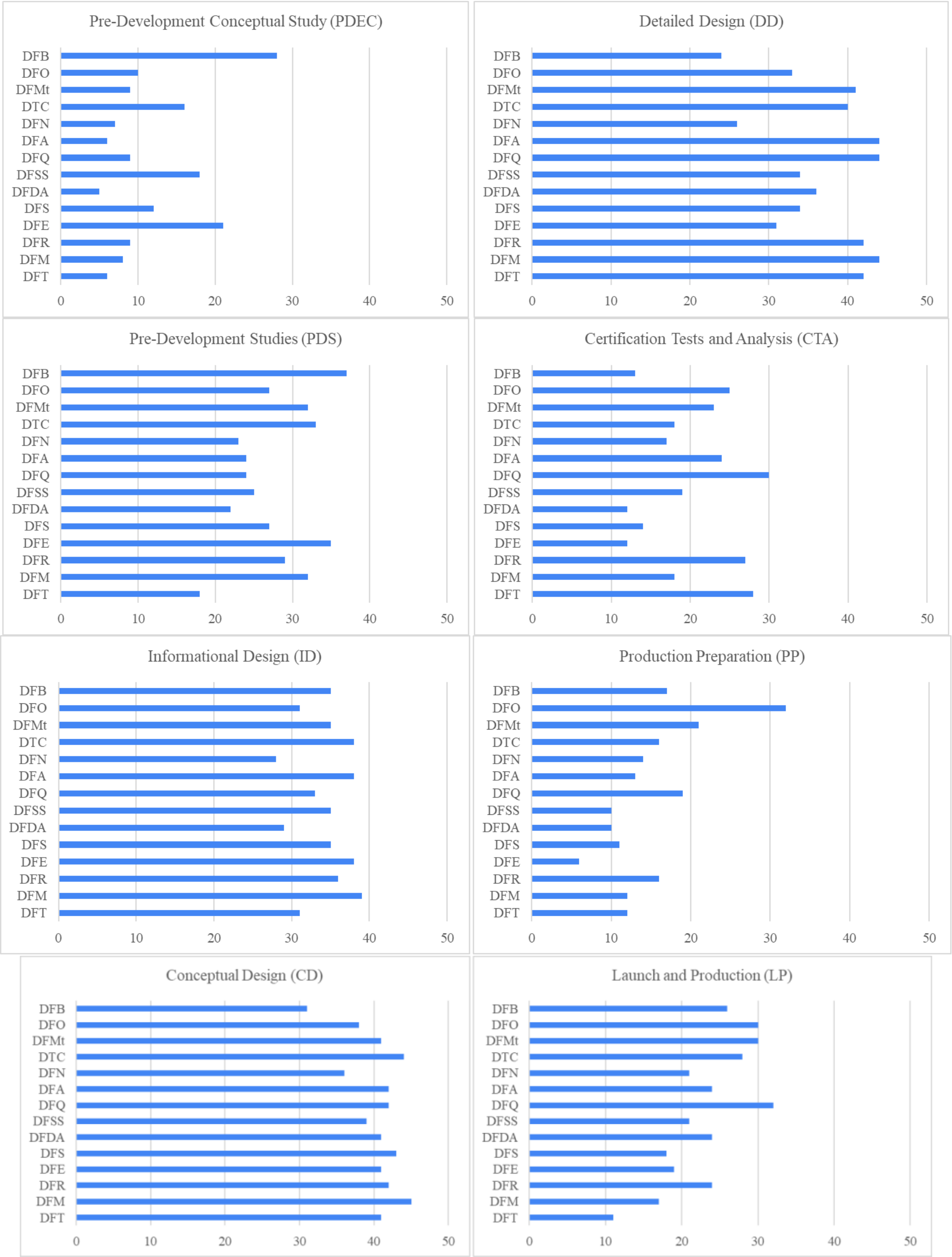
From Figure 9, it is worth noticing another initial insight delivered by the second survey: for "Competitiveness Projects", experts issued importance on DFB and DFO while for “Customer Request Projects”, emphasis is put on DFSS, DFQ and DFO. “Cost Reduction Projects” issues importance on DTC, DFM and DFA, as an expert could expect at first.

4.2 Reduced Data Analyses – AHP Results

Following the next step of the research approach, using the obtained data to apply AHP, it has been created the different Pair-Wise Comparisons of Alternatives (DFXs) per Project Type and per Project Phases. Pair-Wise Comparisons given specific performance criteria (project quality) were also performed to evince implicit cross importance with the Project Type and Project Phases (these is discussed in detail further below). The main Pair-Wise Comparisons matrices obtained are shown in the paper Appendix Section.

It is important to highlight that the values depicted inside the matrices’ cells in the Appendix are based on the estimate of the ratios as numbers using the Fundamental Scale of the AHP by Saaty (1990) shown in Table 8. 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.

The following the next steps to use AHP is to calculate the *Normalized Weights* and check the analysis with the *Consistence Index* (CI). The results pertaining this latter aspect are summarized in Table 9.



Pre-Development Conceptual Study (PDEC)

Detailed Design (DD)

Pre-Development Studies (PDS)

Certification Tests and Analysis (CTA)

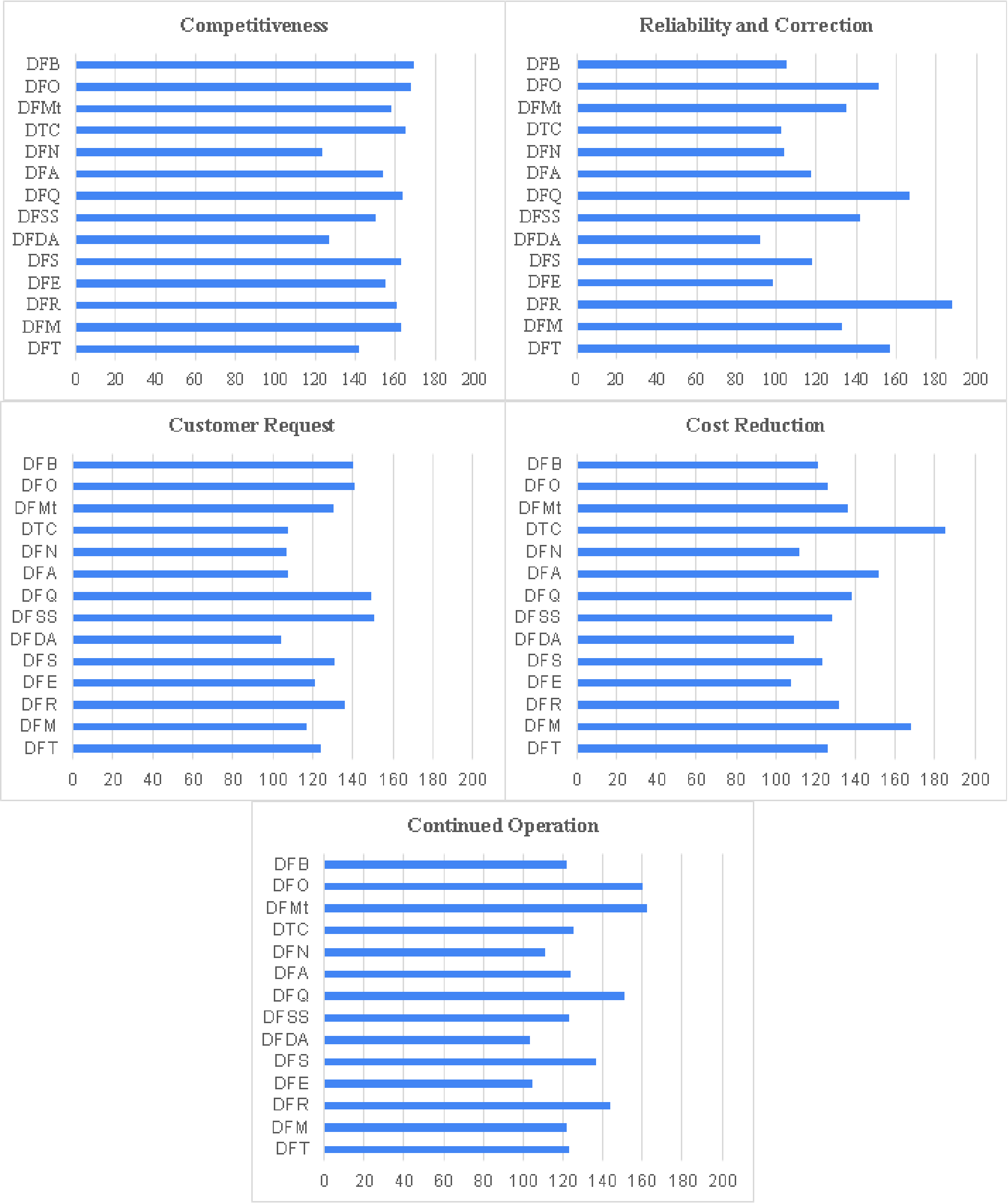
Informational Design (ID)

Production Preparation (PP)

Conceptual Design (CD)

Launch and Production (LP)

Figure 8.Questionnaire 01/02: sum of the DFX grades rated by the participants per Project Phases.


