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Conceptual Reference Model for the Product Development Process Oriented by Design for Six Sigma

Marta Gomes Francisco¹ [0000-0002-5413-6865], Osiris Canciglieri Junior² [0000-0002-8503-9275],
Ângelo Márcio Oliveira Sant'Anna³ [0000-0001-8332-8877]

¹Industrial and Systems Engineering Graduate Program - Polytechnic School - Pontifical Catholic University of Paraná (PPGEPS/PUCPR), Curitiba, Parana, Brazil and Federal Institute of Education, Science and Technology of Paraná (IFPR), Campo Largo, Paraná, Brazil - marta.francisco@ifpr.edu.br

²Industrial and Systems Engineering Graduate Program (PPGEPS) - Polytechnic School - Pontifical Catholic University of Parana (PUCPR); Imaculada Conceição Street, 1155, Prado Velho; CEP 80215-901 - * osiris.canciglieri@pucpr.br

³Federal University of Bahia(UFBA), Salvador, Bahia, Brazil - angelo.santanna@ufba.br

Abstract: Changes in the world market and consumer expectations have changed the way organizations develop new products. Meeting these challenges means doing better from early stages of design, avoiding possible failures and adjustments at a late stage in the development process. Design For Six Sigma (DFSS) has been successfully applied in the product development process (PDP), with the purpose of ensuring convergence to customer specifications, ensuring reliability in product development, reducing or eliminating operational vulnerabilities and increasing product robustness with use of appropriate techniques and tools. This study showed that there is no systematic DFSS structure integrated with a reference model for the product development process that encompasses the entire process, from observing the consumer's need to discontinuing the product in the market. This paper proposes a conceptual model for the product development process oriented to DFSS, based on a systematic study of existing DFSS methods with the integration of a PDP reference model. The research strategy of this study sought to understand the phases of the existing DFSS methods, as well as to identify the factors that determine or contribute to the application of these methods in the product development process. The investigation of the theme showed a lack of standardization of a DFSS method integrated with a reference model for the product development process, which allowed the identification of 11 activities from each phase of the DFSS methods, which were aligned with the 14 activities proposed by the reference model for the MOP & D product development process. This study led to a consensus in the construction of an integrated conceptual model oriented to DFSS concepts with a friendly characteristic for application in the product development process of durable goods.

Keywords: Design For Six Sigma methods, Reference models for product development, PDP, DFSS, Product development and manufacturing process.

1 Introduction

The product development process transforms data and technical possibilities into a market opportunity and information, allowing the design of new products. The transformation of this market opportunity encompasses the quality of the product and process as well as competitive factors such as cost, development time, product, reliability and flexibility (Clark and Fujimoto, 1991; Slack et al., 2002).

Developing new products is a systematic process that integrates different processes and people in an organization with the aim of identifying the needs of users and transforming them into valuable information for the design of a product capable of meeting market expectations. Thus, developing new products for commercial purposes is an important and necessary task for organizations, but they involve several steps, from the identification of the opportunity to the discontinuity of the product in the market, these steps being crucial for the success of the product (Pugh, 1991; Rozenfeld et al., 2006).

To assist organizations in the product development process, several approaches to reference models are presented in the literature in order to assist organizations and professionals. PDP models can present specific approaches with a proposal for a creative process or sustainability, as well as product project management approaching engineering and design. Some reference models are well known in the literature such as Löbach's Model (2001), Baxter's Model (2011), El Marghani Model (2011), Ulrich and Eppinger Model (2012), Vezzoli Model, Kohtala and Srinivasan (2014), Platcheck et al. (2008), Asimow's Model (1968), Cooper's Model: Stage-Gate (1993), Pahl & Beitz Model (1996), Unified Model (Rozenfeld et al., 2006), Cascade Model (Coley Consulting, 2010), Model V (Coley Consulting, 2002), among others (Fernandes, 2017; Pereira, 2014; Sá, 2017).

Incorporated in several product development strategies, we highlight Design For Six Sigma, with an approach that involves the use of engineering and statistical tools that are applied appropriately in each phase of product development. DFSS aims to integrate the principles of the six sigma concepts into product development, focusing on the robustness of the product design and process for the best functioning of the product under different conditions of use, identifying errors and problems likely to occur during the project and then outlining mechanisms of prevention.

