R&D MANAGEMENT

Models with graphical representation for innovation management: a literature review

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In the last decades, the management of innovation has achieved increasing importance in both academic and business environments. For the companies, an effective engagement in innovation efforts involves the adoption of management models to guide the definition of organizational processes to conduct innovation opportunities throughout the organization. In this context, graphical representations can strongly communicate the central propositions of each model, accelerating the diffusion and influence of such models in both academic and business environments. Based on an academic database search, and snowball procedure, models were selected considering the unique characteristics of their graphical representation. This article contributes to the knowledge in the field by proposing a typology of innovation management models, highlighting model's biases, gaps, strengths and weaknesses, and by identifying important tensions among models that spillover to the innovation management field in both research and practice. This article discusses conflicts regarding the limits of the innovation process (events that start and end the process and complementary approaches), the limits of focusing on processes, the differentiation of research and development and new product development activities. In the end, the article addresses emerging approaches related to radical innovation, design thinking and startups, and stresses contributions for research and practice.

1. Introduction

Innovation management is a complex phenomenon with strong interdisciplinary characteristics, and its practice permeates many of an organization's focuses and functional activities (Tatikonda and Montoya-Weiss, 2001; McDermott and O'Connor, 2002). Innovation studies have been developed for decades and cover many areas of knowledge (Martin, 2012). Particularly in the management field, it is important to recognize seminal contributions such as those of Burns and Stalker (1961), who first related innovation in different forms of organizations, and Christensen (1997), who presented the concept of disruptive technology and its consequences for the management of current and new businesses, among many others. Utterback (1970) was one of the first authors who tried to model the innovation process, synthetizing it in a mnemonic and simple graphical representation. Because the models available in the literature often unfold into the specificities demanded by various conditions, this study focuses on general models. The aim of this study is to generate insights that enable a deeper understanding of the innovation management field.

The literature shows several approaches to innovation management, many of them illustrated by a graphical representation, such as the famous funnel analogy or the stage-gates. Any graphical representation tends to emphasize specific aspects of the pillars on which it is built. However, Tidd et al. (2001) argued that there is a convergence around a basic structure of innovation and that a proper balance between simplification and representation is necessary. Moreover, graphical representations give strength and visibility to models, making their understanding as well as their diffusion to practitioners much easier.

Rothwell (1992) performed a historical analysis of innovation management models from the 1960s onwards and found a pattern of evolution that started with linear models and moved to interactive ones. The first generation had a predominance of innovation driven by technology, and the second generation had a predominance of innovation driven by the market, a conflict well addressed by Kline and Rosenberg (1986). The third-generation models recognize technology or market combinations to trigger the process and add return loops between the phases. The fourth-generation models favor the perspective of parallel activities that are aided by alliances and partnerships; fifth-generation innovation is perceived as a continuous process, integrating a comprehensive network of relationships and customized responses.

Studies of innovation management have focused mostly on large companies that have resources in their formal budgets and well-structured product development processes (PDP) or research and development (R&D) operations. Linearity could be considered a key feature of the main models based on the PDP process, as proposed by Salerno et al. (2015). However, as Kline and Rosenberg (1986) state, "innovation is complex, uncertain, somewhat disorderly, and subject to changes of many sorts", which reduces the explanatory power of models that depict innovation as a smooth and well-behaved linear process (Adams et al., 2006). Apart from process representations, graphical models can consider strategy, organization, forecasting, and open innovation, encompassing a vast list and showing the diversity of approaches.

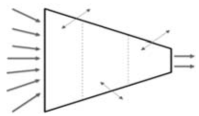
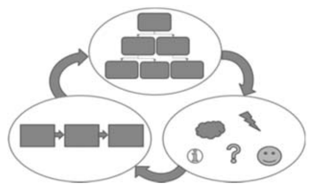
Our study begins with a literature search of innovation process models based on the characteristics of their graphical representations and organizing models into groups that highlight their biases, gaps, strengths and weaknesses. Then, we conduct a review and comparative analysis among models and groups, identifying important tensions among models that spillover to the innovation management field in both research and practice. The ultimate goal is not to build a new convergent model, but rather to highlight both the diversity and gaps among the analyzed models. In doing so, this study organizes the existing knowledge to support choices regarding innovation management for practitioners and shows opportunities for further studies. This article is structured as follows: section 2 presents the methodological approach, which included selecting 16 models for deeper analysis; section 3 discusses the selected models, highlighting their main contributions; section 4 presents an integrated discussion of the models and attempts to extract and interpret their organizational assumptions, biases, gaps and main points of tension; and final considerations and other comments related to models and emerging topics in innovation management are presented in section 5.

2. Methodological aspects

The literature review was initiated by searching the databases of scientific publications. In a search of the *Web of Knowledge* database on September 2016, 2,647 documents were returned for the expression "*innovation process*" and 593 documents were returned for the expression "*innovation management*" + "*model*". Most part of the documents were not aligned with this study's goals.

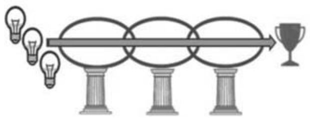
As a rule, innovation management models are most commonly evidenced by their graphical representations. Thus, a way to identify influential models in innovation management is a direct search for those representations. Therefore, articles in the field of

Table 1. Models comparison and grouping.

Group	Authors	Model	Objective (view)	Selectivity	Process-based	Organizational interaction	Organizational capability
Linear models: activities, stages and decision-points 	Pugh (1991)	Total design	Meet the technical specification	No/unclear	**High**	No/minor priority	No/secondary
	Cooper (1993, 1994)	*Stage-Gates*	Meet the business strategy	Yes	**High**	No/minor priority	No/secondary
	Amaral and Rozenfeld (2007)	PDPNet process reference model	Meet the business strategy	Yes	**High**	No/minor priority	No/secondary
	Thomas (1993)	New product development (NPD)	Maximize post-launch evaluation, according to parameters defined in a marketing program	No/unclear	**High**	No/minor priority	No/secondary
	Utterback (1970)	Technological innovation process	Survival and expansion of business competitiveness.	No/unclear	**High**^{2}	No/minor priority	No/secondary
	Roberts (1988)	Technological innovation Process	Systematization of basic and integrated research efforts to NPD	No/unclear	**High**	No/minor priority	No/secondary
Funnel models 	Clark and Wheelwright (1992)	Development funnel	Identify and develop the best opportunities among a universe of possibilities	**Yes**	Medium	**No/minor priority**	No/secondary
	Docherty (2006)	Open innovation funnel	Add value to the organization through multiple methods of treating opportunities in the current business or even by creating new businesses.	**Yes**	Low	**No/minor priority**	Yes/central^{3}
Models focused on **Organization and interaction** 	**Levy** (1998)	Innovation model in high-technology companies	Value capturing in market opportunities	No/unclear	Low	*Yes/central*	*No/secondary*
	Temaguide (1998)	Guide to technology management	Promotion of continuous technological and organizational innovation	No/unclear	Low	*Yes/central*	*No/secondary*