Competitiveness

Reliability and Correction

Customer Request

Cost Reduction

Continued Operation

Figure 9. Questionnaire 02/02: sum of the DFX grades rated by the participants per Project Type.

Table 8. 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

Table 9. Consistency check from the use of the AHP Method.

Index	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%
FINAL Conclusion	**OK**	**OK**	**OK**	**OK**	**OK**

Index	Pre-Development Conceptual Study (PDEC)	Pre-Development Studies (PDS)	Informational Design (ID)	Conceptual Design (CD)	Detailed Design (DD)	Certification Tests and Analysis (CTA)	Production Preparation (PP)	Launch and Production (LP)
CI	0,088	0,028	0,024	0,030	0,027	0,043	0,072	0,042
RI	1,570	1,570	1,570	1,570	1,570	1,570	1,570	1,570
CR	5,61%	1,81%	1,55%	1,91%	1,71%	2,74%	4,57%	2,69%
FINAL Conclusion	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**

From Table 9, 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 method, enabling a more in-depth analysis of the relationships among each DFX and the project types and phases.

The next and final step is to populate the Table 9 with all the normalized values based on DFX and project type, DFX and project phases, and DFX and project quality indicator. Then the calculation of the total partial normalization is performed to obtain the partial values from project type, project phases and project quality. Finally, it is performed the last normalization calculation to obtain the final percentages corresponding to each DFX. This process enables to identify notable trends (including cross-relations), as presented in **Erro! Fonte de referência não encontrada.** which also shows the AHP Overall Weight and Best Alternatives.

This comprehensive analysis investigates the role of Design for X (DFX) methods across various project parameters and phases, employing the Analytic Hierarchy Process (AHP) for a nuanced evaluation. The research reveals the pivotal nature of specific DFXs in influencing project success, underscoring the need for strategic application tailored to project specifics. Some key takeaways are detailed below.

Project Quality Analysis:

Design for Testability (DFT) emerges as a paramount strategy, particularly excelling in scope and cost parameters, an indication of its critical role in ensuring expansive project success and cost-efficiency. Notably, DFT leads with high recommendations, suggesting that easy-to-test designs could potentially reduce defects by a significant margin, streamline production, and lead to substantial long-term cost savings.

Design for Manufacturing (DFM) isn't far behind, especially in the quality parameter, with strong recommendations. This persistent high ranking underscores that manufacturing considerations are pivotal throughout all project phases, potentially influencing project scope, adherence to deadlines, cost containment, and quality assurance by notable percentages.

Table 10. AHP Overall Weight and Best Alternatives Analyses.

DFX	Project Phases							
	Pre-Development Conceptual Study (PDEC)	Pre-Development Studies (PDS)	Informational Design (ID)	Conceptual Design (CD)	Detailed Design (DD)	Certification Tests and Analysis (CTA)	Production Preparation (PP)	Launch and Production (LP)
DFT	1,51%	1,70%	3,63%	5,75%	9,70%	17,13%	3,58%	1,21%
DFM	2,65%	8,67%	11,17%	8,99%	10,62%	3,89%	3,07%	2,33%
DFR	3,84%	6,59%	7,17%	7,19%	8,72%	11,66%	6,62%	6,24%
DFE	16,01%	11,63%	9,23%	6,21%	3,37%	1,59%	1,02%	3,14%
DFS	6,88%	5,72%	7,11%	8,85%	4,38%	2,26%	2,58%	2,85%
DFDA	1,19%	2,70%	3,25%	6,51%	5,36%	1,60%	2,19%	6,44%
DFSS	13,41%	4,20%	7,23%	5,54%	4,56%	5,16%	2,19%	4,39%
DFQ	4,01%	3,81%	5,61%	8,74%	11,82%	17,20%	11,04%	14,78%
DFA	1,65%	3,81%	10,50%	8,74%	11,82%	8,69%	4,60%	6,65%
DFN	2,32%	3,70%	3,12%	3,91%	2,22%	3,76%	5,42%	4,52%
DTC	11,23%	11,87%	10,61%	12,24%	9,60%	4,72%	7,57%	10,62%
DFMt	4,24%	10,83%	8,35%	8,06%	10,85%	8,54%	14,44%	13,71%
DFO	5,19%	6,66%	4,52%	6,38%	4,84%	11,51%	26,25%	13,71%
DFB	25,87%	18,10%	8,50%	2,91%	2,13%	2,28%	9,43%	9,42%
AHP WEIGHTING	**2,13%**	**10,80%**	**17,20%**	**27,69%**	**23,43%**	**6,06%**	**3,73%**	**8,95%**

DFX	Project Types					Project Quality			
	Competitiveness	Customer Request	Reliability and Correction	Continued Operation	Cost Reduction	Scope	Time	Cost	Quality
DFT	3,82%	5,26%	9,83%	4,23%	4,65%	20,74%	21,49%	6,47%	27,10%
DFM	6,48%	4,07%	6,37%	4,02%	12,06%	16,67%	19,03%	17,77%	16,21%
DFR	6,26%	7,97%	16,70%	9,81%	5,51%	15,37%	13,24%	1,19%	11,84%
DFE	5,72%	5,54%	2,39%	3,54%	2,56%	11,58%	11,13%	2,36%	9,41%
DFS	7,28%	7,39%	4,92%	8,76%	4,46%	8,84%	8,42%	1,20%	8,14%
DFDA	2,92%	2,77%	2,13%	2,68%	2,98%	7,22%	7,23%	3,73%	6,99%
DFSS	5,55%	12,28%	8,46%	5,02%	5,86%	5,88%	5,41%	12,49%	5,49%
DFQ	8,95%	12,28%	12,98%	10,43%	8,14%	4,76%	4,23%	8,66%	4,77%
DFA	6,32%	3,48%	5,06%	6,15%	11,41%	2,69%	2,81%	2,49%	3,24%
DFN	2,75%	3,35%	3,32%	3,57%	3,73%	1,62%	1,64%	5,82%	2,14%
DTC	10,15%	3,74%	3,32%	6,86%	18,59%	1,39%	1,40%	24,76%	1,59%
DFMt	8,45%	7,84%	8,14%	14,70%	8,24%	1,08%	1,64%	10,60%	1,03%
DFO	11,99%	12,01%	12,36%	14,70%	6,41%	1,08%	1,40%	1,24%	1,03%
DFB	13,35%	12,01%	4,01%	5,54%	5,42%	1,08%	0,93%	1,24%	1,03%
AHP WEIGHTING	**7,68%**	**43,05%**	**17,83%**	**11,04%**	**3,59%**	**57,95%**	**25,21%**	**9,99%**	**5,65%**

DFX	TOTAL PARTIAL			CONCLUSION
	TOTAL PHASES	TOTAL QUALITY	TOTAL TYPES	
DFT	5,99%	19,61%	4,94%	10,18%
DFM	8,45%	17,15%	4,26%	9,95%
DFR	7,57%	13,03%	8,17%	9,59%
DFE	6,11%	10,28%	3,73%	6,71%
DFS	5,95%	7,82%	5,75%	6,51%
DFDA	4,69%	6,78%	2,20%	4,56%
DFSS	5,37%	6,33%	7,99%	6,56%
DFQ	9,43%	4,96%	9,73%	8,04%
DFA	8,74%	2,70%	3,98%	5,14%
DFN	3,42%	2,06%	2,77%	2,75%
DTC	10,51%	3,72%	4,41%	6,21%
DFMt	9,75%	2,16%	7,40%	6,44%
DFO	7,41%	1,16%	10,15%	6,24%
DFB	6,61%	1,04%	7,72%	5,12%
AHP WEIGHTING	**33,33%**	**33,33%**	**33,33%**	

Project Phase Analysis:

The analysis reveals significant variation across phases for DFXs like "Design for Environment" (DFE) and "Design for Business" (DFB). DFE, for instance, is highly recommended during the Pre-Development Conceptual Study (PDEC), potentially due to growing environmental and sustainability concerns that companies can no longer afford to ignore, given the current global focus on climate change.