Creveling et al. (2003) cite that Design For Six Sigma is guided by an integrated set of tools that are implemented in the phases of a product development process, providing qualitative results summarized in managerial performance indicators of the critical parameters of the product in question, related to a set of requirements obtained based on the customer's voice, in order to achieve 6 sigma standards in the product. DFSS encompasses many tools and best practices that can be selectively employed during the phases of a product development process in order to reduce cost, time and increase quality. In the literature there are several DFSS methods applied in order to develop new products, as well as to improve an existing product. However, DFSS methods do not cover the entire product development process, that is, from initialization to discontinuity of the product on the market.

In order to incorporate all the concepts that permeate the Design For Six Sigma methods applied to product development to a reference model for the integrated product development process, the authors had as a basic premise: How to integrate a product development reference model with the concepts of DFSS methods that is friendly and that meets the dynamics of organizations and consumer expectations?

This study aimed to build a reference model for the integrated product development process oriented to Design For Six Sigma, with the purpose of contemplating all the activities proposed by a reference model as well as the activities and concepts of Design For Six Sigma. The product development model oriented to Design For Six Sigma described, focuses on an integrative approach of the activities that make up the DFSS methods presented in the literature. The characterization of the 11 activities of each phase of the DFSS methods allowed a constructive convergence of the concepts of the DFSS methodology with the integration to a reference model for the product development process (Francisco et al., 2019). Thus, the reference model presented in this study aims to systematize the product development process since the product's initialization and discontinuity with synergy of the Design For Six Sigma concepts and a PDP reference model. The model presented, includes the phases and activities inherent to the manufactured product development process with its particularities within the product's life cycle in the market. This model allows an integration among the teams of different areas and roles of the organization, with activities being performed in parallel to provide a reduction in time and cost as well as improved product and process quality.

2 Design for Six Sigma and reference model for the product development process

Developing new products is always a challenge for organizations, as it is linked to their survival in the competitive market. Constant technological changes and a more observant and discerning consumer develop strategies capable of understanding and identifying potential for business expansion, which are in line with consumer expectations, lower manufacturing cost and quality, are important factors for the development process of product. Design For Six Sigma is an approach with great potential as a product development strategy, as it presents a phased structure that guides in the product development process, as well as the implementation of tools and techniques. DFSS can be defined as a global strategy of continuous improvement, leading organizations to concentrate efforts on systematic projects aiming at 6σ performance and allowing the products developed to be in line with consumer specifications (Awad and Shanshal, 2017; Jenab and Moslehpour, 2018).

Werkema (2005) mentions that Design for Six Sigma can be defined as a systematic methodological approach, characterized by the joint use of statistical and engineering methods. When properly applied, it allows the company to launch the right product on the market, in the shortest time and with minimal cost. Creveling et al. (2003) emphasize that DFSS is a prevention methodology, in which it seeks to do the right activity at the right time during the product development process, assists in the process

of invention, development, optimization, incorporation of new technologies in the product and product verification before launching on the market.

The literature cites several DFSS methods that are applied in the product development process, some of which are better known and frequently applied by organizations, such as: Define, Measure, Analyze, Design and Verify (DMADV); Identify, Design, Optimize and Validate (IDOV); Define, Measure, Analyze, Design, Optimize and Verify (DMADOV); Define, Design, Optimize, Validate (DDOV); Identify, Characterize, Optimize, Validate (ICOV); Define, Measure, Explore, Develop, Implement (DMEDI); Define, Customer, Concept, Design, Implement (DCCDI); Invention and Innovation, Develop, Optimize, Verify (I²DOV); Identify, Define, Develop, Optimize, Verify & Validate (IDDOV); Concept development, Design development, Optimization, Verify, Certification (CDOV) and Define, Characterize, Optimize, Verify (DCOV), among others (Sokovic et al., 2010; Ericsson et al., 2009 and Shahin, 2008). According to the authors Watson and DeYong (2010) the strength of DFSS is not in its independent performance, but comes from the integration of methods and concepts that were developed independently in a system of thought and work that results in product designs that serve customers better and generate attractive profits.

