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Exploring the relationship between product development process and firm performance under the moderating effect of 3D technology and additive manufacturing

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Abstract

The present paper aims to verify the influence of innovation in the product development process on the performance of firm, based on 3D modeling and additive manufacturing (AM), in the perspective of value co-creation. A case study was applied in the (Firm MEDIMAT - Used skull) field of the medical sciences in development of patient-specific m*axillofacial prosthesis.* The research involved the intervention of experts - multidisciplinary teams, doctors, engineers, manufacturers of prosthesis, selected by technical-scientific criteria. The data were extracted using an assessment matrix. To reduce subjectivity in the results achieved the following methods were used complementarily and in combination: multicriteria analysis, psychometric scaling, Spearman and neurofuzzy technology. The results were satisfactory, validating the submitted proposal, allowing to show that it is possible to combine additive manufacturing techniques, traditional processes of production of components and the incorporation of other components, allowing to develop innovative products in very short time frames, with market acceptance and creating business and client value. The use of additive manufacturing techniques has been effective in the reduction of time of product development, helping identify flaws and improving the final quality of the product, since it is possible to perform repetitive tests, such as building a prototype, testing it, re-designing it, building it and testing it again.

Keywords: Innovation in the PDP; patient-specific m*axillofacial prosthesis;* performance of firm; value co-creation; 3D modeling and additive manufacturing.

1. Introduction

Recently, relevant changes have made organizational boundaries more fluid and dynamic in response to the rapid pace of knowledge diffusion (TEECE, 1986), and innovation and international competition (DAMANPOUR, 1996). This helps to reconsider how to succeed with innovation (TEECE, 1986; WHEELWRIGHT AND CLARK, 1992). Thus, innovative companies make use of their capabilities to appropriate the economic value generated from their innovations (TEECE, 1986). Therefore, the supply of innovative products is presented as a quality standard in the race for pressing demands. It is believed that companies that can offer their products to customers more efficiently and faster will probably be in a better position to create a sustainable competitive advantage (Abd Aziz and Samad, 2016) due to knowledge and innovation (TEECE, 1986; JOHANNESSEN, OLSEN AND OLAISEN, 1999).

The introduction of new technologies is clearly evident in innovative products and it is considered one of the most remarkable ways of promoting new functionalities and improving the performance of existing products (Madu, 1989), in addition to being one of the inducers to create competitive advantages in the global market (CAVES, 1979). In this sense, the incorporation of 3D modeling and additive manufacturing technologies, when used in an appropriate way and based on projective methodology, enables innovation, regardless of the complexity of the object intended to be designed. In this perspective, the present paper aims to verify the influence of innovation in the product development process on the performance of firm, based on 3D modeling and additive manufacturing, in the perspective of value co-creation.

The use of additive manufacturing techniques has been effective in the reduction of time of product development, helping identify flaws and improving the final quality of the product, since it is possible to perform repetitive tests, such as building a prototype, testing it, re-designing it, building it and testing it again. As such, it enables to create client and business value. Creating value involves innovation that creates or increases valuation of the benefits from consumption. A case study was applied in the (Firm MEDIMAT - Used skull) field of the medical sciences in development of patient-specific m*axillofacial prosthesis.* The article is divided according to the following sections: Background Framework of conceptual model and hiphotesis; Verification of the conceptual model and subjacent analyzes subjacent; conclusions and implications.

2. Theoretical Background

The interest in developing customized prostheses that offer a higher quality of life to the patient is growing. An acceptable methodology to manufacture customized prosthetics patients within a few days consists of acquiring two-dimensional medical images by CT (Computed Tomography) or NMR (Nuclear Magnetic Resonance);transforming the medical images into three-dimensional virtual models, modeling the virtual prosthesis and the fixation systems in 3D CAD; manufacturing of the model (of the prosthesis and fixation systems) by additive manufacturing; making chemically-inert ceramic moldings; and to manufacture prostheses in biocompatible metal alloys (Cobalt-Chromium alloys, Titanium and its alloys and some stainless steels) by the precision casting process by lost models.