(Continued)

Table 1. (*Continued*)

Group	Authors	Model	Objective (view)	Selectivity	Process-based	Organizational interaction	Organizational capability
	Jonash and Sommerlatte (1999)	Advanced and high-performance innovation model	Development of innovations continuously and sustainably within the company.	No/unclear	Low	*Yes/central*	*No/secondary*
Capability-centered models	Kamm (1987)	Integrative approach to organizational innovation	Organizational transformation through innovation	No/unclear[1]	Low[2]	*Yes/central*	*No/secondary*
	Goffin and Mitchell (2010)	Innovation Pentathlon	Leveraging organizational strategy of innovation	Yes	Medium	**Yes/central**	**Yes/central**
	Hansen and Birkinshaw (2007)	Innovation value chain	Maximizing innovation flow along the chain, identify and improve weak links	Yes[1]	Low	**Yes/central**	**Yes/central**
	Bessant et al. (2005)	Emerging routines for managing disruptive innovation	Leveraging competitiveness in the context of disruptive or incremental innovation	Yes	Low	**Yes/central**	**Yes/central**
	O'Connor et al. (2008)	DNA	Systematization of Radical Innovation in the organization	Yes[4]	Low	**Yes/central**	**Yes/central**

[1]There is no funnel or a related "shape" to communicate the idea of selectivity in these models, but the "selection" phase plays central role in Hansen and Birkinshaws's (2007) model. Kamm (1987) also considers selection, but in a peripheral manner among many other steps in a circular model.
[2]Although Utterback's (1970) model shows just three general subprocesses, each one is represented attached to well defined activities explained in text-box. In turn, Kamm's (1987) is less detailed in terms of activities related to the process itself, but they appear mixed to some other processes related to organizational issues.
[3]Typically, open innovation models tend to keep few connections to the theoretical field of organizational capabilities. However, to the extent that the models claim for external partnerships to perform inbound or outbound process connections, both the number of innovation projects managed and the competencies available to manage them increase and become a central argument of these proposals.
[4]Selectivity here is for new bussiness platforms.

"Business, Management and Accounting" were searched in the Scopus database using the term *Innovation Process*, which returned 10,730 documents. Five journals returned more than 200 results each (Research Policy, 430; Technological Forecasting and Social Change, 329; Technovation, 325; International Journal of Technology Management, 248; and Journal of Product Innovation Management, 243). Using the same term in the ScienceDirect database but directly searching for images and filtering according to matching journals between the two databases (with the only exception of the International Journal of Technology Management), 1,204 representations were returned. Sorting by relevance and graphically analyzing the first 120 results, only 24 of the results could actually be considered models of innovation management. The remaining representations were distributed among network diagrams, organizational models, and others. This search confirmed the plurality of approaches for innovation management.

Another issue that influenced which models were included in the analysis was how to elect "classic" models. Recurrent models in the literature, such as the development funnel by Clark and Wheelwright (1992) and the stage-gates by Cooper (1993), gained notoriety through the books in which they were first presented and would not be identified in a traditional search of indexed articles. No doubt, these models have inspired many other innovation models (Katz, 2011), which was confirmed after reviewing the bibliographic references of the articles returned. This fact led us to rethink the option of just applying replicable algorithms (as performed by systematic literature reviews) in favor of a more flexible approach. Thus, the search was extended to books that contained graphical models of innovation management. This search was conducted in the archives of universities in the authors' research network. We refer to this procedure as a snowball method.

At this point, it is important to mention that studies in the field of fuzzy front end (FFE) of innovation, although always present among the models searched, were not taken for analysis. They were not considered central to this study since their focus is on minimizing risks and uncertainties associated with innovation prior to engaging in other processes. Among the several models initially searched through the effort reported, we selected 16 that showed significant points of dissimilarity. Four basic criteria helped to identify these dissimilarities and inspired grouping the selected models: (i) the idea of project selectivity, which was normally implied in a graphical representation of multiple projects and their funneling; (ii) the presence of a process basis, evidenced by the centrality of describing activities, stages, and/or decision points (also expressed by the number of phases in which the process unfolds); (iii) the importance given to strategic and organizational elements, e.g., organizational functions and/or departments or subjacent aspects such as leadership, culture, etc., and their interaction; and (iv) the notion of capabilities that enable the organization to conduct innovation efforts in a regular way. The next section starts with an explanation of the model grouping and analyzes the models included in each group according to their main contributions.

3. Models descriptions and analysis

Looking at 120 academic articles and tens of books, we selected 16 models to guide our analysis and discussion (Table 1). The last four columns of Table 1 highlights the criteria applied to group the models. The dashed lines are used to limit general similarities within a group, whereas bold or italic cells highlight the dissimilarity between a group and the others. Grey backgrounds help to identify the model groups.

In the subtopics that follow, we summarize the main contributions of the models surveyed according to the suggested grouping.

3.1. NPD linear models: activities, stages and decision points

The first category of models focuses on the NPD process. According to Table 1, the main dissimilarity between this group and the other groups is the presence of a strong process-based approach, which renders models highly prescriptive. Utterback (1970) pioneered studies that led to process models, proposing the following steps: (i) idea generation (design concept or technical proposal); (ii) problem solving (invention); (iii) implementation (bringing the prototype to the first use, i.e., industrialization); and (iv) dissemination (generating economic and social impact). The idea of the process is clearly stated, although the idea of decision points is not.