In this study, the authors observed in the theoretical line of investigation 11 activities that are performed by the different phases of the different DFSS methods. In this study, the authors observed in the theoretical line of investigation 11 activities that are performed by the different phases of the different DFSS methods. In this way, the authors were able to identify the similarities and gaps in the activities of the different phases of the existing methods (Francisco et al., 2019). Figure 1 seeks to summarize the 11 activities and gaps observed in the DFSS methods.

From the analysis of the activities of the DFSS methods, the authors sought to integrate these activities with a reference model for the Product Development Process. Thus, the reference model for the product development process applied in this integration of concepts was the model idealized by Pereira (2014), known as MOP&D. The MOP&D reference model was conceived through a careful analysis of the different approaches to development process models that are present in the literature. The MOP&D reference model presented in Figure 2, contains in its structure 3 macrophases: Pre-development, Development and Post-development. These macrophases are broken down into six phases: Initiation, Planning, Design, Implementation, Production and Maintenance, being summarized in 14 different stages. Thus, the authors incorporated the 14 activities proposed by the reference model for the MOP&D product development process (Pereira, 2014; Pereira et al., 2014; Pereira and Canciglieri, 2014), with the 11 activities observed through the theoretical line of investigation of the DFSS methods.

ACTIVITIES / OBJECTIVES OF THE PHASES OF THE DFSS METHODS	DFSS METHODS	STEPS	DMADIC	DMADOV	DDOV	ICOV	DMEDI	DCCDI	I ² DOV	PIDOV	IDDOV	DIDES	CDOV	DCOV	IDEAS	DMADV	IDOV
	Define/identify/ plan the product design, the goals and constraints	1	✓	✓	✓		✓	✓		✓	✓	✓	✓			✓	✓
	Generate new ideas-creating something new- Define innovation project	2							✓								
	Improve existing product	3															
	Identify/ measure the consumers necessities and translate them in functional requirements of the product	4	✓	✓		✓	✓	✓	✓	✓	✓			✓		✓	✓
	Conceptual idea of the product, selection and choice	5		✓		✓	✓	✓					✓			✓	
	Project/development/execution of the product	6	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Design / development of process concepts	7									✓						
	Optimize product and process design	8		✓	✓	✓	✓		✓	✓	✓			✓			✓
	Evaluation of the product in the production process in meeting the defined specifications	9		✓	✓	✓			✓			✓	✓		✓	✓	
	Evaluation of process performance to identify best practices and correction of errors in production	10					✓	✓			✓			✓	✓		✓
	Maintain product control in the process to meet defined specifications	11	✓									✓			✓		

Fig. 1. Activities of DFSS methods.

Based on the study of the 11 activities of the DFSS methods and the 14 activities of the reference model for the MOP & D product development process, the authors proposed the integration of these activities by identifying the existing gaps, as shown in Figure 3, in order to allow alignment of the concepts and the design of a conceptual reference model PDP oriented to DFSS.

Macro-phases	Phases	Stages	The MOP&D Model (Pereira, 2014)
Pre-Development	Initialization	1	Statement of Demand
	Planning	2	Scope Definition
		3	Project Planning
Development	Design	4	Study of Principles
		5	Conceptual Design
		6	Preliminary Design
		7	Detailed Design
		8	Refinement of the Design
	Implementation	9	Manufacturing Process Design
		10	Manufacturing and Finishing Product
		11	Marketing Planning
Pos-Development	Production	12	Product Launch
	Maintenance	13	Review Post Launch
		14	Discontinue Product