Recently, reverse engineering and the increasing development of modeling technologies based on medical images obtained from CT and NMR, among others, allow the construction of three-dimensional anatomical structures models (3D CAD). Based on these three-dimensional models, advanced manufacturing techniques designed by additive manufacturing have been used to construct physical models whose main applications are BÁRTOLO AND BIDANDA, 2008; WINDER AND BIBB, 2006; FÉLIX et.al, 2011): surgical training (simulation); preoperative planning; provision of guidelines during surgery; improvement of diagnostic quality; design of osteo-integrable fixation devices; manufacture of prostheses for the patient; elaboration and clarification for the patient/family and obtaining consent for the intervention. It was observed some progress in the field of additive manufacturing, with some development also related to the design of devices / approaches to applications in tissue engineering.

In a study conducted by Patricio et.al (2013), the authors investigated the use of PCL and PCL / PLA scaffolds produced by using a new additive biomanufacturing system called BioCell Printing. Scaffolds are used in tissue engineering as a physical and biological support for seeding cells, and transplanting them into an organism (Lebourg and Suay and Ribelles, 2012; Chen, Yoo and Atala, 1999). Poly (İ-caprolactone) (PCL) is extensively used to produce scaffolds for tissue engineering applications due to its biocompatibility, biodegradability, structural stability and mechanical properties. The results showed that BioCell Printing system produces scaffolds with regular and reproducible architecture, presenting no toxicity and enhancing cell attachment and proliferation.

It was also possible to observe that the addition of PLA to PCL scaffolds strongly improves the biomechanical performance of the constructs. Patricio et.al. (2014) estudaram the effect of poly lactic acid (PLA) addition into poly (e-caprolactone) (PCL) matrices, as well the influence of the mixing process on the morphological, thermal, chemical, mechanical and biological performance of the 3D constructs produced with a novel biomanufacturing device (BioCell Printing). Results showed that the addition of PLA to PCL scaffolds strongly improves the biomechanical performance of the constructs. Additionally, polymer blends obtained by solvent casting present better mechanical and biological properties, compared to blends prepared by melt blending.

In summary, the manufacture of a patient customized prosthesis has several advantages such as: reduction of the time required for the execution of the surgical procedure; reduction of risks and suffering for the patient; more efficient assembly, being applied directly to the damaged area without the need to remove large amounts of healthy bone; repairing of large affected areas (large empty spaces); manufacture of complex forms; reduction of surgical revisions. Through the use of suitable software such as *Materialise*, it is possible to isolate certain organs or tissues, obtaining a set of data that can be used for the manufacture of exact replicas of the organ through additive manufacturing technologies (FELIX et.al. (2011).

3. Methodological Framework

3.1. Framework of Conceptual Model: Constructs and hiphotesis

This section examines the conceptual model (Figure 1) and presents the hypotheses to be tested throughout this work.

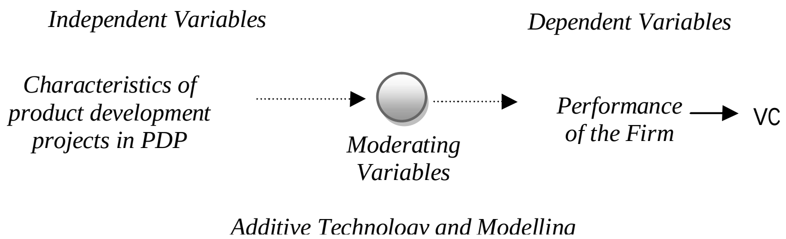

Figure 1: Framework of Conceptual Model

The following variables and hypotheses of this study were raised:

Independent Variables: from the findings in the literature the following Characteristics of product development projects were identified: Production capacity (PC); Congruence with the strategy (CS) ; Strength of the Client (SC); Market research (MR); Impact on Strategy (IS) ; Technical Complexity (TC) ; Costs (C) ; *Client needs analysis* (CNA) ; Durability technical and market (DTM) ; Financial Risk (FR); Platform for growth (PG) ; Channels to Market (CM); Skills (SK); Access to external technologies (AET); Risks of environmental security (RES); Proprietary position (PP); Synergy with other business operations (SOBO); and Raw material (RM).