Roberts (1988) proposed a model focused on technology development that highlights the different types of activities and decisions involved in a project throughout some stages. However, the most known innovation process model is probably Cooper's (1993) stage-gates for NPD (Figure 1). The graphic design of this process emphasizes the set of proposed steps, each one consisting of a list of preset, cross-functional, and parallel activities. The input for each stage is a gate that controls the process and serves as a

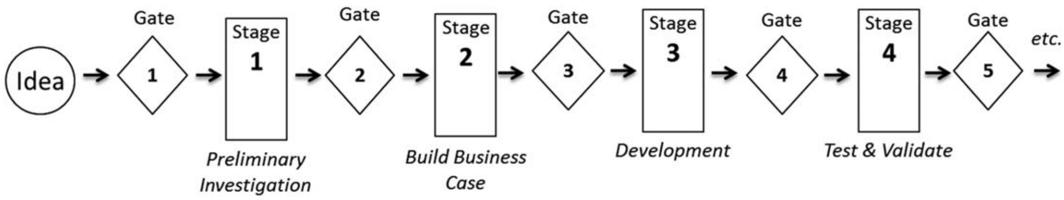


Figure 1. Cooper's second generation *Stage-Gates*®.
Source: Cooper (1993).

point for both evaluation and monitoring. Rozenfeld et al. (2006) and Amaral and Rozenfeld (2007) expanded Cooper's process scope, including information and product life cycle, grouping NPD stages into three distinct macro-phases ranging from strategic planning for the product until its discontinuation.

Pugh (1991) presented the "total design model", which focuses on the technical uncertainties of NPD and is geared towards complex-structure products following a divergence-convergence cycle: starting from a general specification, it deepens understanding in the component design level and reassembles the results into a complete product, which is then compared to the initial target.

Thomas (1993) proposed that each stage of the NPD has different dimensions—ideas, concepts, prototypes, products, and marketing programs—and that each specific product development demands a different maturity dynamic for each dimension (Figure 2).

To summarize the main contributions of the models focused on the NPD process, the development of innovations essentially follows a set of stages and decisions ranging from the idea to the fully development of an opportunity until its launch. Thus, the process tends to converge on a continuous reduction of a diverse array of risks. Typically, these NPD models are substantiated by the assumption, which is sometimes untrue, that ideas for innovation can be well

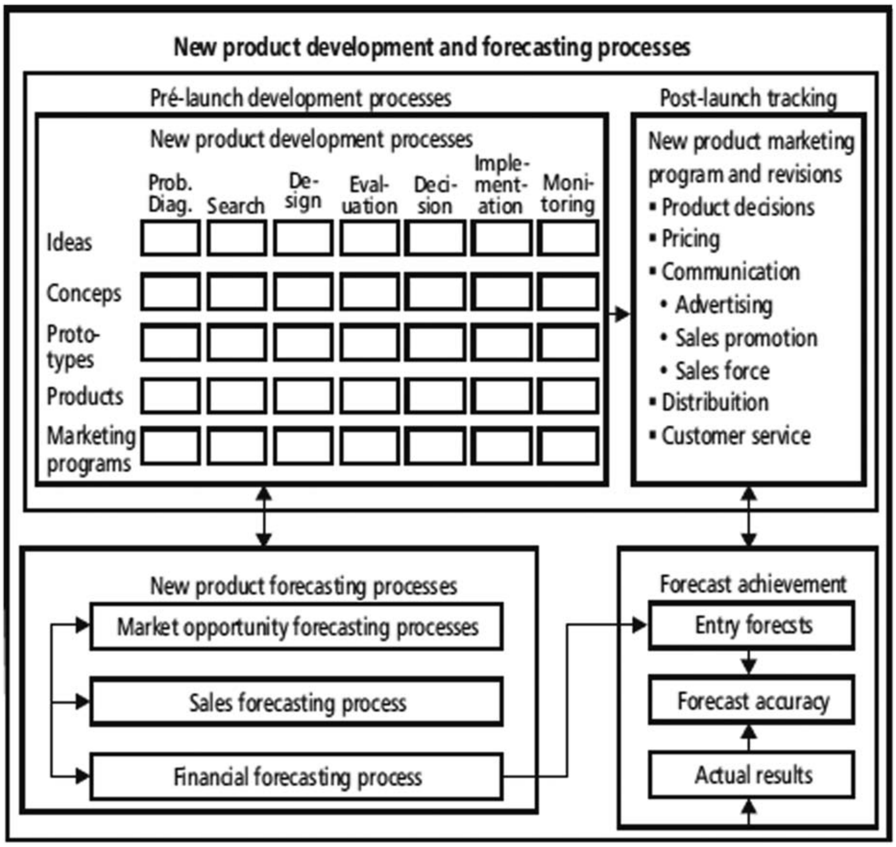


Figure 2. New product development and forecasting processes.
Source: Thomas (1993).

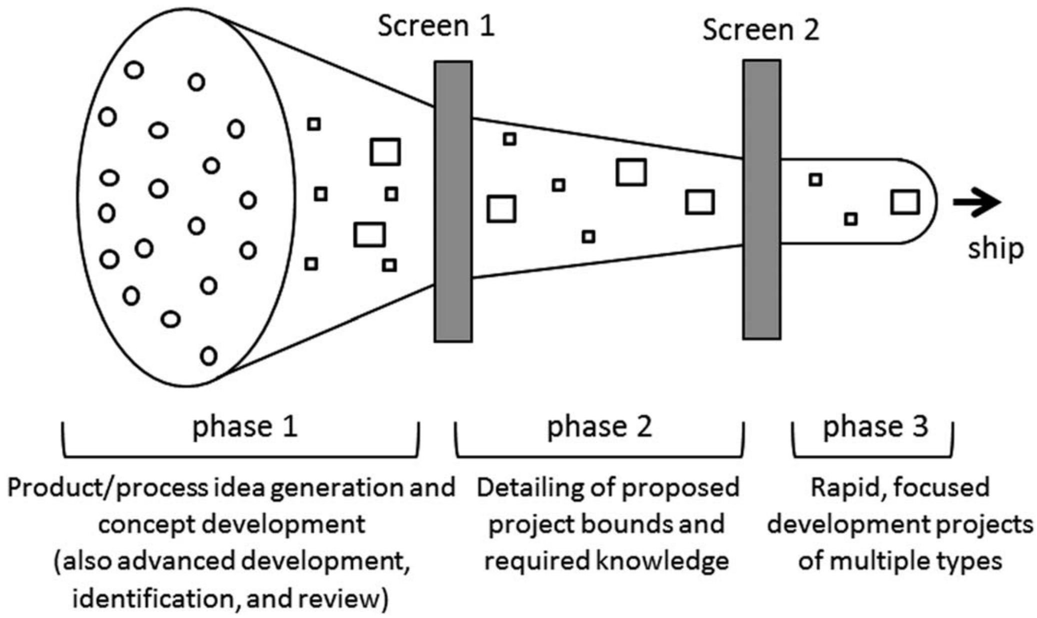


Figure 3. Clark & Wheelwrigth's development funnel.
Source: Clark and Wheelwright (1992).

defined by a company's existing technology range, by its defined strategy, or by the market. The result is a greater adherence to incremental innovations.

