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New Product Development Process on High-Tech Innovation Life Cycle

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***Abstract*—**This work will provide a new perspective of exploring innovation thematic. It will reveal that radical and incremental innovations are complementary during the innovation life cycle and accomplished through distinct ways of developing new products. Each new product development process will be constructed according to the nature of each innovation and the state of the product development. This paper proposes the inclusion of the organizational function areas that influence new product´s development on the new product development process.

***Keywords*—**Cross-functional, Incremental Innovation, New Product development Process, Radical Innovation

I. Introduction

WINNERS in this permanent changing environment, are those who pursuit continuously new methods to generate competitive advantages [1]. High-Tech enterprises successfully accomplished these advantages through the creation of innovations [2], [3]. Knight [4] defines innovation as *"the adoption of a change which is new to an organization and to the relevant environment"*. In order to capture the essence of innovation from an overall point of view, Garcia and Calantone [5] reviewed the 1991 OECD study quoting that "*innovation is an iterative process initiated by the perception of a new market and/or new service opportunity for a technology-based invention which leads to development, production, and marketing tasks striving for the commercial success of the invention*".

The continuum searching of innovations in order to guarantee high-tech company´s sustainability [2], [4], [6], led many researchers to investigate in the innovation field. However, these investigations had some level of ambiguity due to the abundance of different innovation characteristics and its categorization aim [5], [7]. Since the categorization of different types of innovations provide a better identification of all organizational and environmental influences to the innovation [4]-[10], becomes essential to reduce the categorization ambiguity by addressing the type of innovation according to its application field for an optimum innovation management. Thus, according to the type of change in an organization, it is possible and useful to theorize innovation in multiple types [4], [7], [9]. In high-tech industry, companies aim to change in technology or product field [4], [7].

In environments of rapid technological change, like in high-tech industries, companies have to be aware to the strategy of developing new products or innovations [2], [4]. High-tech companies can never be certain of how they will perform in the future [3] and much less when their new technologies emerge [11]. Either the new product development (NPD) succeeds spectacularly or the company wastes a large amount of resources and don´t innovate [3]. Thus, to companies sustain competitive being innovative, all their organizational structure must be align to the contingencies of their environment, strategy, and technology [1]. Besides a perfect organizational structure configuration to a timely responsive and flexible product innovation, it´s necessary to integrate company´s capabilities in executing and managing the NPD process in order to innovate [12]-[14].

It is important to clarify that an idea to be considered an innovation, have to pass through the idea incubation into production, and add economic value to the firm, becoming the output of the NPD process [5]. This process is probably the best decision factor of the success or failure of the new product [5], [14], [15] and a standard procedure required from ISO 9000 and adopted by the European Community members and many other countries to provide quality to the new product and consistently in meeting customer requirements [16].

Thus, the process to innovate will involve high-performance routines to drive new products from idea to commercialization [12], [17] incorporating activities from distinct organizational function areas [12], [18], [19], according to the nature of the innovation.

II. Literature review

A. Innovation

There are many investigations with the aim to classify innovations [2], [4], [5], [7]-[10], [20]. Essentially, innovations are classified according to the functional areas that they will impact [4], [7]. Previous researchers revealed that innovations are differentiated as administrative, technological, organizational-structure, or in terms of product innovation. Later, under a technical/product innovation approach, Dewar and Dutton [7], in 1986 proposed radical and incremental innovations. In 2002, Garcia and Calantone [5] expend this categorization introducing the "*really new innovation*". However in a management point of view, it is only interested in classifying completely different typologies,

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due to the fact that completely different innovation characteristics will truly differentiate their NPD process. If the characteristics are very similar, the management focus will be dispersed.

Incremental innovation refers to a progressive, continuous, and cumulative innovation without a new scientific component for the improvement of the present technology [2]. In a High-tech product perspective, incremental innovation is the incremental/improvement of the existing technology/product in the existing market [5], [10], generally it involves the next version of an existing product or process [10], [20]. This type of innovation can be a quick and effective competitive weapon in the short-term growth of the organization, protecting or increasing the company´s position on market [5], [9], [10]. For example, besides improving existing technology, incremental innovation can actuate accordingly to the markets: an obsolete technology from a certain industry may be new to a different market [5].