Moderating variables: from the findings in the literature were identified: Advanced systems modeling 3D CAD and rapid prototyping and additive technology.

Dependent Variables: the following dependent variables were selected for this research: *Performance of the Firm:* P1: Impact on Customer; P2: Business results; and P3: Percentage of Sales Innovative Products.

Hypothesis:

H1: The modeling 3D CAD and rapid prototyping and additive technology influence to a greater or lesser degree the performance of firm in the PDP.

H2: Optimal Efficiency Rate of effects of the incorporation of technological innovations based on 3D modeling and additive manufacturing in the performance of company PDP depends of the combination and interaction of the projects characteristics of the companies.

3.2 Sample and Data Collection

The case study of multiple products was elaborated in a MEDIMAT firm - Used skull, in a field of the medical sciences in development of patient-specific m*axillofacial prosthesis*, in Portugal. The study was designed, based on the literature and confirmed by the assessment of experts. The research involved the intervention of experts, selected by technical-scientific criteria. The research involved the intervention of experts - multidisciplinary teams, doctors, engineers, manufacturers of prosthesis, new product project managers, experienced product planning personnel, innovation managers, engineers, designers, organizational managers, R&D managers, technology managers, planning, and technological innovation and modeling managers. The data collection was performed using a scale/matrix assessment questionnaire. The experts issued their judgments through a scale questionnaire for the first external validation. Before applying the final collection instrument, a pretest was conducted with experts to clarify whether the instructions were clear and objective; to verify that the questions were objective and without interpretation ambiguity; and to investigate possible comprehension problems by the experts on the expected responses. There were few adjustment suggestions. To reduce subjectivity in the results achieved the following methods were used complementarily and in combination: multicriteria analysis, psychometric scaling and neurofuzzy technology. Next, these procedures were detailed.

4.Conceptual Model Verification and Underlying Analyses

This section presents the verification procedures for the conceptual model. This article aims to show the effects of the incorporation of technological innovations based on 3D modeling and additive manufacturing in the performance of companies, in the PDP. This section is structured in Four phases: *Phase 1: Determination of Critical Success Factors (CSF) of firm. Phase 2: Identification and evaluation of characteristics of product development in relation to CSFs. Phase 3: Evaluation of characteristics of product development projects - PDP in relation to performance of firm, under modeling 3D CAD and additive technology,* and *Phase 4: Determination of the effects of the incorporation of technological innovations based on 3D modeling and additive manufacturing in the performance of company using Neurofuzzy Technology and value co-creation.* Next, these procedures were detailed.

Phase 1: Determination of Critical Success Factors (CSF) of firm

This phase is focused on determining the CSF, and is itself structured in two stages: (A) identification of CSF and (B) evaluation of CSF. As a result, a hierarchical structure of CSFs is obtained.

Phase 2: Identification and evaluation of characteristics of product development in relation to CSFs

In this phase are evaluated the characteristics of product development projects fuzzy front-end PDP in relation to CSFs, in light of literature and the Method of Categorical Judgments of Thurstone (1927). Thus, the research is based on the literature and confirmed by the assessment of experts. In other words, prioritize the “characteristics of product development projects” according to their classification using the method Categorical Judgments. After this procedure, the following characteristics are evaluated using the multicriteria methods in the light of the data obtained by the experts. The methods used were *Compromise Programming, Electre III and Promethee II*.

Phase 3: Evaluation of characteristics of product development projects - PDP in relation to performance of firm, under modeling 3D CAD and additive technology

In this section the evaluation of characteristics of product development projects fuzzy and performance of firm are determined using Spearman's correlation. The method is often used to describe the relationship between two ordinal characteristics. The data are extracted by the experts from a judgment matrix.