3.2. Funnel models: selectivity in a multi-project perspective

The classical model of Clark and Wheelwright (1992) presents the idea of a funnel, characterizing the selectivity of projects (Figure 3). Although this idea is implicit in NPD models, the funnel graphically and explicitly shows selectivity. The graphical model effectively communicates that only a few among several ideas will gain space in an organization's portfolio. The funnel analogy has been widely accepted and incorporated into further models.

After the dissemination of open innovation ideas (see, e.g., Chesbrough, 2003), Docherty (2006)

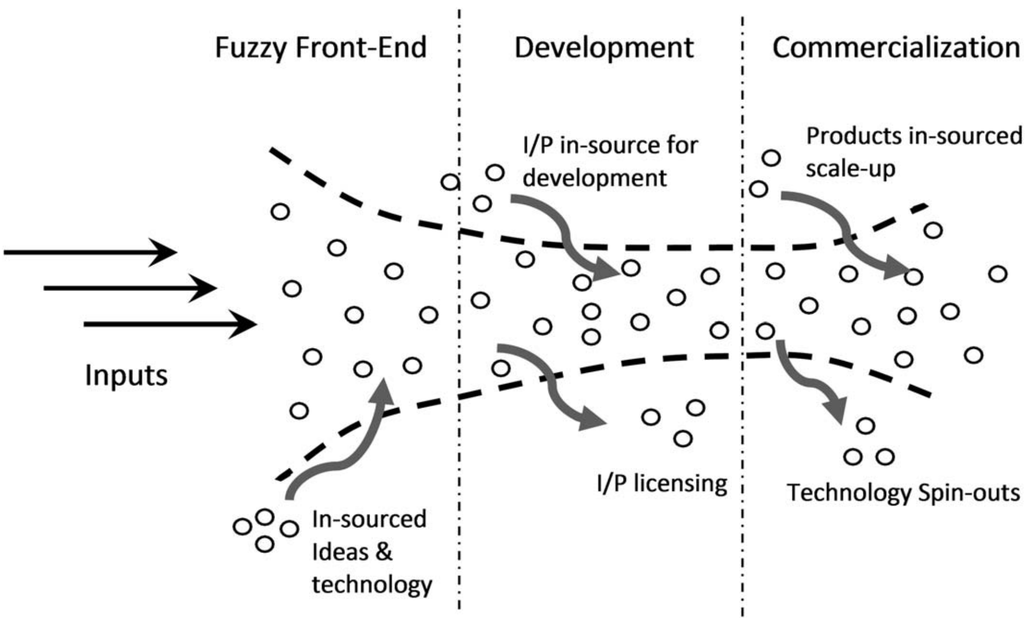


Figure 4. Docherty's open innovation funnel.
Source: Docherty (2006).

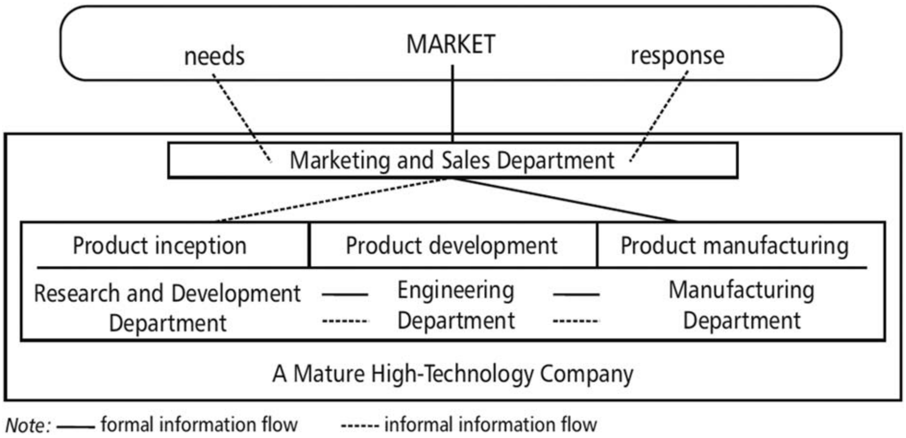


Figure 5. Levy's innovation model for high technology companies.
Source: Levy (1998).

proposed a funnel aggregating multiple options for intermediate inputs and outputs in a system (Figure 4). Cooper (2008) also sought to adjust his model to add the characteristics of open innovation. As proposed by Huizingh (2011), "the basic premise of open innovation is opening up the innovation process" and the central question concerns knowledge: the internal use of external knowledge (inbound process) and/or the external exploitation of the knowledge generated in a company (outbound process). Nevertheless, the nature of the models has remained intact: stages and funneling.