While incremental innovation is often built on knowledge collected around consumer´s experiences with the existing product, radical innovation is built upon the needs of those costumers [20]. Radical innovations is not used to address a demand variance, but instead to emerge and create entire industries, products, and markets, making the concurrent products obsolete [5], [21].

Ettlie et al. [9] states that "*organizations match their structure for the innovation situation*". In addition, Koberg et al., [21] identify the organizational environment, structure, process, and management, the factors that most favor the frequency of incremental and radical innovations. Therefore, each type of innovation will entail different efforts from the organizations and will be executed according to the organization aims. While incremental innovation exhibits low levels of uncertainty, and usually follows a well-defined development organized process, radical innovation exhibits much higher levels of uncertainty, and is often transformative and disruptive of the existing organizational development process [8]. Their main characteristics will be distinguished in the table I.

TABLE I
RADICAL INNOVATION VERSUS INCREMENTAL INNOVATION

	Radical Innovation	Incremental Innovation
Organization Structure	Centralization Aggressive technology	Decentralization Traditional technology
Environment	High uncertainly	Moderate uncertainly
Innovation cause	Market needs	Consumer´s needs
Development process	Low level of knowledge High complexity	Moderate level of knowledge Moderate complexity
Technology	New	Existent
Duration	Long-term	Short-term
Risk	High risk	Moderate risk
Financial resources	High	Limited

B. New Product Development Process

The actual process of product development is still considered among innumerous researchers as a "black box" [22]. Since many investigators view the NPD process within different perspectives [17], [18], [22]-[24], this paper will map five NPD process in the table II, based on a technology perspective. Nevertheless, most of them based their process on staging the NPD process accordingly to the state of the product during its development.

TABLE II
MAIN NPD PROCESS CHARACTERIZATION

Author (year)	NPD process	NPD stages
Kagioglou, Cooper, Aouad, Sexton, Hinks, and Sheath [18] (1998)	4 main stage-gate® system containing 10 phases	Pre-project Pre-construction Construction Post-completion
Boer [24] (1999)	5 stages	Raw ideas Conceptual project Feasibility Development Early commercialization
Cooper [17] (2001)	6 stage-gate® system	Discovery Scoping Business case Development Testing and validation Launch
Schroeder [23] (2003)	3 stages	Concept development Product design Pilot production/testing
Ulrich and Eppinger [22] (2004)	5 stages	Concept development System level design Detail design Testing and refinement Production ramp-up

Schroeder [23] indicates three typical development phases: Concept development, Product design, and Pilot production/testing . While Ulrich and Eppinger [22] propose a NPD process focus on the product design, Boer [24] approaches the NPD process through the influence of R&D organizational department. In Ulrich and Eppinger ´s point of view, the new product to be developed have to pass throughout the "*concept development*", "*system-level design*", "*detail design*", "*testing and refinement*", and "*production ramp-up*". According to Boer, the NPD will differentiate five R&D stages during its development: Beginning with "*Raw ideas*", the second stage is the "*Conceptual project stage*". Next will be the "*Feasibility stage*" and "*Development stage*". Finally, the fifth and last stage is the "*Early commercialization stage*". One other researcher, Cooper [17], proposed six stage-gate® systems, allowing in each stage, separated by gates, the involvement of multiple functional departments to provide an in-depth review and consequently a control checking points. Each gate is a control checkpoint or a go-no-go decision maker which according to a specific criterion, transforms the outputs from the previously stage into the inputs of the next stage. His model drives new products through "*Discovery*", "*Scoping"*, "*Business case*", "D*evelopment*", "*Testing and validation*", until "*Launch*" stage. Kagioglou et al. [18] design and construct a NPD process based on four stage-gate® systems in the manufacturing industry. They incorporate in four stages distinct phases and distinguish "*hard gates*" from "*soft gates*" according to the level of importance applied in the decisions of each gate. As other investigators, they recognize the pre-project as a NPD stage. The mainly difference between their models is the conceptualization perspective. In other words, the difference of the models presented by these NPD researchers and many other investigators depends on the aim and on the detail that each one requires for efficiently characterize the development of new products towards their perspective. Although, it is possible to verify that the main activities and competences to develop new products are present within almost every NPD process.