"Design for Operation" (DFO) stands out during the Production Preparation (PP) with an exceptional 26.25% recommendation. This peak suggests that a failure to consider operational aspects before a product goes live could result in costly post-launch modifications, potentially increasing project costs.

Project Type Analysis: The data provides interesting insights when dissected by project type. In projects labeled as "Competitiveness," DFB and DFO take the lead, highlighting their combined role in maintaining a competitive edge, potentially affecting market share by significant fractions. Conversely, “Customer Request Projects” emphasize DFSS and DFQ, underlining the critical nature of quality and six sigma principles in meeting customer expectations, which could influence customer retention rates.

The analysis also shows that "Reliability and Correction Projects" give importance to DFR, with "Continued Operation Projects" focusing on DFMt and DFO, suggesting these strategies could be pivotal in reducing operational downtimes by significant percentages. For projects aimed at “Cost Reduction,” DTC emerges as crucial, likely due to its direct impact on the bottom line.

Project Type Analysis:

The analysis offers compelling insights into the significance of various Design for X (DFX) criteria across different project phases, from the survey phase. It underscores the criticality of DFB, DFE, and DFS in the Pre-Development Conceptual Study (PDEC), with DFB, DFE, and DTC being pivotal in the Pre-Development Studies (PDS). The Informational Design (ID) phase values DFM, DFA, DFE, and DTC, while the Conceptual Design (CD) and Detailed Design (DD) phases highlight the importance of DFM, DTC, DFS, and DFQ, DFA, respectively. The Certification Tests and Analysis (CTA) and Production Preparation (PP) phases stress DFQ, DFT, DRF, and DFO, DFMt, DFQ, with the Launch and Production (LP) phase echoing the significance of DFQ, DFMt, and DFO. Venn graphic delineates the fluctuating emphasis on DFXs, revealing DFE, DFB's varying stages of relevance, and the consistent recommendation for DFM and DFQ. The study advocates for a strategic, phase-specific application of DFXs to enhance design and development, supported by the Analytic Hierarchy Process (AHP) methodology for prioritizing DFX criteria. This approach is exemplified in the aerospace industry, indicating a nuanced strategy that prioritizes safety, reliability, and sustainability in early stages, shifting towards quality, assembly optimization, and innovation in later phases. The findings serve as a guide for product development planning, project assessment, and education across sectors, suggesting a periodic reevaluation of DFX priorities to match evolving project needs.

Final Project Analysis:

In a comprehensive view (see Figure 10), DFT, DFM, and DFR command the highest final recommendations, each hovering just below the 10% mark. Their dominance implies that these design principles are foundational to achieving overall project success, potentially influencing project outcomes by double-digit percentages. However, it is worth noticing the lower recommendations for DFN (Design for Network) and DFDA (Design for Disassembly), which indicate their more specialized roles. Their lower usage, particularly DFN with recommendations under 5%, suggests that networking considerations might not be universally applicable but could be critical in projects specifically focused on network design.

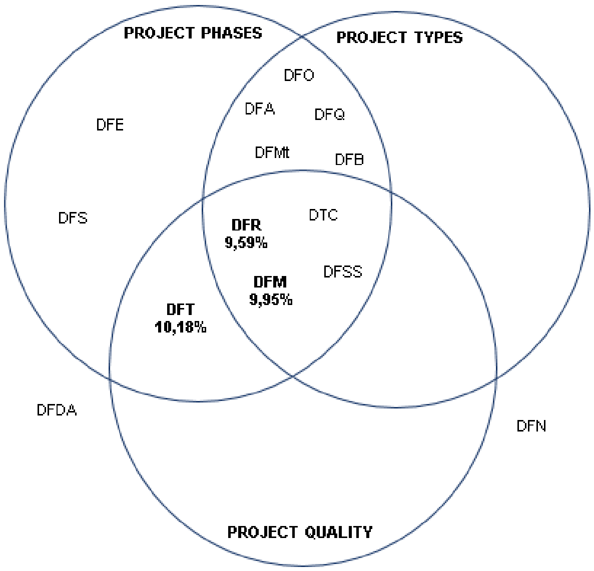


Figure 10. Final Results Venn Graphic

In essence, this detailed analysis underscores the multifaceted roles of DFXs, each holding varied significance depending on the project's quality benchmarks, operational phases, and inherent nature. Strategic application of these methodologies, informed by these numerical insights, is indispensable for achieving nuanced project objectives and overarching success. This data-driven approach not only facilitates informed decision-making but also highlights potential areas for cost savings, quality improvement, and efficiency enhancements, which are crucial for maintaining a competitive edge in today's dynamic market landscapes.

4.3 APP - A DFX Attribution Method in the Aerospace Domain

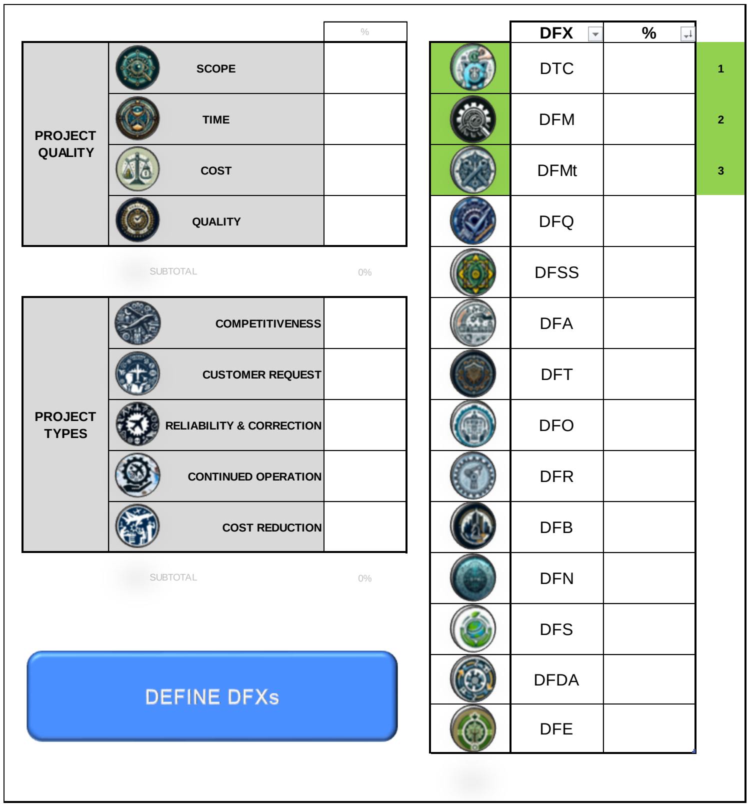
To achieve the main goal of this paper, the knowledge gathered in the previous sections are used to build a tool (an Excel Application - *App*) which is intended to help project managers in the first phase of option for a specific DFX approach to be used in a given context. A picture of the main page of the *App* is shown in Figure 11. This *App* is based on the data obtained and the Analytic Hierarchy Process (AHP) method. It is designed to output the suitability relevance (percentage) of each recommended Design for X (DFX) methodologies, given as input, for a specific project scenario, the relative importance (%) the project manager asserts for the various project types (portfolio in Table 2), project phases (see Table 3) and main quality criteria (see Table 4). The influence of the project phase is considered, being embedded in the analyses taking the percentages of importance raised in the previous section. In the following, A step-by-step guide for using the tool is shown below. Furthermore, the section provides some illustrative examples of applications and analyses it could support.

4.3.1 Use of the App

The app provides tailored recommendations for DFX methodologies based on user-defined project parameters. It utilizes the Analytic Hierarchy Process (AHP) to weight user inputs and generate a list of DFXs that best match the project's needs. The first step is to Input Project Quality Criteria Importance: input percentages for the following project quality criteria, ensuring their sum equals 100%: Scope; Time; Cost; Quality. The app uses these inputs to understand the performance areas of the project to focus.