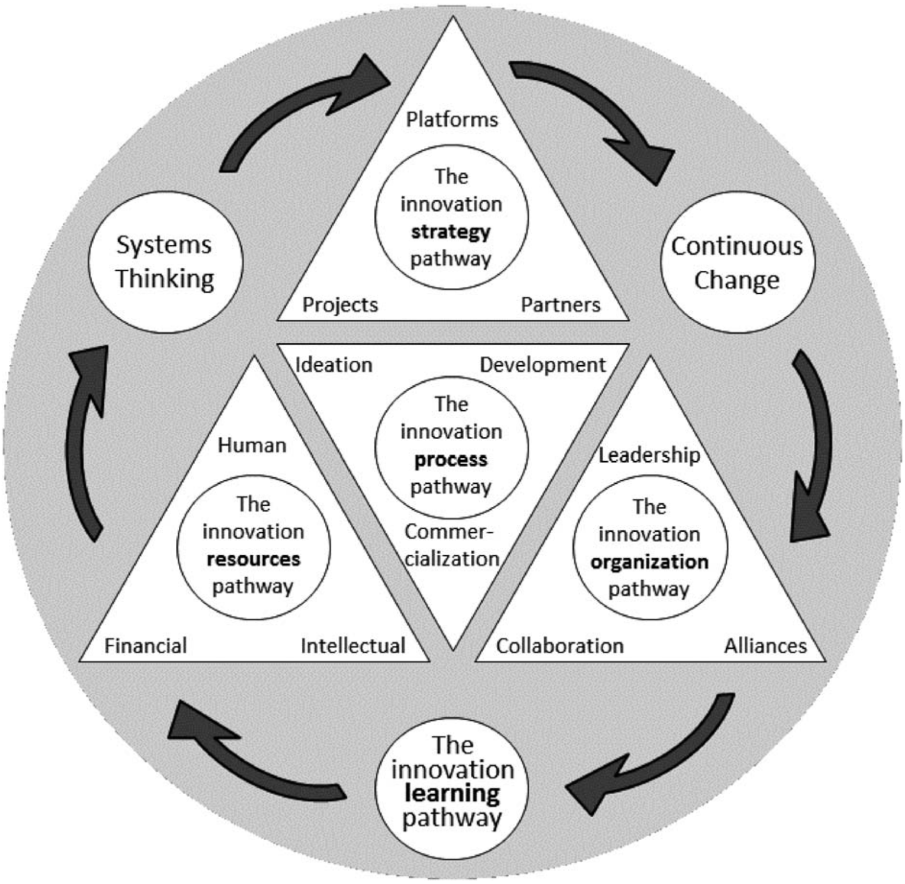


Figure 6. Jonash & Sommerlatte's model.
Source: Jonash and Sommerlatte (2001).

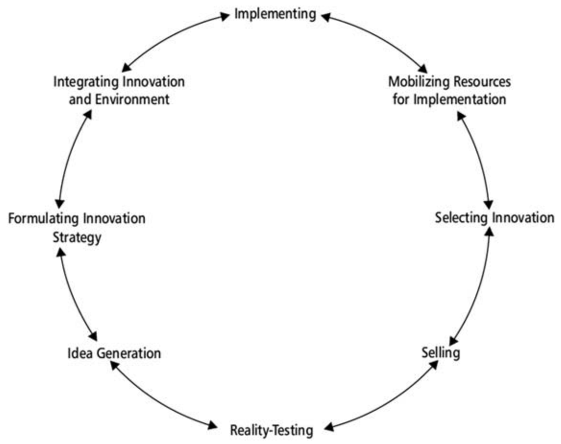


Figure 7. Integrative approach for organizational innovation. Source: Kamm (1987).

In short, funnel logic demonstrates that the process of innovation development occurs in environments with scarce resources. Not all ideas become projects, and not all projects will be developed to launch. The open innovation funnel induces dramatic changes in terms of resource allocation, knowledge management policy (e.g., intellectual property (IP) management) and competence building/outsourcing. Therefore, it proposes a broader view of the processes underlying innovation.

3.3. Models focused on strategy, organization and interactions among organizational elements

Levy (1998) emphasizes interdepartmental relationships and power struggles (Figure 5). When a company becomes mature in the market, the need to organize product development in a formal structure increases, to which this model responds with strongly departmentalized activities.

Jonash and Sommerlatte's (2001) model seeks to demonstrate how different organizational functions are established around the innovation process and the elements (culture, leadership, learning, and strategic clarity, among others) that permeate this process. The authors argued that innovation must be a strategy for the entire company and should not be limited to R&D departments (Figure 6).

Following this view, Temaguide (1998) proposes the management of technology and innovation according to a business perspective. The model identifies five key elements in the innovation process: scan (the environment), focus (attention and efforts on an innovation strategy), resources (provide the necessary resources), in-place (implement innovation), and learn. In turn, Kamm (1987) merges organizational aspects with the NPD phases. Each stage of the innovation process has an interactive connection to underlying organizational aspects, generating both organizational transformation as the process adjustment. The circular representation challenges the notion that a defined point triggers or terminates the process (Figure 7).

In summary, these models emphasize the role of strategy, structure, and resource allocation to support the innovation process. The development of innovations continuously transforms the organization, and this transformation consolidates the organizational ability to innovate, thus forming a virtuous cycle.

3.4. Capability-centered models

This topic covers models focused on managerial priorities to improve innovation; links with strategy and organization; ambidexterity; and the specificity of radical innovation for the generation of new business platforms.

Hansen and Birkinshaw (2007) proposed the "innovation value chain", consisting of idea generation, selection and conversion, and diffusion. Each of these stages is considered to be a link in a chain (Figure 8) and the model proposes that organizations' managerial efforts should address the weakest link, a

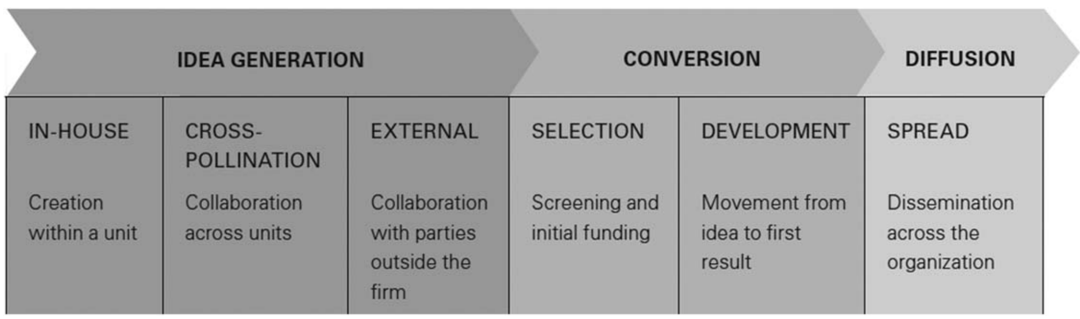


Figure 8. Hansen & Birkinshaw's innovation value chain. Source: Hansen and Birkinshaw (2007).