There isn´t a consensus model to characterize which functional areas influence the NPD [19], [22], [25]-[27]. Essentially, it depends on company´s based-strategy [19], [22], the level of innovation and uncertainty [24], [28]-[30], and according to the particular characteristics of the product [22]. Almost every NPD studies focus their research on the cooperation of marketing and R&D to develop new products, although recent studies recommended a more complex, real and numerous cooperation. Ulrich and Eppinger [22] suggest marketing, design, and manufacturing as the most central functions on NPD. Song et al. [29] adds to marketing and R&D, the production and finance. Bacon´s et al., [25] research, gave us a good example of the functional influences during the idea generation stage. They revealed that the creation of an idea requires an information flow between innumerous corporate or divisional functions, including engineering, research, marketing, and manufacturing.

In this NPD literature review it´s possible to conclude that many researchers agree in at least three fundamental stages on developing new products: The conceptual, development, and commercialization. However, accordingly with Boer´s process and also with a six month NPD process analysis within a high-tech enterprise of photovoltaic tracking systems, it was verified that for efficiently manage the NPD process two more stages should be added to the main three: Feasibility and Validation.

III. MODEL

A. Innovation under enterprise´s life cycle

In the high-tech´s growth process for maintaining competitive advantage, emerges the necessity of choose the suitable innovation, whereas radical or incremental innovation in a dynamic and never-ending activity [1], [2]. Qin and Wang, [2] proposed four stages to characterize the growth process of high-tech firms: Start-up, Growth, Maturity, and Revival stage. They suggested that at the Start-up and Revival stages of high-tech enterprises, they should pursuit radical innovation, and at Growth and Maturity stages firms should adopt incremental innovations. Garcia and Calantone [5], research indicates that radical innovations are adequate for the early and final stages and incremental innovations for the intermediate stages (see figure 1).

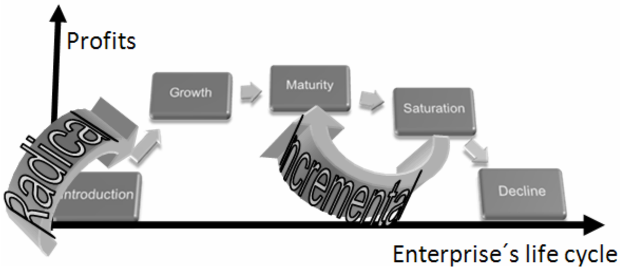

Fig. 1 Enterprise´s life cycle under innovation

Therefore, during the *enterprise´s life cycle*, the product´s introduction on the market could be better achieved with radical innovation, and to maintain the product on its level of maturity on the market, it should be subjected to incremental innovation. After the product reaches its decline in market, enterprises should again develop a new radical innovation approach. This process represented in figure 1, is in accordance with many researchers [2], [5], [32] that consider radical and incremental innovations complementary. While incremental innovation keeps companies competitive, radical innovation creates competitiveness [32]. Their relationship will ensure a competitive advantage over a long-term. The best product´s management will have to cover all its life cycle [18] including the development process of radical and incremental innovations.

Due to the radical and incremental complementarity during the enterprise´s life cycle, this work proposes a model of Innovation Life Cycle, through a continuous and cyclic process of radical and incremental innovation during the enterprise´s life cycle (figure 2).

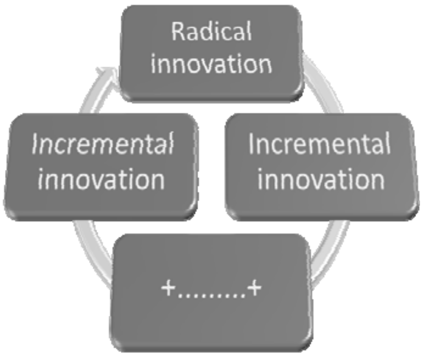

Fig. 2 Innovation under Enterprise´s Life Cycle

The idea generation arises from the conjugation between a market necessity and the company´s capabilities [5], [20], [21], [33]. While incremental ideas are created to assure customer´s needs, usually around consumer´s experiences with the existing product [20], radical ideas intents to create entire industries, products, and markets [5], [21]. Due to its distinct impact level, incremental innovation in comparison with radical innovation uses less functional work. Further, this work proposes for each innovation nature, a specific NPD process to provide a universal methodology in deploying innovations during the enterprise´s life cycle.