In the following, Input Project Types Importance (percentages) for the following project types, with their total summing up to 100%: Competitiveness; Customer Request; Reliability & Correction; Continued Operation; Cost Reduction. These inputs help the *App* to gauge the strategic objectives of the project.

Next, Inputs are Processed via AHP (once the user click "Define DFX's") to compare and prioritize different DFX methodologies. AHP creates a matrix based on the inputs and calculates the relative importance of each DFX. Then, Results are generated, ranking the DFXs based on their calculated importance scores. The *App* displays a list of recommended DFXs in order of their relevance to the project's quality and type criteria. Users can use this list as a guideline for focusing their design and development efforts.



DFX	%	
DTC		1
DFM		2
DFMt		3
DFQ		
DFSS		
DFA		
DFT		
DFO		
DFR		
DFB		
DFN		
DFS		
DFDA		
DFE		

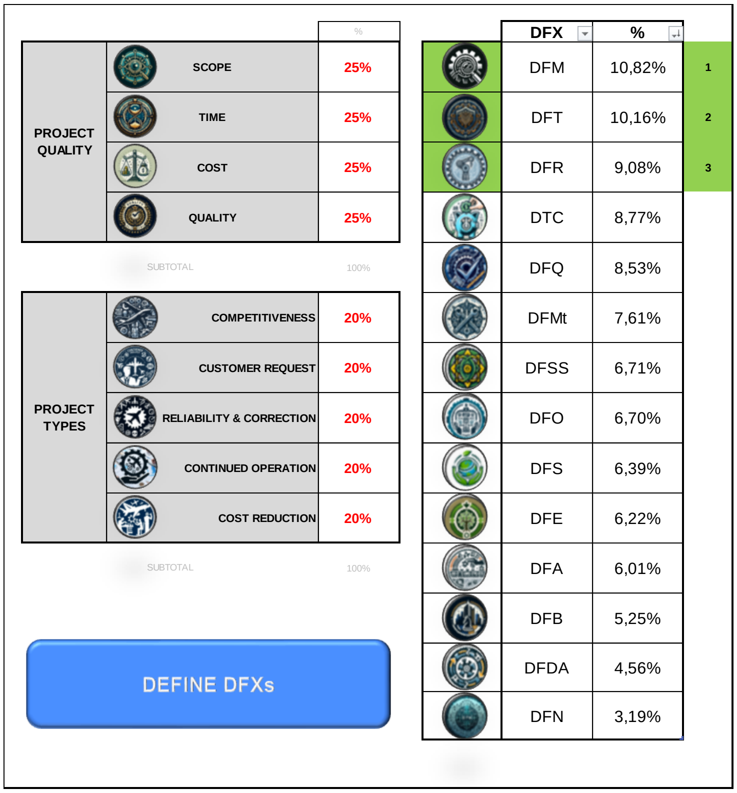
Figure 11. View of the first page of the App (A DFX Attribution Method in the Aerospace Domain).

An iterative and time-to-time using is recommended, where users can modify the inputs (percentages for project qualities and types) to see how different focus areas influence the recommended DFXs. This feature allows for exploring various scenarios and planning for diverse project requirements. This tool is a powerful resource to aid project managers, designers, and teams to align their design strategies with their project's specific needs and objectives, ensuring optimal project outcomes.

4.3.2 Analyses – Illustrative Scenarios

In the first example, each category has sub-categories with equal weightings, giving a balanced approach to evaluating project considerations. ‘Project Quality’ comprises Scope, Time, Cost, and Quality, each weighted at 25%, highlighting the fundamental aspects of project management. ‘Project Types’ encompasses Competitiveness, Customer Request, Reliability & Correction, Continued Operation, and Cost Reduction, each with a 20% weight, reflecting the broader strategic objectives that projects may aim to fulfill. The output is depicted in Figure 12.

Figure 12 shows the tool has made the following three major DFX Recommendations with nearly the same level of importance: DFM (Design for Manufacturing) and DFT (Design for Testability) top the list, evincing their critical role in meeting diverse project requirements, from managing scope and cost to enhancing competitiveness and reliability. DFR (Design for Reliability) and DTC (Design to Cost) follow closely, emphasizing the importance of reliability and cost-efficiency in both project quality and types.



		%
PROJECT QUALITY	SCOPE	25%
	TIME	25%
	COST	25%
	QUALITY	25%
	SUBTOTAL	100%
PROJECT TYPES	COMPETITIVENESS	20%
	CUSTOMER REQUEST	20%
	RELIABILITY & CORRECTION	20%
	CONTINUED OPERATION	20%
	COST REDUCTION	20%
	SUBTOTAL	100%

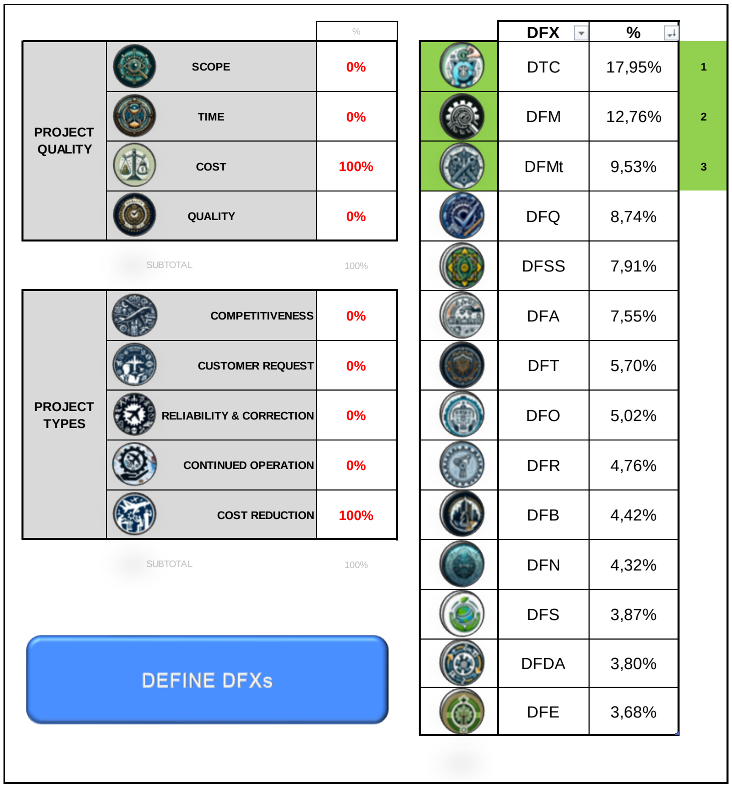
DFX	%	
DFM	10,82%	1
DFT	10,16%	2
DFR	9,08%	3
DTC	8,77%	
DFQ	8,53%	
DFMt	7,61%	
DFSS	6,71%	
DFO	6,70%	
DFS	6,39%	
DFE	6,22%	
DFA	6,01%	
DFB	5,25%	
DFDA	4,56%	
DFN	3,19%	

Figure 12. Scenario 01 – Equal importance to Project Types and Project Quality Performance.

This case is a kind of complex multi-objective design, where nothing has been predetermined at all. The data suggests a need for a balanced approach in selecting DFX methodologies. While DFM and DFT emerge as broadly applicable, the importance of other DFXs should not be understated, especially in projects with specific focuses. The even distribution across project quality and types suggests that no single aspect should dominate the decision-making process. Instead, a strategic application of DFXs, tailored to the specific needs and goals of the project, is crucial. The percentages associated with each DFX offer a guide for prioritizing various aspects depending on the project's specific objectives. Recognizing the strengths and applications of each DFX can lead to more informed decisions, enhancing the overall efficacy and success of projects.

The second example focused insights into the DFX preferences when cost considerations are paramount. The inputs were exclusively (100%) on "COST" under Project Quality and "COST REDUCTION" under Project Types. Figure 13 depicts output for this case. DTC (Design to Cost) attained 17.95%, highlighting its primary relevance in cost-focused projects. DFM (Design for Manufacturing) follows with 12.76%, suggesting that manufacturability is a crucial factor in controlling costs. DFMt (Design for Maintainability): holds 9.53%, indicating that ease of maintenance is important for long-term cost reduction. Products that are easier to maintain can incur lower costs over their lifecycle.