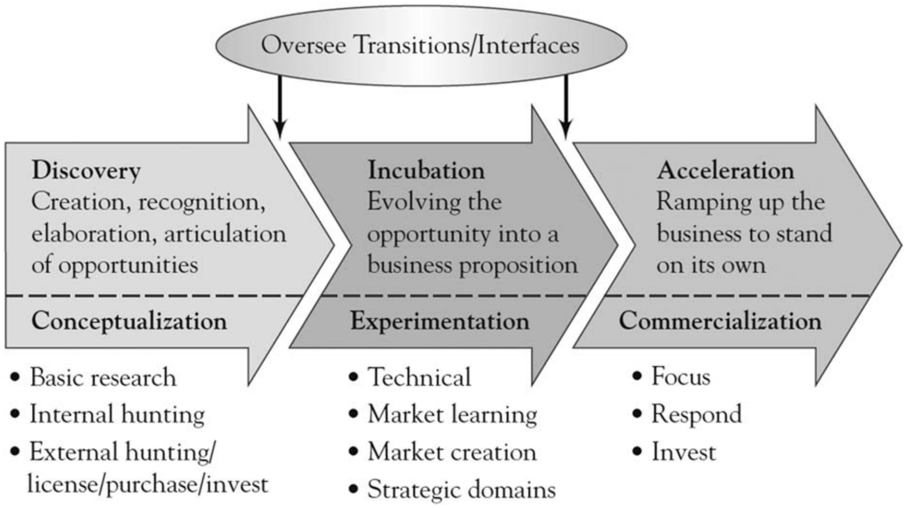


Figure 9. The DNA Model.
Source: O'Connor et al. (2008).

similar logic to that of the theory of constraints. This model also highlights the need to pre-fund ideas to strengthen them before their registration for formal evaluations.

Goffin and Mitchell (2010) presented a model consisting of three procedural and two organizational elements. The central axis of the model refers to the typical NPD process, but they added people and organization to support innovation. The innovation strategy guides the entire process.

Bessant et al. (2005) considered that incremental and disruptive innovations require different processes, following the idea of other organizational ambidexterity studies (e.g. O'Reilly and Tushman, 2004). Innovation strategy and organizational parameters are in the background of the model's graphic representation, and learning is a mandatory stage at the end of the process.

O'Connor et al. (2008) proposed the DNA model to cope with the challenges of organizing and managing systematic radical innovation, targeting the generation of new business platforms (Figure 9). The model consists of three phases: discovery (creation, recognition, elaboration, and articulation of opportunities), incubation (to isolate discovery from day-to-day pressures) and acceleration (scaling up the business until it becomes sustainable and further transferring to a business unit).

In summary, the models mentioned in this section go beyond the development of new products and reinforce the need for balanced organizational "hardware and software". The models for radical innovation deepen the understanding of analytic tools by using different approaches than the models for incremental innovation. Here, the focus is not on the process, but on general organization.

4. Analysis and implications

We now proceed to an analytical discussion of the models. Their strengths are graphical representation and simplicity, making managerial interpretation easy. Their weaknesses are numerous. We discuss the following aspects of such models: (i) the borders of the innovation process (events that mark its start and finish) and implications for the scope of innovation management; (ii) the absence of contemporary issues of innovation management (such as life cycle management and open innovation); (iii) the poor distinction between R&D and NPD issues; and (iv) the difficulty of addressing radical innovation.

First of all, innovation models are somewhat imprecise in regards to the events that mark the beginning and the end of the process. Many models propose that "ideas" trigger the process without a concise definition for this term. What are these "ideas" about? Strictly speaking, ideas are desirable at any point of the innovation process. Moreover, even the notion that generating ideas is the first challenge demands caution, since Salerno et al. (2015) showed that an innovation process can be started with a sale or even by a public call. In addition, even if the early beginning of the innovation process could receive special attention by "fuzzy front end" studies, Katz (2011) states that there are also fewer studies dedicated to the understanding of the final stage of the process (the "fuzzy back end"), a problem also noted by Adams et al. (2006).

At this point, it is relevant to compare the models to extract insights and complementarities with respect to (1) the central purpose of the process; (2) its starting event; and (3) its final event (Table 2). The practical

Table 2. Models comparison: start and end events.

Group	Authors	Model	Start event	Final event
NPD Linear models: activities, stages and decision-points	Pugh (1991)	Total design	Market research	Sale
	Cooper (1993; 1994)	*Stage-Gates*	Idea generation/discovery	Commercial launch
	Amaral and Rozenfeld (2007)	NPD unified model	Need, demanded by strategic planning	Product discontinuation
	Thomas (1993)	New product development (NPD)	Gaps identified in evaluations of current products, aggregated into marketing, sales and finance efforts	Post-launch product monitoring
	Utterback (1970)	Technological innovation process	Idea generation. It results of the integrated knowledge of a need and of technical means associated with it	Dissemination: first use (processes) or market introduction (product)
	Roberts (1988)	Technological innovation Process	Recognition of opportunity (technical feasibility and potential demand)	Use of technology and/or dissemination
Funnel models	Clark and Wheelwright (1992)	Development funnel	Idea generation and conceptual developments	No precise definition. It is generically named "ship."
	Docherty (2006)	Open innovation funnel	Opportunity capturing. Funnel is permeable to inputs in any stages: idea generation, internal development, acquisition of licenses, products for scale-up, among others.	Capturing the project value. Funnel is permeable to outputs at any stages: licensing, sale of partially developed projects, and spin-outs, among others.
Models focused on strategy-organization and interactions among organizational elements	Levy (1998)	Innovation model in high-technology companies	Identification of market needs	"Response to the market"
	Temaguide (1998)	Guide to technology management	Scan the environment: innovation needs and potential opportunities. Emphasizes, however, that innovation can start anywhere: focus, resources, implementation or scan.	"Implementation." The model, however, highlights a given circularity, so that each implementation triggers a new scan
	Jonash and Sommerlatte (1999)	Advanced and high-performance innovation model	Idea generation (ideation)	Commercialization
	Kamm (1987)	Integrative approach to organizational innovation	Idea generation. It is emphasized that innovation can begin at any point in the process, which presents itself as a circular model.	Actual tests (after-sales), feeding new idea generation
Capability-centered models	Goffin and Mitchell (2010)	Innovation Pentathlon	Idea generation guided by an innovation strategy	Market (products, processes, services)
		Innovation value chain		

(Continued)

Table 2. (*Continued*)

Group	Authors	Model	Start event	Final event
	Hansen and Birkinshaw (2007)		Idea generation (internally or collaboratively)	Dissemination: dissemination throughout the corporation and the market
	Bessant et al. (2005)	Emerging routines for managing disruptive innovation	Implicitly, idea generation, but authors generically refer to triggering the process	Implementation and learning
	O'Connor et al. (2008)	DNA	Creation, recognition, elaboration and/or articulation of opportunities (conceptualization)	Ramping up the business to stand on its own (commercialization)

question here is not at which point the process begins or ends, but what is the perimeter of the innovation management efforts and what are the events that mark the need for other managerial approaches (such as basic research, continuous improvement or product lifecycle management).