B. Proposed New Product Development process

It has been theorized and empirically tested that NPD process will change according to the characteristics of the innovation [5] and as Green et al. [33] states "*The better we understand this construct, the better we will understand other aspects of innovation management*". In addition, a survey conducted by Ettlie and Elsenbach [34] of 72 automotive engineering managers involved in supervision of the NPD process, found that about a third of the managers, modified their NPD process to optimize the development process according to the different types of innovation.

High-tech companies entail an enormous focus in providing all their resources in the development of innovations [2], [4], [35], [36], [37]. As the development of new products requires distinct capabilities from different functional areas [16], [20], [19], enterprises will integrate cross-function according to the competences needed during the development of new products [36], [37]. Moreover, almost every high-tech enterprises also look to the stage-gate systems as a model to conciliate their environment high pressures in reducing the time of developing new products and at the same time improving product quality [6], [18]. These formal gates between stages can provide an opportunity for multifunctional teams to review status, ensure consensus on objectives, and approve plans for the next NPD stage [17], [18], [24].

Thus, for a better NPD management, this work attends to detail the functional areas which influence the NPD process during each NPD stage, without falling into redundancy, and institute stage-gates to assured the quality of the product and of the NPD process. The better will be the organization of NPD data and its ability to transparency reality, superior will be its management and control. This work proposes an improvement of the Cooper´s NPD stage-gate® process, within a five stages and four gates. During this NPD process, each stage represented in the figure 3 will entail internal and external organizational resources, skills, and functional competences and through a determined criterion each gate will control and evaluate the procedures taken in the previous stage to decide whether the project should move forward [12], [15], [17], [20], [24], [28].

Each innovation´s NPD process will only differ regarding the amount of functional competences needed to accomplish its development. In this perspective, the expertise marked in a broken box in the figure 3, i.e. quality, at the feasibility stage production, and at the product concept stage marketing personnel, will really be insignificant during incremental development, since it is only need an overall knowledge of these areas which can be, and should be provided by the project team leader.

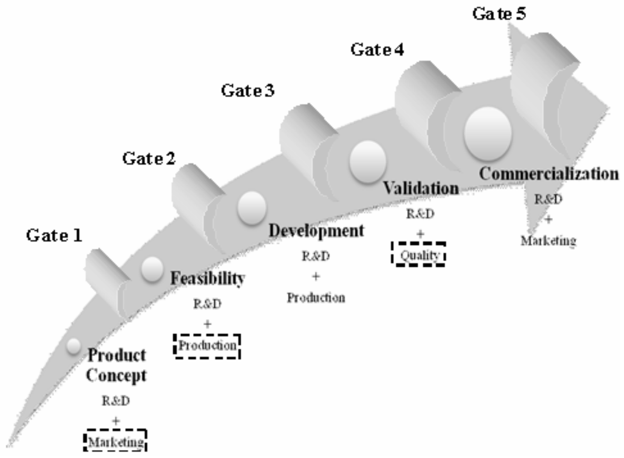

Fig. 3 Proposed NPD process

This NPD process was defined in terms of the state of the product during its development [22], [23] and was characterized regarding the organizational function areas that most influences the product at that time. This design is essentially made to better detect and face the high-risks on the development of new products, since the higher is the level of distinction between different NPD functional areas within each stage, the better will be the detection of risks and its assessment.

Through many cross-functional investigations on NPD [19], [22], [25], [28], [27], it´s possible to verify that the main functional areas which influence the development of new products are marketing, R&D, and production. Acknowledging these functions involvement with the work developed on each NPD stage [24], [28], [29], and a six month NPD monitorization of a high-tech enterprise, the quality department will perform almost all validation procedures. Therefore this work proposes its integration on the set of the functional areas that influence the development of new products. Each stage will contain current activities, which according to the NPD literature review can be briefly described as:

1. Product concept

The best factor of differentiation on NPD process from other competitors is the capacity of meeting customer needs [15]. Since the assessment of customer needs are incorporated in this phase, most of the NPD failures can be later associated with this phase [24]. This stage will integrate tremendous multi-functional competences [22] to create, recognize, formulate, and select the market opportunities [32] in accordance with company´s strategies and capabilities [24]. It is establish a set of specifications which measure in detail the customer pretentions to the product [22]. Usually, this process is performed informally, through discussions among scientists with industrial experience and marketers [24]. Before selecting the concept, the ideas generated are taken into conceptualization through its technology shaping [20], [22], [24], [32], and then it is taken a technological viability analysis to verify each economic potential, by comparing the strengths and weaknesses of the concepts [22]. Thereby, the product concept stage is accomplished through marketing and R&D cross-functional integration [22], [24].