Fig. 2. Reference models for Process Development Product

INTEGRATION OF THE ACTIVITIES/OBJECTIVES OF THE DFSS METHODS IN THE ACTIVITIES OF THE MOP&D MODEL (PEREIRA, 2014)		DFSS METHODS													
		DMADIC	DMADOV	DDOV	ICOV	DMEDI	DCCDI	I ² DOV	PIDOV	IDDOV	DIDES	CDOV	DCOV	IDEAS	DMADV
Statement of Demand	1	✓	✓		✓	✓	✓	✓	✓	✓			✓	✓	✓
Scope Definition	2	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓
Product Planning	3														
Study of Principles	4														
Conceptual Design	5		✓		✓		✓					✓			✓
Preliminary Design	6														
Detailed Design	7	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Refinement of the Design	8		✓	✓	✓	✓		✓	✓	✓			✓		✓
Manufacturing Process Design	9								✓						
Manufacturing and Finishing Product	10		✓	✓	✓			✓	✓		✓	✓		✓	✓
Marketing Planning	11														
Product Launch	12														
Review Post Launch	13														
Discontinue Product	14														

Fig. 3. Activities of the DFSS methods contemplated in the reference model MOP&D

3 Results

Following with the analysis of the 11 activities of the phases and gaps observed in the DFSS methods by the authors Francisco et al, 2019, a constructive correlation of these activities was sought with the 14 activities presented in the reference model MOP&D idealized by Pereira (2014). That said, it was possible to outline the construction of a conceptual model for the product development process oriented to DFSS. In the DFSS-PDP conceptual model, the 3 macrophases of the product development process are being contemplated - Pre-development, Development and Post-development, and each macrophase is fragmented into 5 phases - Planning, Design, Implementation, Industrialization and Monitoring. The phases of the DFSS-PDP model are broken down into 8 stages, in which the activities relevant to each phase of the model will be performed, as well as the implementation of engineering tools and techniques. Therefore, the DFSS-PDP model emphasizes the deficiencies analyzed in the DFSS methods and incorporates with the integrated product development model MOP&D (Pereira, 2014), idealizing a conceptual model for the process of developing a feasible product for application in the durable goods industry that can allow the organization a better performance of the quality of the product and process, promoting cost reduction and preventing failures during the manufacturing process.

Figure 4 summarizes the conceptual model DFSS-PDP conceived by merging the studies of the DFSS methods and the reference model MOP&D. A questionnaire to assess the structure of the proposed reference model, including the proposed phases, activities, tools and engineering techniques, summarized in Figure 5, was directed to five specialists in the area of durable goods product development, working in national and multinational companies of different industrial segments. In the model evaluation

questionnaire, the Likert Scale was applied with a variation from 1 to 5, with the following qualitative representation: Does not meet the expectation; meet the expectation a bit; partially meet the expectation; meet the expectation almost fully and meet the expectation fully was applied to analyze the degree of importance observed by the specialists. Through Cronbach's alpha reliability analysis, it was possible to guarantee the consistency of the questionnaire for the model, in which it was validated with an alpha value of 0,78. The result obtained was shown to be promising, since the coefficient value is above 0.70.