Since the procedural approach reveals to be inefficient to model the innovation process when uncertainty is high, the organizational dimension became the focus of some models, particularly those covered in subtopic 3.4. However, the models poorly discuss the links among the phases of the process and the functional structure that supports them. Discussion based on organizational theory is rare.

NPD-based models, such as stage-gates or funnel models, were developed to improve the quality of the process by establishing a logic of project selection and evaluation to diminish the risks of investing in bad projects. Other considerations are not central to those models. In this sense, the models do not bring theoretical or practical insights concerning many contemporary aspects of innovation management, such as open innovation, life cycle management, organization for innovation, or systematic radical innovation. For instance, an open innovation approach raises new questions for innovation management models, like: Must an external idea be evaluated with the same criteria of an internal one? How should a process with partners be set up? How should partners be managed? How should a fruitful search of external contributions be set up? How should co-design processes be set up?

The same reasoning applies to life cycle management (highlighted by Rozenfeld et al., 2006; Amaral and Rozenfeld, 2007), organizational issues (e.g. Goffin and Mitchell, 2010) and approaches to radical innovation (e.g. O'Connor et al., 2008). How does life cycle management affect the process? What are the key points for organizational support? What are the characteristics of leadership for each phase of the process? Knowing that NPD models are well suited for incremental innovation (O'Connor, 2012), which ones are well suited for radical innovation?

The graphical models analyzed here have other limitations. Innovation in products and business models tends to increasingly occur cross-industry (Gassmann et al., 2010). In these situations, network management elements such as governance, collaboration and upgrading (Humphrey and Schmitz, 2000) can also shape innovation management processes, decision criteria and resource allocation. This context also tends to foster architectural innovations, since the organizational impact of changing the product structure is lower in horizontal networks (Henderson and Clark, 1990). Modularization in product design (Chen and Liu, 2005) may also catalyze the use of an open model for innovation management by standardizing interfaces among components developed by different companies.

In general, the innovation process models poorly address the distinctions between technological development and product development (R&D and NPD), even though these challenges involve very different dynamics in terms of learning, time and competencies. R&D has different characteristics than NPD, and research has different characteristics than development (Iansiti, 1995; Chiesa, 1996). Mixing these functions in a single model can be misleading once R&D is more intense in some businesses than others (Pavitt, 1984) as observed in pharmaceutical industry (Chiesa, 1996).

Cooper (1994) and Cohen et al. (1998) have added previous stages in their models to cope with the challenges of applied research, but do not address the different natures of R&D and NPD. Even though Front End studies such as Khurana and Rosenthal (1998) discuss the activities that should be performed before starting a typical NPD, several of these models are not clear about whether they simply represent activities prior to the NPD process or whether they are new processes with their own management approach. This distinction is present in studies such as Terwriesch and Ulrich (2008), who propose different bundles to manage the innovation portfolio, and Clark and Wheelwright (1992), who affirm that a company may have a funnel for products and other for technologies.

The discussion introduced in the previous paragraphs highlights a current, central point for innovation models: which models fit best to radical or incremental innovation. Tidd et al. (2001) stated that radical and incremental innovation require different approaches in terms of organization and management. This argument is generally found in organizational ambidexterity studies (e.g. O'Reilly and Tushman, 2004, 2013). The similarity among products or projects in an organization is consistent with the use of models that are rich in details of the operational phases, such as Pugh (1991), Cooper (1993), Rozenfeld et al. (2006) or Thomas (1993). For this reason, some innovation models are considered "mechanistics", recovering the expression introduced by Burns and Stalker (1961). In fact, we expect that incremental innovation face predictable challenges in predictable phases.

Radical innovation, by turn, presents higher levels of uncertainty, which affects the predictability of the project, breaking the sequence of pre-defined activities. In such cases, the adoption of mechanistic models with their rigid sequence of activities and decision criteria undermines the Radical Innovation (O'Connor, 2012). The recognition of this challenge results in less detailed models in terms of activities, stages and sequences (e.g. O'Connor et al., 2008). Therefore, we refer to such models as "organic" models. However, the way in which the uncertainties are distributed or concentrated along the development process is also relevant. In this sense, if technological and/or marketing uncertainties are concentrated at a project's starting point—but, once solved, the rest of the challenge is fairly predictable—front end approaches might be combined with mechanistic models to fit the problem. Assumptions and implications of such consideration should be explored in light of practice.

Innovation models based on the concept of ambidexterity, such as that by Bessant et al. (2005), highlight that the management of radical innovation demands specific organizational structures that differ from those involved in incremental innovation. Although recent research reveals different modes of ambidexterity (O'Reilly and Tushman, 2013), the central concern is that a unique process (and its subjacent organizational elements) will not fit the demands of different bundles of innovation opportunities. Nevertheless, these texts do not address how to set up ambidexterity or how to effectively manage radical innovation in an organizational environment.

The DNA model (O'Connor et al., 2008) aims to fill this gap. Systematic radical innovation must be supported by a well-designed management system. O'Connor (2012) suggested that to be systematic and perennial, the management of radical innovation requires a specific organizational function, with its own team, missions, roles and responsibilities. The study of Bagno et al. (2015) is an example of this type of approach. However, the bias of DNA is in its adequacy for big companies composed by a corporate level and a set of business units. The challenge of innovating radically is strongly marked by the typical rigidness of such a structure and its problems in transferring the responsibility for innovation through management levels and business units.