This analysis reveals a strong focus on cost reduction. While this is important, exclusively prioritizing cost can overlook other critical aspects like quality, customer satisfaction, and sustainability. Even within a cost-focused strategy, the varied percentages suggest that a mix of DFX methods should be employed. For instance, while DTC is predominant, incorporating aspects of DFM, DFMt, and DFQ can lead to a more balanced approach, ensuring cost efficiency without compromising on other essential factors along lifecycle.



		%
PROJECT QUALITY	SCOPE	0%
	TIME	0%
	COST	100%
	QUALITY	0%
	SUBTOTAL	100%
PROJECT TYPES	COMPETITIVENESS	0%
	CUSTOMER REQUEST	0%
	RELIABILITY & CORRECTION	0%
	CONTINUED OPERATION	0%
	COST REDUCTION	100%
	SUBTOTAL	100%

DFX	%	
DTC	17,95%	1
DFM	12,76%	2
DFMt	9,53%	3
DFQ	8,74%	
DFSS	7,91%	
DFA	7,55%	
DFT	5,70%	
DFO	5,02%	
DFR	4,76%	
DFB	4,42%	
DFN	4,32%	
DFS	3,87%	
DFDA	3,80%	
DFE	3,68%	

Figure 13. Scenario 02 -Full emphasis in cost.

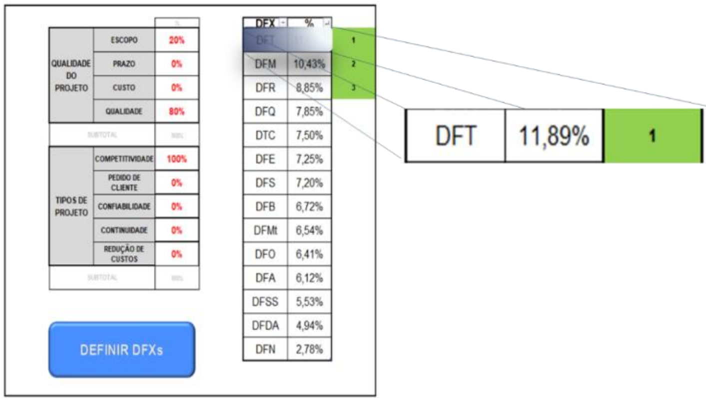
4.4 Additional Verification - Retrospective Analysis

In the quest for empirical substantiation of the methodological framework presented within this discourse, a meticulous retrospective analysis was undertaken. This analysis delved into the historical data pertaining to a project, hereafter referred to as "XWYZ" to maintain confidentiality. The project, conceptualized to bolster competitive advantage, faltered on the full realization of scope comprehension, necessitating unanticipated rework.

The analytical technique adopted herein is grounded in the classical logical construct known as *modus tollens* a form of negative reasoning in propositional logic. By applying this deductive reasoning, it is postulated that the absence of the intended outcome, namely 'successful project completion as adjudicated by comprehensive quality criteria,' logically infers the possibility that the methodological prescriptions, most notably the DFX approach as recommended by the proffered tool, were not adequately adhered to during the project's execution.

The project "XWYZ" was besieged with multifarious challenges at the outset, encompassing the procurement of premium quality components to navigating the intricacies inherent in sophisticated design paradigms. The project was bound by a liberal completion timeline, ostensibly within the normative industrial timeframes, with fiscal allocations strategically dispersed over the developmental trajectory. However, it is of significant note that the project team eschewed a selective DFX stratagem, opting instead for a non-discriminatory emphasis on quality performance indices.

In this contextual backdrop, it is posited that, had the design team been furnished with the insights from the tool delineated in this exposition at the project's genesis, they would have been steered towards the adoption of a particularized DFX methodology be it Design for Testability (DFT), Design for Reliability (DFR), or Design for Quality (DFQ). These approaches, whose salient features are encapsulated in Figure 14, are corroborated by the extant scholarly literature to be of paramount importance in managing scope efficaciously.



		%
QUALIDADE DO PROJETO	ESCOPO	20%
	PRAZO	0%
	CUSTO	0%
	QUALIDADE	80%
SUBTOTAL		[illegible]
TIPOS DE PROJETO	COMPETITIVIDADE	100%
	PEDIDO DE CLIENTE	0%
	CONFIABILIDADE	0%
	CONTINUIDADE	0%
	REDUÇÃO DE CUSTOS	0%
SUBTOTAL		[illegible]

DFX	%	
DFT	[illegible]	1
DFM	10,43%	2
DFR	8,85%	3
DFQ	7,85%	
DTC	7,50%	
DFE	7,25%	
DFS	7,20%	
DFB	6,72%	
DFMt	6,54%	
DFO	6,41%	
DFA	6,12%	
DFSS	5,53%	
DFDA	4,94%	
DFN	2,78%	

DFT	11,89%	1

Figure 14. Project XWYS _ APP Recording.

The retrospective analysis ventures beyond mere evaluative measures; it seeks to ascertain the contributory efficacy of DFX methodologies in circumventing the pitfalls encountered by project "XWYZ." The inductive reasoning that emerges from the analysis is predicated on the hypothesis that a targeted DFX approach could have potentially obviated the need for additional rework. It would have provided a structured, criteria-based focus, facilitating a more coherent alignment with the project's objectives and quality benchmarks.

The simplification inherent in this retrospective approach should not be misconstrued as a trivialization of the complexities of causality within project management. Rather, it should be perceived as an illustration of the potential for methodological tools to pivot the trajectory of a project towards a more favorable outcome. The exemplification provided by the "XWYZ" project serves to underscore the pertinence of methodical selection and application of design methodologies in early project stages, which could be seminal in precluding scope creep and ensuring alignment with quality parameters.

In conclusion, this retrospective analysis elucidates the implications of the methodological tool's absence, which, if present, could have been instrumental in steering the project towards a fulsome scope realization without the exigencies of rework. The discourse thus advocates for the primacy of a structured methodological approach in project design, especially one that is attuned to the nuanced demands of quality performance criteria.

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, DFX and project phases, DFX and project quality, 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 for each project phase (Pre-Development Conceptual Study (PDEC); Pre-Development Studies (PDS); Informational Design (ID); Conceptual Design (CD); Detailed Design (DD); Certification Tests and Analysis (CTA); Production Preparation (PP); Launch and Production (LP).) considering too the project quality (Scope, Time, Cost and Quality). In special, it is interesting to observe the main DFX technological areas do not retains absolute but relative importance in each project type context.

In light of the insights presented, it is plain that the Design for Excellence (DFX) methodology is a strategic imperative in the aerospace industry's product development landscape, transcending a one-size-fits-all approach. The complexity inherent in aerospace projects necessitates a framework like DFX, which addresses the multifaceted dimensions of product development and strategically aligns with the industry's progressive dynamics.

This research highlights the criticality of a nuanced approach to employing DFX, one that demands a deep understanding of both the DFX technological areas and the unique contours of each project. The initial mapping of DFX's technological areas, as explored in this research marks a significant stride towards this understanding, providing industry professionals with a foundational guidepost.

Particularly, Design for Testability (DFT), Design for Manufacturing (DFM), and Design for Reliability (DFR) emerge as cornerstone methodologies, especially in projects geared towards Operational Continuity and Competitiveness. These strategies, focusing on ensuring that products are efficiently manufacturable, reliably functional, and adequately testable, represent a triad of excellence in aerospace development.

Moreover, the findings emphasize the pivotal role of the engineering team's experiential knowledge in harnessing the full potential of DFX methodologies. The human element, characterized by expertise and adaptability, remains central to innovation and efficiency in this technologically driven sector.

Looking ahead, the dynamic nature of the aerospace industry, marked by rapid technological advancements and evolving regulatory standards, calls for an agile and strategic application of DFX. This agility involves not only staying abreast of technological trends but also cultivating a culture of continuous learning and adaptability among project teams.

In conclusion, the future of aerospace product development hinges on strategically curated and agile DFX applications, underpinned by a robust understanding of technological areas and an emphasis on continuous team competence development. By integrating DFT, DFM, and DFR into the initial stages, projects stand to benefit from reduced costs, enhanced quality, and streamlined processes, meeting the rigorous demands of aerospace standards. This work serves as a catalyst for further exploration and refinement in this direction, potentially paving the way for predictive and AI-assisted decision-making frameworks in the DFX application, ultimately propelling the aerospace industry into a new era of innovation, efficiency, and excellence.