The reality of the product development environment is against the common notion that after the initiation of the product development, the idea generation stage will be frozen [4]. Due to the market uncertainty, there could be the necessity of changing the primordial specifications of the product.

2. Feasibility

The next stage is the "*feasibility*" analyzes of the product concept. As Boer [24] states, "*the main tasks of this stage are to resolve the known issues and generate the cost and performance data that engineers and marketers need to undertake development*". Initially, this stage will verify if the technology of the product concept satisfies all customer needs [22] and then it will be addressed a set of product architectures, such as performance procedures, designs, materials, manufacturing cost estimation, and component standardizations to generate the data required to the next stage [22], [24]. After accomplish the feasibility stage, the costs of failures during the NPD process increase exponential [24], because the errors in the previous stages will be magnified. Thus, this stage, will confirm the NPD success before committing additional funds and to safeguard their business they should patented their innovation [38].

3. Development

Once the gate 2 opens the development stage, i.e. after being assured the data needed for the next stage, R&D department takes the product concept into manufacturing [24]. In this stage, prototypes will be manufacture according to the deliverables of gate 2 [15], [17], [20], [32]. This stage will comport time and extraordinary expenditures [20], [22], [24], [32].

4. Validation

After the development of the prototypes, the personnel responsible for its validation can actually interact with them in a realistic context [20] transforming ambiguity into concrete issues. Early in the validation stage, quality specialists review the product specifications through in house prototype tests, and field tests with customers, to insure that all product requirements, such as environmental and regulatory considerations, or even ISO standards, are achieved [16], [17]. After the product is in conformity, NPDT should provide all product´s documentation, including user manuals, production procedures, and installation instructions to be further used within the organization [16].

5. Commercialization

Most of the times, the technology innovation doesn´t itself create industry disruption [11], but together with its application on the market it does. Therefore, before the product is taken into full production, it´s distribution channels should be defined.

Even in the commercialization stage, R&D will interpret a small role. In case of the appearance of any issue associated to the product, the R&D personnel are the best experts to resolve it [24]. Therefore, the R&D will be responsible to control this stage, incrementing performance advances and to support customer needs.

As proposed in the figure 3, the R&D department is represented in all new product development process from the beginning to the end. This occurrence is in agreement with Boer´s [24] perspective and with an exploratory study of technology transfer and human interaction issues in Hi-Tech industrial organizations conducted by Jassawalla and Sashittal [26]. In their 46 R&D managers interviewed, they concluded that while R&D emerges in comparison with other functional areas in influencing the NPD, marketing is the other function that most participate in the NPD process, as can we verify in the product concept stage and at the commercial stage. Notwithstanding, each functional area will have a fundamental role in the life cycle process of NPD. While production functional area is concerned with effiency in production and cost minimization, R&D and Marketing have in general interesting in creating change through new products and new technologies [29].

IV. Conclusion and Future Research

This paper proposes a conceptual framework of the innovation life cycle in the high-tech industry, through several researches in the innovation area. The cycle proposed based on extensive literature review is characterized throughout the development of radical and incremental innovations. The proposed model emphasizes the complementarity of radical and incremental innovation, since radical innovation creates competitiveness and incremental innovation keeps companies competitive.

Each type of innovation will entail the same NPD stages, but due to its distinct development activities will require different cross-function integration. While incremental innovation should allow quick competitive advantage and a low project cost reducing the functional collaboration and NPD duration, the decision to innovate radically promotes greater changes to the organization´s operations incorporating a complex fusion of ideas and knowledge from different organizational domains. The adoption of the proposed NPD process for the innovation life cycle of a high-tech enterprise will establish its consistent application, reducing inexperience and mistakes through the process, and will provide a perfect organized data to allow a NPD management of excellence on high-tech companies.

The proposed model is currently being tested for future validation considering the projected organizational function areas and using the stage-gates system as point controls for NPD risk management.

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