Phase 4: Determination of the effects of the incorporation of technological innovations based on 3D modeling and additive manufacturing in the performance of company using Neurofuzzy Technology and value co-creation

This phase focuses on determining the Optimal Efficiency Rate (OER) of the effects of the incorporation of technological innovations based on 3D modeling and additive manufacturing in the performance of company using Neurofuzzy Technology. It is a process whose attributes usually possess high subjectivity characteristics, in which the experience of the decision maker is very significant. Thus within this spectrum there is the need for a tool that allows adding quantitative and qualitative variables that converge towards a single evaluation parameter (CURY,1999); Von Altrock, 1997). The model shown here uses the model of Cury (1999). Based on the Neurofuzzy technology, the qualitative input data are grouped to determine the comparison parameters between the alternatives. The technique is structured by combining all attributes (qualitative and quantitative variables) in inference blocks (IB) that use fuzzy-based rules and linguistic expressions, so that the preference for each alternative priority decision of the optimal rate of the effects of the additives technologies and modeling 3D on the performance determinants, in terms of benefits to the company, can be expressed by a range varying from 0 to 10. The neurofuzzy model is described below.

Determination of Input Variables (IV): This section focuses on determining the qualitative and quantitative input variables (IV). These variables are extracted from the independent variables (dimensions of Characteristics of product development projects). The linguistic terms assigned to each IV are: High, Medium and Low.

Determination of Intermediate Variables and Linguistic Terms: The qualitative input variables go through the inference fuzzy process, resulting in linguistic terms of intermediate variables (IVar). In summary, the fuzzy inference occurs from the base-rules, generating the linguistic vector obtained through the aggregation and composition steps. For example, when the experts' opinion was requested on the optimal efficiency rate of effects of the incorporation of technological innovations based on 3D modeling and additive manufacturing in the performance of company, the response was 8.0. Then the fuzzification (simulation) process was carried out, assigning LOW, MEDIUM and HIGH linguistic terms to the assessment degrees at a 1 to 10 scale. Degree 8, considered LOW by 15% of the experts, MEDIUM by 45% and HIGH by 40% of the experts. In summary, the expert's response enabled to determine the degree of certainty of the linguistic terms of each of the input variables using the fuzzy sets. The results confirm the *H2: optimal efficiency rate of effects of the incorporation of technological innovations based on 3D modeling and additive manufacturing in the performance of company, in the PDP depends on the combination and interaction of the projects characteristics of the companies.* The generic fuzzy sets were defined for all qualitative IVars, which always exhibit three levels of linguistic terms: a lower, a medium and a higher one. After converting all IVars into its corresponding linguistic variables with their respective DoC, the fuzzy inference blocks (IB), composed of IF-THEN rules, are operated based on the MAX-MIN operators, obtaining a linguistic value for each intermediate variable and output variable of the model, with the linguistic terms previously defined by the judges. With the input variables, the rules are generated. Every rule has an individual weighting factor, called Certainty Factor (CF), between 0 and 1, which indicates the degree of importance of each rule in the fuzzy rule-base. And the fuzzy inference occurs from the rule-base, generating the linguistic vector OV (OV- Output Variable*)*, obtained through the aggregation and composition steps.

Determination of Output Variable – Optimal efficiency rate of effects of the Incorporation of technological innovations based on 3D modeling and additive manufacturing in the performance of company. The output variable (OV) of the neurofuzzy model proposed was called Optimal Efficiency Rate of optimal efficiency rate of effects of the incorporation of technological innovations based on 3D modeling and additive manufacturing in the performance of company. The fuzzification process determines the pertinence functions for each input variable.

Fuzzy Inference: The fuzzy inference rule-base consists of IF-THEN rules, which are responsible for aggregating the input variables and generating the output variables in linguistic terms, with their respective pertinence functions.

Defuzzification: For the applications involving qualitative variables, as is the case in question, a numerical value is required as a result of the system, called defuzzification. Thus, after the fuzzy inference, fuzzification is necessary, i.e., transform linguistic values into numerical values, from their pertinence functions (VON ALTROCK, 2008).