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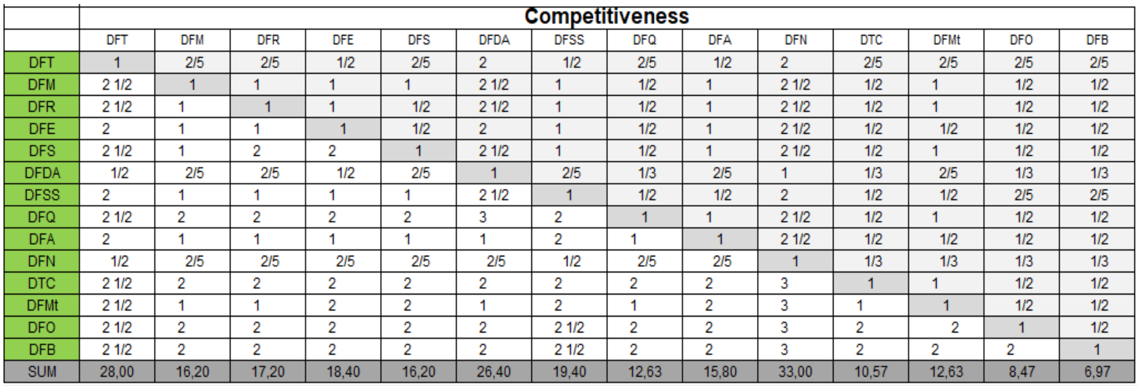
7. RESPONSIBILITY NOTICE

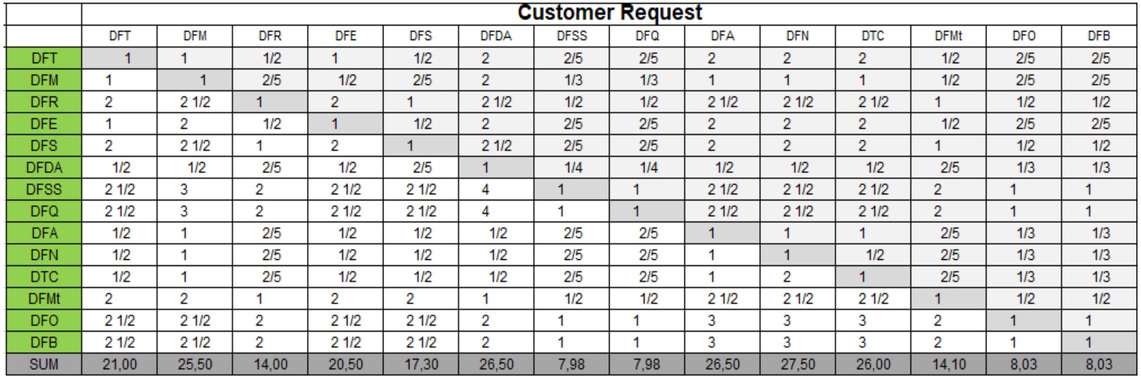
The authors are the only responsible for the printed material included in this paper. All the subjects that contributed to this research answering the questionaries agreed and signed a Consent Form allowing unlabeled data to be used by the authors. Request for sharing the raw data from questionaries can be evaluated upon request by main author.

8. APPENDIX

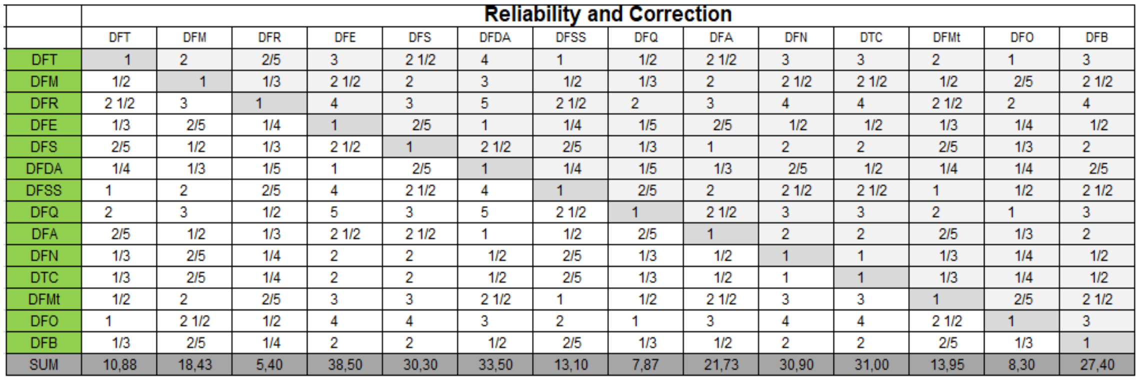
A.1 - Fundamental Scale of the AHP - Project Type



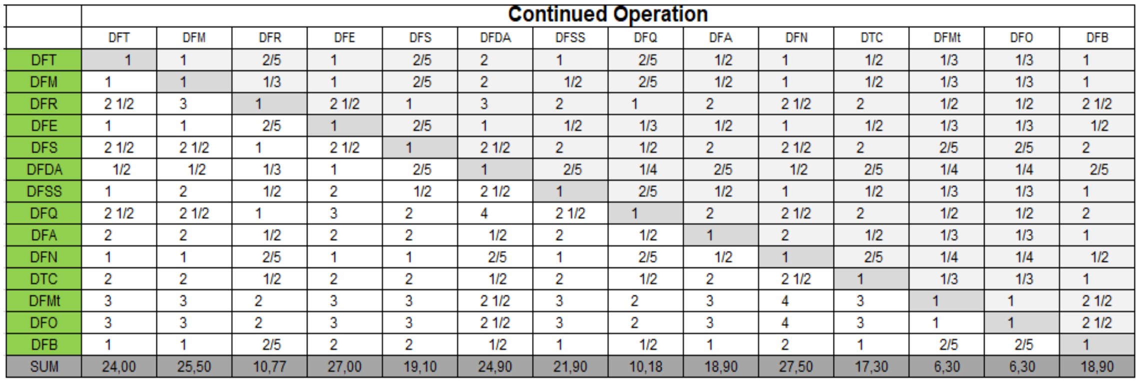
	Competitiveness													
	DFT	DFM	DFR	DFE	DFS	DFDA	DFSS	DFQ	DFA	DFN	DTC	DFMt	DFO	DFB
DFT	1	2/5	2/5	1/2	2/5	2	1/2	2/5	1/2	2	2/5	2/5	2/5	2/5
DFM	2 1/2	1	1	1	1	2 1/2	1	1/2	1	2 1/2	1/2	1	1/2	1/2
DFR	2 1/2	1	1	1	1/2	2 1/2	1	1/2	1	2 1/2	1/2	1	1/2	1/2
DFE	2	1	1	1	1/2	2	1	1/2	1	2 1/2	1/2	1/2	1/2	1/2
DFS	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



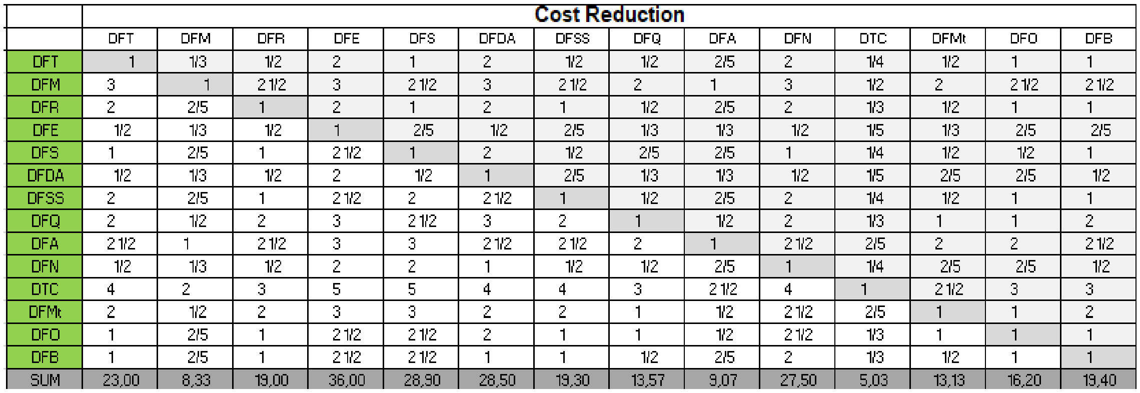
	Customer Request													
	DFT	DFM	DFR	DFE	DFS	DFDA	DFSS	DFQ	DFA	DFN	DTC	DFMt	DFO	DFB
DFT	1	1	1/2	1	1/2	2	2/5	2/5	2	2	2	1/2	2/5	2/5
DFM	1	1	2/5	1/2	2/5	2	1/3	1/3	1	1	1	1/2	2/5	2/5
DFR	2	2 1/2	1	2	1	2 1/2	1/2	1/2	2 1/2	2 1/2	2 1/2	1	1/2	1/2
DFE	1	2	1/2	1	1/2	2	2/5	2/5	2	2	2	1/2	2/5	2/5
DFS	2	2 1/2	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