In this context, it is also important to recognize an increasing debate over "probe and learn" approaches, which arise in opposition to the "best plan". Here, the expression "best plan" refers to the majority of the innovation models, that suit best to the challenge of big companies that face resource allocation problems among many projects seeking to avoid failures. In this context, a failure is often associated with relevant financial losses, brand damage, and regulation problems. Although the learning is always an important fruit of any failure, it may be so much expensive. However, there are other contexts, such as new ventures, where learn from failures is a compensatory strategy for radical innovation. Gassmann et al. (2010) recognized the importance of approaches towards early exposure, but the “probe and learn” strand is strongly supported by startup studies such as Ries (2011) and Blank (2013). The extent in which an approach may benefit the other is also an opportunity for further discussion.

In matter of fact, models for radical innovation in incumbent large companies and in startups are less frequent in the literature. Nevertheless, the importance of radical innovation probably will lead to an increase interest in such approaches. The next section discusses emerging trends.

5. What’s next? Emerging trends and potential impacts in innovation management

The main models with graphical representation we discussed above have some common characteristics. First, they focus mainly on processes, whether processes like stage-gates or macro processes like Jonash and Sommerlatte (1999) on the integration of organizational functions around innovation. Second, they were conceived based on medium-large established companies with enough projects to justify the creation of an organizational process. Third, their methodology is also similar: to look at what companies were doing, get patterns, rationalize them and propose a model. The general focus is on incremental innovation, since companies do not engage in many radical projects simultaneously, if any. Utterback’s model of innovation process, Cooper’s stage-gate, Clark and Wheelwright’s development funnel, they all present these characteristics. Exceptions are the efforts towards the understanding of how firms organize systematic radical innovation, like DNA model (O’Connor et al., 2008).

The process approach towards incremental innovation seems to be well discussed. Different models are based on the same idea-to-launch process. Criticisms of this fixed invariable sequence are also at hand, with alternative processes (e.g., Salerno et al, 2015). In that sense, emerging approaches for innovation models focus on radical innovation for incumbent firms (O’Connor et al., 2008) and on-the-web culture for startups, like Lean Startup (Ries, 2011), design thinking, and some support activities as crowdfunding or maker spaces. It is not expected that the methodology of our review senses such approaches. Nevertheless, they are important, and we must contour bias inherent of any methodology.

Design thinking is an emerging theme in both literature and practice (Brown, 2009; Moote, 2013; Keeley et al, 2013). It has been propelled by Stanford D-School and by the success of the firm Ideo. It proposes a guideline for designing products, where observation of potential users and testing through prototypes are key issues. For further investigation, we would suggest that design thinking acts mainly in the idea generation phase of the innovation process, by structuring idea generation to be more successful. Also, design requires further studies to formalize a better definition—it can be related to a form, to a traditional engineering project, or, according to Verganti and Dell’Era (2014) to innovation in the making sense of things.

The lean startup approach focuses on value creation in new technological ventures. It proposes to be fast in conceiving the product and testing it on the market. It is a different rationale comparing to Porter’s approach to strategy or to stage-gates process to manage innovation. Interestingly, the approach to systematic radical innovation in large incumbent firms and the approach to new value creation in technological startups have important similarities. First, the search for modeling radical innovation management efforts by researching companies and startups practices. Second, they both highlight the utmost importance of uncertainties and their management by the firm. For instance, both for O’Connor et al. (2008) and for Ries (2011), market is a construction; it is not a priori given. Tools and tests are proposed for reducing uncertainties, like learning plan by O’Connor et al. (2008) and minimum viable product by Ries (2011). In this context, corporate acceleration (Kohler, 2016) is emerging as a hot topic, focused on programs and processes to foster collaboration between established companies and startups.

6. Final considerations and implications for research and management practice

This study reviewed and analyzed the literature related to innovation management models with graphical representation. Although the diversity of the samples could lead to an understanding that such models may not be combined, they are all presented and called in literature as innovation management models. The work has a clear limitation as it does not address all the literature on innovation management, but only those models with graphical representations. However, it covers many of the most diffused models, such as Cooper’s stage-gates and Clark and Wheelwright’s development funnel, as well as some emerging models related to radical innovation, design thinking, and startups.

We have identified the models by several means: traditional search in academic databases, the knowledge of the authors and of their network (including the referees of the article, which gave us important suggestions), and snowball procedure.

The analysis of these models led us to highlight the importance of defining the points that trigger and end innovation processes. The end of such processes are not very clear, and we provided a better understanding of the final phase (launch, dissemination, market, etc.), covering its various possible meanings and implications for innovation management in organizations. After, we discussed how organizations define structures, roles and responsibilities to address the systematic development of radical innovations. The importance of radical innovation is widely accepted, but few models explicitly focus on it. Therefore, understanding how corporations can set up a radical innovation capability is still a field that deserves further research. Although some models emphasize the funneling of projects, issues such as portfolio balancing, considering different portfolios for technologies, incremental projects, and radical projects are rarely touched. Finally, the majority of models address incremental innovation, although they do not explicitly state this. The understanding of competence building and the relationship among organizational instances involved in radical innovation, such as R&D, NPD, engineering, business units, and finance, are other promising research topics.

Contributions to research

The article contributes to knowledge and research in the field in an incremental way. First, by identifying the problems and open questions related to innovation models based on graphical representation. It proposes a typology of models according to the dimensions they consider: NPD, funnel, strategy-organization, and capability-centered models. Obviously, models are not normally monotonic. However, they have an emphasis and main contributions that shape their focus. A brief critical analysis of each model was then performed, highlighting the strengths and weaknesses of each class of models and of each model analyzed. The article also highlights some issues on how decision making systems (e.g. those for project selection and evaluation) impact the innovation process and vice versa. Here there is a research opportunity, since the organizational and management schemes have fine intricacies that need to be better understood. For instance, procedural models tend to cope with different types of projects in the same process, discouraging the more radical ones. In the end, new trends are highlighted, suggesting new streams for deepening the research and the knowledge on innovation management models.

Contributions to practitioners

Practitioners, i.e., R&D managers, innovation managers, product development managers, etc., are exposed to many different approaches. Our research, by categorizing and critically analyzing the different models, can help these individuals to better decide which model is best suited for the problems they are facing. The typology of models can alert them to the main characteristics of each model and their strengths and weaknesses. Making the characteristics of each model explicit in a comparative way can help decision making for innovation strategies, organizations and processes.

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