Case Study: MEDIMAT firm (used skull) in the field of the medical sciences in development of patient-specific maxillofacial prosthesis

This application starts from the need to elaborate interventions in the manufacture of prosthetics according to the patient's needs. These are complex and frequent interventions. The manipulation of medical images from STL files, obtained from CT and MRI (DICOM files) imaging medical examinations, allows the rapid materialization of the organs and parts of the human body using the techniques of additive manufacturing, model conversion and precision die casting of biocompatible alloys, reducing the patient suffering through a better diagnostic, surgical planning and intervention and recovery time (FELIX et.al., 2012). A methodology accepted as being adequate to manufacture prosthetics customized to the patient within a few days consists of: acquiring two-dimensional medical images by CT (Computed Axial Tomography) or NMR (Nuclear Magnetic Resonance); transforming medical images into three-dimensional virtual models; modeling the virtual prosthesis and the fixation systems in 3D CAD; manufacturing of the model (both of the prosthesis and the fixation systems) by additive manufacturing technologies; making chemically-inert-ceramic moldings; and to manufacture prostheses in biocompatible metallic alloys (Cobalt-Chromium alloys, titanium and its alloys and some stainless steels) by the precision casting process by lost models.

The use of STL editors such as 3Matic and others, associated with 3D CAD software, allows the design of customized prostheses and optimized by multidisciplinary teams of doctors, engineers, prosthesis manufacturers, etc (FELIX et.al., 2012). In this perspective, the research was elaborated in the light of the specialized literature and to demonstrate the feasibility and plausibility of the modeling, a case study was carried out in the company MEDMAT for providing the DICOM file of the skull. The skull that served as a model for the development of prosthetics customized to the patient was provided by MEDMAT Innovation, Porto, Portugal, for scientific publication at INEGI (FELIX et.al., 2011, 2012).

From a purely academic perspective, and fundamentally with the objective of acquiring some knowledge in the manipulation of biomodelation software, the process of selecting the areas that needed prostheses to perform the maxillofacial reconstruction of the model in question was started. The methodology used in the approach to the solution of this kind of problem was and it is recommended that it be always implemented with the support of multidisciplinary teams of professionals from several areas of knowledge, such as medicine, engineering, among others.

The objective of this work was mainly to develop a process of obtaining inert ceramic shells for biocompatible leakage with the focus on the leakage of titanium alloys. In all phases of skull modeling, we used the demonstration versions of software materialise, namely MIMICS, 3-Matic and Magics. Using the three-dimensional (STL) file provided by *Medmat Innovation*, the following methodology was used for the development of prostheses: (i) Evaluation of the three-dimensional model and identification of damaged areas of the skull; (Ii) definition of a plane of symmetry of the skull; (iii) selection of healthy skull parts for mirror copy for the damaged areas; (iv) mirroring of the healthy parts, in order to obtain the pre-forms of the future prostheses; (v) Subtraction of the intersection zones (excess of material) between existing bone and future prostheses; (vi) modeling of the future prostheses: obtaining uniform thin walls; smoothing the sharp edges; and definition of the fixation zones to the healthy bone.

The processing: the skull and prosthesis models were fabricated by stereolithography (SL 7810 resin) in a 3D SLViper equipment available at INEGI (Institute of Industrial Engineering / University of Porto) (Figure 2). In this step, the contraction that occurs in the casting process must be added to the additive manufacturing models. These models were used to produce silicon molds for wax injection (FELIX et.al., 2012). The production stages of silicon mold and wax models can be eliminated when using a one from AM in SL quikcasting because it can be used directly as a model to make the ceramic shells and has the great advantage of being easier to eliminate by calcination than the SL models. For the production of the ceramic shells, low reactivity ceramics were used using the previous experience described in some studies of the authors (FELIX et.al., 2012). The difficulties in filling the fine and complex forms during the leakage of titanium alloys are overcome through the use of vacuum and a differential pressure control system of the induction melting furnace existing in INEGI.