A.2 - Fundamental Scale of the AHP - Project Phases -

	Pre-Development Conceptual Study (PDEC)													
	DFT	DFM	DFR	DFE	DFS	DFDA	DFSS	DFQ	DFA	DFN	DTC	DFMt	DFO	DFB
DFT	1	1/3	1/4	1/8	1/5	2	1/7	1/4	1	2/5	1/7	1/4	1/4	1/8
DFM	3	1	2/5	1/7	1/4	3	1/6	2/5	2 1/2	2	1/5	2/5	2/5	1/8
DFR	4	2 1/2	1	1/6	1/3	4	1/5	1	3	2 1/2	1/5	1	1/2	1/7
DFE	8	7	6	1	4	7	2	5	7	6	2 1/2	5	5	1/3
DFS	5	4	3	1/4	1	5	1/4	2 1/2	5	4	1/3	2 1/2	2	1/6
DFDA	1/2	1/3	1/4	1/7	1/5	1	1/8	1/5	2/5	1/3	1/7	1/5	1/5	1/9
DFSS	7	6	5	1/2	4	8	1	5	6	6	2	5	4	1/4
DFQ	4	2 1/2	1	1/5	2/5	5	1/5	1	3	2 1/2	1/5	1	1/2	1/7
DFA	1	2/5	1/3	1/7	1/5	2 1/2	1/6	1/3	1	2/5	1/7	1/4	1/4	1/8
DFN	2 1/2	1/2	2/5	1/6	1/4	3	1/6	2/5	2 1/2	1	1/6	1/3	1/3	1/8
DTC	7	5	5	2/5	3	7	1/2	5	7	6	1	4	3	1/5
DFMt	4	2 1/2	1	1/5	2/5	5	1/5	1	4	3	1/4	1	1/2	1/7
DFO	4	2 1/2	2	1/5	1/2	5	1/4	2	4	3	1/3	2	1	1/7
DFB	8	8	7	3	6	9	4	7	8	8	5	7	7	1
SOMA	59,00	42,57	32,63	6,64	20,73	66,50	9,37	31,08	54,40	45,13	12,61	29,93	24,93	3,13

	Pre-Development Studies (PDS)													
	DFT	DFM	DFR	DFE	DFS	DFDA	DFSS	DFQ	DFA	DFN	DTC	DFMt	DFO	DFB
DFT	1	1/5	1/4	1/5	1/4	2/5	1/3	1/3	1/3	1/3	1/5	1/5	1/4	1/6
DFM	5	1	1	1/2	2	3	2 1/2	2 1/2	2 1/2	2 1/2	1/2	1	2	2/5
DFR	4	1	1	2/5	1	2 1/2	2	2	2	2 1/2	2/5	1/2	1	1/3
DFE	5	2	2 1/2	1	2 1/2	3	2 1/2	3	3	3	1	1	2 1/2	1/2
DFS	4	1/2	1	2/5	1	2	1	2	2	2	2/5	2/5	1	1/3
DFDA	2 1/2	1/3	2/5	1/3	1/2	1	2/5	1/2	1/2	1/2	1/4	1/4	2/5	1/5
DFSS	3	2/5	1/2	2/5	1	2 1/2	1	1	1	1	1/3	1/3	1/2	1/4
DFQ	3	2/5	1/2	1/3	1/2	2	1	1	1	1	1/3	1/3	2/5	1/4
DFA	3	2/5	1/2	1/3	1/2	2	1	1	1	1	1/3	1/3	2/5	1/4
DFN	3	2/5	2/5	1/3	1/2	2	1	1	1	1	1/4	1/3	2/5	1/4
DTC	5	2	2 1/2	1	2 1/2	4	3	3	3	4	1	1	2	2/5
DFMt	5	1	2	1	2 1/2	4	3	3	3	3	1	1	2	2/5
DFO	4	1/2	1	2/5	1	2 1/2	2	2 1/2	2 1/2	2 1/2	1/2	1/2	1	1/3
DFB	6	2 1/2	3	2	3	5	4	4	4	4	2 1/2	2 1/2	3	1
SOMA	53,50	12,63	16,55	8,63	18,75	35,90	24,73	26,83	26,83	28,33	9,00	9,68	16,85	5,07

	Informational Design (ID)													
	DFT	DFM	DFR	DFE	DFS	DFDA	DFSS	DFQ	DFA	DFN	DTC	DFMt	DFO	DFB
DFT	1	1/3	2/5	2/5	2/5	1	2/5	1/2	2/5	2	2/5	2/5	1	2/5
DFM	3	1	1	1	2	2 1/2	2	2	1	2 1/2	1	2	2 1/2	2
DFR	2 1/2	1	1	1/2	1	2	1	1	1/2	2 1/2	1/2	1	2	1
DFE	2 1/2	1	2	1	1	2 1/2	1	2	1	2 1/2	1	1	2	1
DFS	2 1/2	1/2	1	1	1	2	1	1	1/2	2 1/2	1/2	1	2	1
DFDA	1	2/5	1/2	2/5	1/2	1	2/5	2/5	1/3	1	1/3	2/5	1/2	2/5
DFSS	2 1/2	1/2	1	1	1	2 1/2	1	1	1/2	2 1/2	1/2	1	2	1
DFQ	2	1/2	1	1/2	1	2 1/2	1	1	2/5	2	2/5	1/2	1	1/2
DFA	2 1/2	1	2	1	2	3	2	2 1/2	1	2 1/2	1	1	2	1
DFN	1/2	2/5	2/5	2/5	2/5	1	2/5	1/2	2/5	1	1/3	2/5	1/2	2/5
DTC	2 1/2	1	2	1	2	3	2	2 1/2	1	3	1	1	2	1
DFMt	2 1/2	1/2	1	1	1	2 1/2	1	2	1	2 1/2	1	1	2	1
DFO	1	2/5	1/2	1/2	1/2	2	1/2	1	1/2	2	1/2	1/2	1	2/5
DFB	2 1/2	1/2	1	1	1	2 1/2	1	2	1	2 1/2	1	1	2 1/2	1
SOMA	28,50	9,03	14,80	10,70	14,80	30,00	14,70	19,40	9,53	31,00	9,47	12,20	23,00	12,10

	Conceptual Design (CD)													
	DFT	DFM	DFR	DFE	DFS	DFDA	DFSS	DFQ	DFA	DFN	DTC	DFMt	DFO	DFB
DFT	1	1/2	1/2	1	1/2	1	1	1/2	1/2	2	1/2	1	1	3
DFM	2	1	1	1	1	1	2	1	1	2 1/2	1	1	2	3
DFR	2	1	1	1	1/2	1	1	1	1	2	1/2	1	1	2 1/2
DFE	1	1	1	1	1/2	1	1	1/2	1/2	2	1/2	1	1	2 1/2
DFS	2	1	2	2	1	1	1	1	1	2	1/2	1	2	2 1/2
DFDA	1	1	1	1	1	1	1	1/2	1/2	2	1/2	1	1	2 1/2
DFSS	1	1/2	1	1	1	1	1	1/2	1/2	1	2/5	1/2	1	2 1/2
DFQ	2	1	1	2	1	2	2	1	1	2	1/2	1	1	2 1/2
DFA	2	1	1	2	1	2	2	1	1	2	1/2	1	1	2 1/2
DFN	1/2	2/5	1/2	1/2	1/2	1/2	1	1/2	1/2	1	2/5	2/5	1/2	2
DTC	2	1	2	2	2	2	2 1/2	2	2	2 1/2	1	1	2	2 1/2
DFMt	1	1	1	1	1	1	2	1	1	2 1/2	1	1	1	2 1/2
DFO	1	1/2	1	1	1/2	1	1	1	1	2	1/2	1	1	2
DFB	1/3	1/3	2/5	2/5	2/5	2/5	2/5	2/5	2/5	1/2	2/5	2/5	1/2	1
SOMA	18,83	11,23	14,40	16,90	11,90	15,90	18,90	11,90	11,90	26,00	8,20	12,30	16,00	33,50