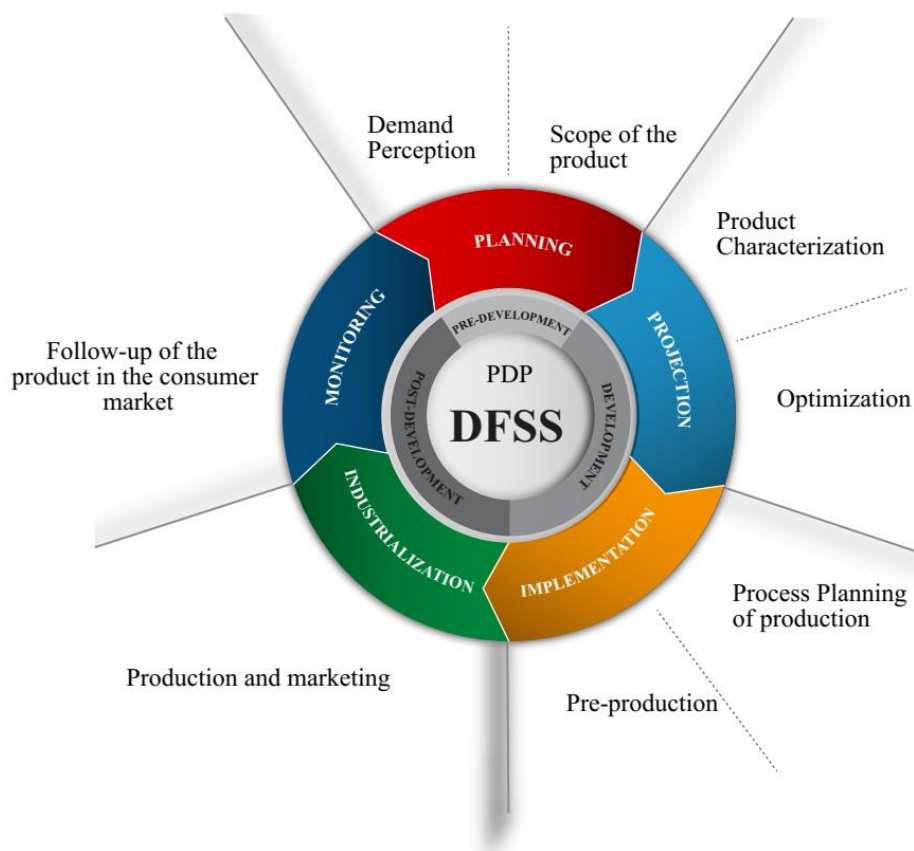


Fig. 4. Conceptual model for the product development process oriented to the Design For Six Sigma.

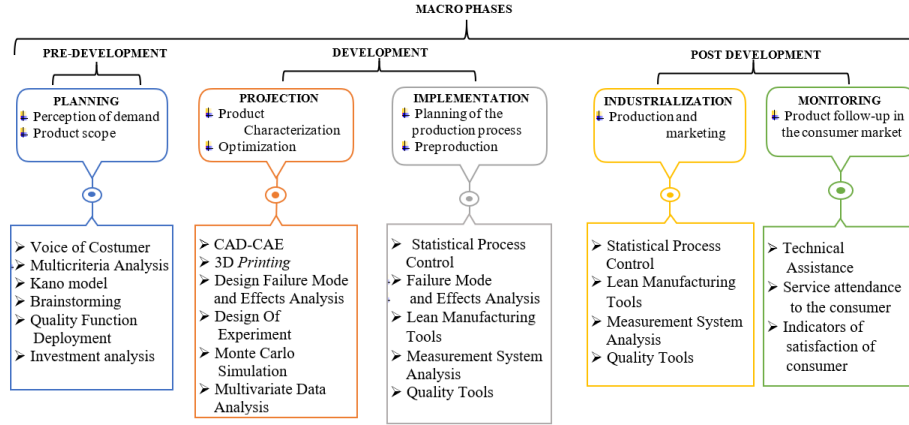


Fig. 5. Engineering tools and techniques suggested for the proposed model.

4 Final Discussion

The present study revealed that the application of Design For Six Sigma and its various methods allows to ensure reliability and convergence to product specifications during the development process. However, DFSS methods do not systematize a product development process from initialization up to product discontinuity PDP reference models seeks to systematize and address the entire product life cycle. Thus, the authors identified the key activities performed by the DFSS methods, summarized in 11 activities, which were incorporated into the 14 key activities of the reference model for the MOP&D product development processes. Therefore, the authors integrated these activities, based on a constructive and theoretical research relationship, led to the alignment of a conceptual reference model for the DFSS-oriented product development process. The model proposed by the authors, aims to ensure greater reliability and robustness to the product development process with reduction / elimination of operational weaknesses through the application of appropriate techniques and tools in all phases of the product development process, from initialization up to discontinuity of the product on the market. The proposal of the PDP-DFSS conceptual model is to provide a dynamic and friendly product development system capable of contemplating the expectations of the organization and the consumer in the product development process in less time, competitive price and cost reduction.

The PDP-DFSS conceptual model was evaluated by experienced professionals in the product development area, who, through a questionnaire, evaluated the structure of the conceptual model with the proposed phases, activities, tools and engineering techniques. In the analysis of the questionnaire's consistency, Cronbach's alpha coefficient was applied, presenting a value of 0,78. Therefore, the reliability of the results obtained was verified, ensuring greater robustness and relevance to the research. The object of exploration of future research, includes the application of the conceptual model PDP-DFSS in the development of a product.

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