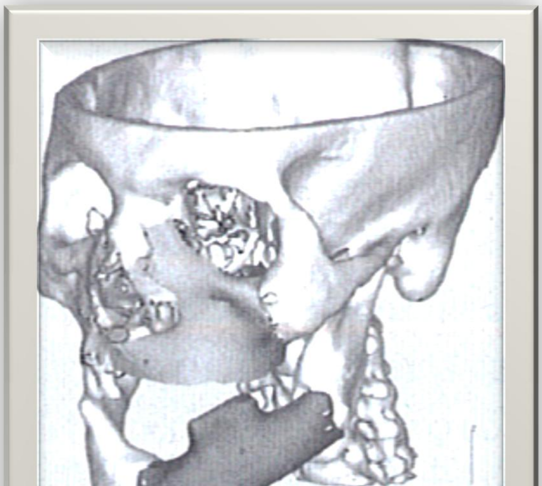

Figure 2: Mounting of the prostheses on the skull

This approach is valid also if a direct method (e.g. selective laser sintering or electron beam melting) to realise the prostheses is carried out (JARDIN, 2014). The disadvantage of the indirect method to manufacture the prostheses is contraction (I would prefer the term shrinkage) and the difficulty to fill all the parts of the mould with the ceramic powder (these concepts have been already provided within manuscript). The advantage is that there is more flexibility in the material selection and in the material design when using the indirect approach of AM through the mould & casting approach (DE SANTIS et al., 2005). For the manufacture of the ceramic shells ceramic particles and alloys were used. The stereolithography model (AM) used to manufacture the silicone mold and the silicone mold with the wax model (obtained by injection) inside the mold are shown below (Figures 3 and 4).

Figures 3 e 4: Stereolithography model (AM) used to manufacture the silicone mold and the silicone mold

The manipulation of medical images from STL files obtained from CT and MRI imaging (Dicom files) enables rapid materialization of the organs and parts of the human body using the techniques of additive manufacturing, model conversion and precision casting of biocompatible alloys, reducing the patient suffering through better diagnosis and surgical planning (FELIX et.al., 2012). The use of STL editors such as *3matic* and others, associated with 3D CAD software allows the design of customized prostheses and optimized by multidisciplinary teams of doctors, engineers, prosthesis manufacturers, etc. The use of additive manufacturing technologies associated with conversion processes, despite being costly processes, allows to materialize customized and optimized prostheses and test their fitness and fixation systems to other parts of the human body, which can also be obtained through these techniques (FELIX et.al., 2012).

5.Underlying Analyzes

This section is structured in three phases:

Phase 1: Determination of Critical Success Factors (CSF) of firm.

Phase 2: Identification and evaluation of characteristics of product development projects in relation to CSFs.

Phase 3: Evaluation of characteristics of product development projects in relation to performance of firm, under modeling and additive manufacturing. And

Phase 4: Determination of effects of additive Technologies and 3D on performance of firm in perspective of the characteristics of projects. Next, these procedures were detailed using the "Skull" product.

Phase 1: Determination of Critical Success Factors (CSF) of firm (production of Skull): The section present the results of critical success factors (CSF) of firm (Table 1).

Table 1: Classification of CSF

CSF	C1	C2	C3	C4	Total	Ranking
Economic /Financial	-1,22067	-1,22067	-1,22067	-0,43073	-4,09274	**2º**
Technical	-1,22067	-1,22067	-0,76471	-0,13971	-3,34576	**4º**
Market	-1,22067	-1,22067	-1,22067	-1,22067	-4,88268	**1º**
Political	-1,22067	-1,22067	-1,22064	0,13971	-3,52227	**3º**
Environmental	-1,22067	-1,22064	-0,13971	1,220642	-1,360378	**5º**

Phase 2: Identification and evaluation of Characteristics of product development projects in relation to CSFs

This section evaluates the Characteristics of product development projects in relation to CSFs. This procedure was developed using the multi-criteria analysis, with the methods Compromise Programinng, Electre III e Promethee II. The results produced by this prioritization enable managers to better focus their efforts and resources on managing the capacities that perform best, which results in achieving the goals sought by the companies. The results show the ranking of Characteristics in relation CSF: Strength of the Client (SC) and Client Needs (1ª); Congruence with the strategy (CS)(2º); Impact on Strategy (IS) (3º); Production capacity (PC) (4º); Costs (C) (5º); Market research (MR)(6º); Others. The prioritization process obeys the judgment of the evaluators (experts). With the results of the judgment matrix, the methods were applied: Promethee II, Electre III and Compromise Programming to evaluate the innovation capacities in relation to the performance of the companies. Next, the degree of correlation between the dimensions of projects characteristics and performance of the firm, under modeling 3D CAD and additive technologies was determined. For this Spearman's multivariate statistical technique was used. The technique adapts to the case in question.