	Detailed Design (DD)													
	DFT	DFM	DFR	DFE	DFS	DFDA	DFSS	DFQ	DFA	DFN	DTC	DFMt	DFO	DFB
DFT	1	1/2	1	3	2 1/2	2	2 1/2	1/2	1/2	6	1	1	2 1/2	7
DFM	2	1	1	2 1/2	2 1/2	2	2 1/2	1	1	4	1	1	2 1/2	4
DFR	1	1	1	2 1/2	2	2	2	1/2	1/2	3	1	1	2 1/2	4
DFE	1/3	2/5	2/5	1	1/2	2/5	1/2	1/3	1/3	2	1/3	1/3	1/2	2 1/2
DFS	2/5	2/5	1/2	2	1	1/2	1	1/3	1/3	2 1/2	2/5	2/5	1	2 1/2
DFDA	1/2	1/2	1/2	2 1/2	2	1	1	2/5	2/5	2 1/2	1/2	2/5	1	3
DFSS	2/5	2/5	1/2	2	1	1	1	1/3	1/3	2 1/2	2/5	2/5	1	2 1/2
DFQ	2	1	2	3	3	2 1/2	3	1	1	4	1	1	2 1/2	4
DFA	2	1	2	3	3	2 1/2	3	1	1	4	1	1	2 1/2	4
DFN	1/6	1/4	1/3	1/2	2/5	2/5	2/5	1/4	1/4	1	1/4	1/4	1/3	1
DTC	1	1	1	3	2 1/2	2	2 1/2	1	1	4	1	1/2	2	4
DFMt	1	1	1	3	2 1/2	2 1/2	2 1/2	1	1	4	2	1	2	4
DFO	2/5	2/5	2/5	2	1	1	1	2/5	2/5	3	1/2	1/2	1	2 1/2
DFB	1/7	1/4	1/4	2/5	2/5	1/3	2/5	1/4	1/4	1	1/4	1/4	2/5	1
SOMA	12,34	9,10	11,88	30,40	24,30	20,13	23,30	8,30	8,30	43,50	10,63	9,03	21,73	46,00

	Certification Tests and Analysis (CTA)													
	DFT	DFM	DFR	DFE	DFS	DFDA	DFSS	DFQ	DFA	DFN	DTC	DFMt	DFO	DFB
DFT	1	5	1	9	9	9	4	1/2	2	6	5	2 1/2	2	9
DFM	1/5	1	1/4	3	2 1/2	3	1/2	1/4	1/3	1	1	1/3	1/3	2 1/2
DFR	1	4	1	5	4	5	2 1/2	1/2	2	3	3	2	1	5
DFE	1/9	1/3	1/5	1	2/5	1	1/4	1/6	1/5	1/3	1/4	1/5	1/6	1/2
DFS	1/9	2/5	1/4	2 1/2	1	2	1/3	1/6	1/5	2/5	1/3	1/4	1/5	1
DFDA	1/9	1/3	1/5	1	1/2	1	1/4	1/6	1/5	1/3	1/4	1/5	1/6	1/2
DFSS	1/4	2	2/5	4	3	4	1	1/4	1/3	2	1	2/5	1/3	3
DFQ	2	4	2	6	6	6	4	1	2 1/2	4	4	2 1/2	2	5
DFA	1/2	3	1/2	5	5	5	3	2/5	1	2 1/2	2 1/2	1	1/2	4
DFN	1/6	1	1/3	3	2 1/2	3	1/2	1/4	2/5	1	1/2	1/3	1/4	2 1/2
DTC	1/5	1	1/3	4	3	4	1	1/4	2/5	2	1	1/3	1/3	2 1/2
DFMt	2/5	3	1/2	5	4	5	2 1/2	2/5	1	3	3	1	1/2	4
DFO	1/2	3	1	6	5	6	3	1/2	2	4	3	2	1	4
DFB	1/9	2/5	1/5	2	1	2	1/3	1/5	1/4	2/5	2/5	1/4	1/4	1
SOMA	6,66	28,47	8,17	56,50	46,90	56,00	23,17	5,00	12,82	29,97	25,23	13,30	9,03	44,50

	Production Preparation (PP)													
	DFT	DFM	DFR	DFE	DFS	DFDA	DFSS	DFQ	DFA	DFN	DTC	DFMt	DFO	DFB
DFT	1	1	1/3	9	1	2 1/2	2 1/2	1/4	1/2	2/5	1/3	1/5	1/7	1/3
DFM	1	1	1/3	5	1	2	2	1/4	1/2	2/5	1/3	1/5	1/7	1/3
DFR	3	3	1	6	3	3	3	2/5	2	2	1	1/3	1/5	1/2
DFE	1/9	1/5	1/6	1	1/5	1/4	1/4	1/7	1/6	1/6	1/7	1/8	1/9	1/7
DFS	1	1	1/3	5	1	1	1	1/5	2/5	1/3	1/4	1/5	1/7	1/4
DFDA	2/5	1/2	1/3	4	1	1	1	1/5	1/3	1/3	1/4	1/6	1/7	1/5
DFSS	2/5	1/2	1/3	4	1	1	1	1/5	1/3	1/3	1/4	1/6	1/7	1/5
DFQ	4	4	2 1/2	7	5	5	5	1	3	2 1/2	2	1/2	1/5	2
DFA	2	2	1/2	6	2 1/2	3	3	1/3	1	1/2	2/5	1/4	1/6	1/3
DFN	2 1/2	2 1/2	1/2	6	3	3	3	2/5	2	1	2/5	1/4	1/6	2/5
DTC	3	3	1	7	4	4	4	1/2	2 1/2	2 1/2	1	1/3	1/5	1/2
DFMt	5	5	3	8	5	6	6	2	4	4	3	1	1/4	2
DFO	7	7	5	9	7	7	7	5	6	6	5	4	1	4
DFB	3	3	2	7	4	5	5	1/2	3	2 1/2	2	1/2	1/4	1
SOMA	33,41	33,70	17,33	84,00	38,70	43,75	43,75	11,38	25,73	22,97	16,36	8,23	3,26	12,19

	Launch and Production (LP)													
	DFT	DFM	DFR	DFE	DFS	DFDA	DFSS	DFQ	DFA	DFN	DTC	DFMt	DFO	DFB
DFT	1	1/4	1/6	1/5	1/4	1/6	1/5	1/7	1/6	1/5	1/7	1/7	1/7	1/6
DFM	4	1	1/3	2/5	1/2	1/3	2/5	1/5	1/3	2/5	1/4	1/5	1/5	1/4
DFR	6	3	1	2 1/2	2 1/2	1	2	1/3	1	2	2/5	2/5	2/5	1/2
DFE	5	2 1/2	2/5	1	1	1/3	1/2	1/5	1/3	1/2	1/4	1/4	1/4	1/3
DFS	4	2	2/5	1	1	1/3	2/5	1/5	1/3	2/5	1/4	1/4	1/4	1/4
DFDA	6	3	1	3	3	1	2	1/3	1	2	2/5	2/5	2/5	1/2
DFSS	5	2 1/2	1/2	2	2 1/2	1/2	1	1/4	2/5	1	1/3	1/3	1/3	2/5
DFQ	7	5	3	5	5	3	4	1	2 1/2	3	2	1	1	2
DFA	6	3	1	3	3	1	2 1/2	2/5	1	2	2/5	2/5	2/5	1/2
DFN	5	2 1/2	1/2	2	2 1/2	1/2	1	1/3	1/2	1	1/3	1/3	1/3	2/5
DTC	7	4	2 1/2	4	4	2 1/2	3	1/2	2 1/2	3	1	1/2	1/2	1
DFMt	7	5	2 1/2	4	4	2 1/2	3	1	2 1/2	3	2	1	1	2
DFO	7	5	2 1/2	4	4	2 1/2	3	1	2 1/2	3	2	1	1	1
DFB	6	4	2	3	4	2	2 1/2	1/2	2	2 1/2	1	1/2	1	1
SOMA	76,00	42,75	17,80	35,10	37,25	17,67	25,50	6,39	17,07	24,00	10,76	6,71	7,21	10,30

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