Phase3: Determination of the effect of Characteristics of projects on the performance of firm under additive technologies

Using correlation of Spearman, the result show strongly correlation between ROI – Business results and Additive Technologies and Modeling 3D (0,9). From a business perspective, this can be explained by the need to conduct new technologies for development of new products and processes; in addition to product quality improvement. The Congruence with the strategy (CS), Market, Strength of the Client (SC), Production capacity (PC) / Access to external technologies (AET) and Additive Technologies and Modeling 3D are strongly correlated and together have a strong influence on the business return dimension (0,8). In this perspective in value create for the Client (Client Satisfaction), there is the strongly correlation between Additive Technologies and Clients Needs and Client Strongly (0,8). This confirms the hipothesis: *H1 - The modeling 3D CAD and rapid prototyping and additive technology influence to a greater or lesser degree the performance of firm in the PDP.*

Phase 4: Determination of effects of the incorporation of technological innovations based on 3D modeling and additive manufacturing in the performance of companies, in light of characteristics of projects using Neurofuzzy Technology

The results is described below.

Determination of Input Variables (IV): This section focuses on determining the qualitative and quantitative input variables (IV). These variables were extracted (11 variables) from the independent variables (dimensions of *characteristics of projects* of the company). The linguistic terms assigned to each IV are: High, Medium and Low. In summary, based on data collected, to achieve this step, the top 11 projects characteristics (Production capacity (PC); Congruence with the strategy (CS); Strength of the Client (SC); Market research (MR); and Others. For example (hypothetical), when the expert's opinion was solicited about which desired degree of projects characteristics the product development manager should have, the answer was 8.0. Next, the fuzzification process (simulation) took place, assigning the linguistic terms: LOW, MEDIUM and HIGH levels of evaluation on a 1 to 10 scale. For score 8, considered LOW by 0% of the specialists, MEDIUM by 55% and HIGH by 45%. The fuzzy inference takes place from the base of rules, generating the linguistic vector obtained through the steps of aggregation and composition.

Determination of Intermediate Variables and Linguistic Terms: The qualitative input variables go through the inference fuzzy process, resulting in linguistic terms of intermediate variables (IVar). Thus, the linguistic terms assigned to IVar are: Low, Medium and High. The intermediate variables were obtained from: A - Market Performance: Channels to Market (CM), Strength of the Client (SC), Market research (MR), *Client needs analysis* (CNA), Access to external technologies (AET); and Others. The architecture proposed is composed of nine expert fuzzy system configurations, qualitative input variables that go through the *fuzzy* process and through the inference block, thus producing an output variable (OV), called intermediate variable (IVar). Then, the IVars, which join the other IVar variables form a set of new IVars, thereby configuring a sequence until the last layer in the network. In the last layer of the network the output variable (OV) of the *neurofuzzy* Network is defined. This OV is then subjected to a defuzzification process to achieve the final result: Optimal Efficiency Rate.

Determination of Output Variable: Optimal efficiency rate of effects of the incorporation of technological innovations based on 3D modeling and additive manufacturing in the performance of company (Client Satisfaction). The result, i.e., the numerical value scale corresponds to value for optimal efficiency rate. With this result (optimal efficiency rate) produced for a better combination and interaction of characteristics of project ("Skull") of the Company, that converged toward a single parameter. To illustrate this, assuming that the study-object company demonstrate the following optimal efficiency rate of effects of the incorporation of technological innovations based on 3D modeling and additive manufacturing on the performance of company, i.e., creating value for the customer (based on project characteristics) (Figure 5).

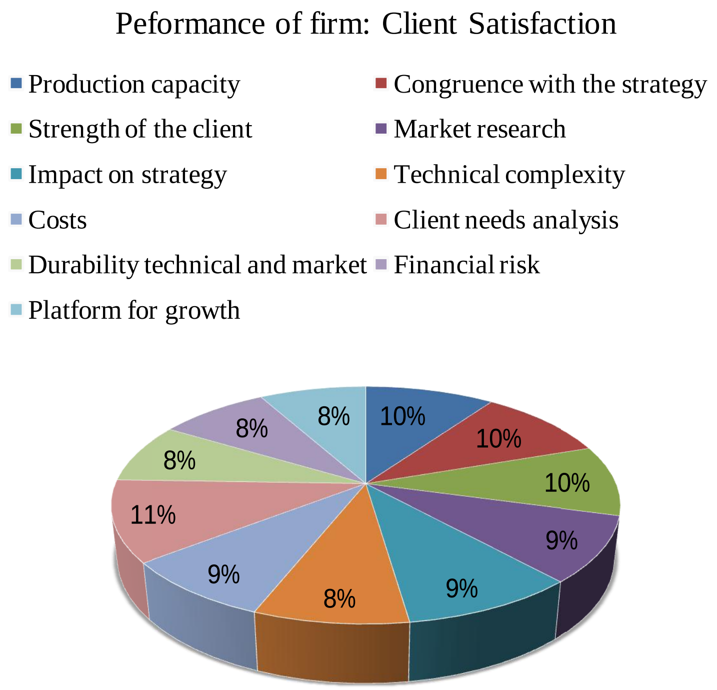

Figure 5: Optimal efficiency rate of effects of the incorporation of technological innovations based on 3D modeling and additive manufacturing in the performance of company for each project characteristics

It is concluded that: "Client needs" analysis and "Strength of the client", show efficiency in the combination of characteristics of project "Skull" in perspective of value creation based on Client Satisfaction.

5. Conclusion

The present paper aims to verify the influence of innovation in the product development process on the performance of firm, based on 3D modeling and additive manufacturing, in the perspective of value co-creation. A case study was applied in the (Firm MEDIMAT - Used skull) field of the medical sciences in development of patient-specific m*axillofacial prosthesis.* The study sought to cover a gap in the literature on the effects of 3D modeling and additive technologies on the company performance in the light of creating value for the customer, and therefore for the business. It is believed that technological interventions such as the present application are undoubtedly more effective, faster and more accurate.

The increase in the life expectancy has become the main cause of the pathology that promotes the need for interventions in the manufacture of prostheses. However, they are rarely tailored to the patient, requiring complex and frequent surgical procedures. Therefore, the interest in developing customized prostheses that offer a higher quality of life for the patient is growing. Additive manufacturing presents itself as a plausible and feasible mechanism aimed at improving the quality of lifes (FELIX et.al., 2012).

The general additive manufacturing has significant advantages for engineering and medicine, such as optimizing the interface between operator and software; reduction of time, cost and errors of development of the physical model; application in manufacturing operations of future prototypes to increase the productivity and accuracy of physical models; production of other manufacturing tools; and gatheringof fine details and producing physical models. The results refer to additive technologies as a mechanism that allows to increase business value from the perspective of the project, especially in the strength and needs characteristics of the client, aligned with the strategy and costs of production.

The effect on the development of new products by technologies is intensive. It confirms the state of the art, in which companies must recognize the technical and scientific potentialities that give quick answers to the existing techniques, allowing to meet the demands of markets to be constructed or changed, since it allows the development and introduction of new products, the reduction of production costs, more competitive prices and higher financial return, and customer value creation (KAFOUROS AND BUCKLEY, 2008). Creation refers to the process of integrating different resources (firms and customers, co-production, co-design, and co-development) from different actors in order to actualize their value potential. Value is understood as customer value, firm value, or both (SAARIJÄRVI, KANNAN, AND KUUSELA, 2013).

According to the dominant literature (PRAHALAD AND RAMASWAMY, 2002; LUSH, VARGO, AND WESSELS, 2008), BALLANTYNE AND VAREY (2006), current research shows a clear trend to understand the value of the customer produced not by the producing company, but by the consumer when he is using the product and when he is interacting with the suppliers in the process of co-creation with them. In this perspective, the introduction of new technologies is considered one of the most remarkable ways of promoting the value creation.

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