RESEARCH PAPER

The changing context of innovation management: A critique of the relevance of the stage-gate approach to current organizations

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ABSTRACT

The stage-gate method was initially developed as a description of the new product development practices within high-performing firms. At its heart the concept is simple: and the flow of activity of a stage-gate includes project action, information generation, analysis and decision. Research has shown that the stage-gate method has been extremely successful in many contexts. The question of whether the approach is suitable for all projects in all situations is a principal faultline within the literature. Proponents argue that adaptations and evolutions of the stage approach enable it to be universally applied. This paper provides a critical review of the literature and we identify chronic limitations of stage-gate when evaluated against contemporary challenges, including VUCA (volatility, uncertainty, complexity and ambiguity), environment, digitization and open innovation. We remain critical about whether these contemporary currents are best approached by yet another reconfiguration of stage-gate building blocks. We argue that high uncertainty (caused by these currents) requires the flexibility to change fundamental elements of a project, including the underlying concept and the target market, which means that stage-gate is not well suited to innovation processes addressing these contemporary challenges. We propose a typology to show its suitability.

Introduction

The stage-gate model is one of the classical management models in the area of new product development (NPD) and its benefits have been well documented (see Griffin, 1997; Cooper et al., 2002;Cooper and Edgett, 2012). However, there is also a history of criticism of phased NPD processes. In the 1980s, it was suggested that the 'old, sequential approach to developing new products simply won't get the job done' (Takeuchi and Nonaka, 1986, p.137). Later, Smith (2008) argued that phased NPD is too rigid for today's increasingly turbulent environment. As a response to this, alternative models have been introduced to solve limitations of stage-gate, including lean PPD (Khan *et al.*, 2013), six sigma (Yang and El-Haik, 2009), agile/scrum (Ovesen, 2012), and lean start-up (Ries, 2011). A recent body of work on stage-gate/agile hybrids has also emerged, discussing the use of iteration within stages and new team management models, such as scrum (Conforto and Amaral, 2016; Cooper and Sommer, 2016; Sommer *et al.*, 2015). These recent changes to the stage-gate model illustrate that industry practice in NPD has moved on since stage-gate models were first introduced over 30 years ago. Many firms nowadays also embrace more iterative, creative and entrepreneurial product development concepts, such as open innovation (Brunswicker and

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Chesbrough, 2018), effectuation theory (Brettel *et al.*, 2012) and crowdsourcing (Lüttgens *et al.*, 2014). This then forms the basis of our research question: How relevant is stage-gate for NPD today? This paper contributes to the stream of research on stage-gate (Cooper, 2016, 2017). Previous research has identified a number of limitations and this paper pulls this distributed literature together and contributes to it by identifying new challenges posed by such concepts as open innovation, lean innovation and entrepreneurial R&D start-ups (Ries, 2011), as well as various social and technological developments.

The purpose of this paper is to clarify the lines of debate surrounding stage-gate. We examine why these criticisms persist and explore whether there may be fundamental weaknesses at play. We suggest a more realistic assessment of the suitability of stage-gate for new product development using a typology. We offer a comprehensive analysis of the persistent limitations of the stage-gate approach, thereby contributing to the stream of literature on stage-gate approaches to new product development (Cooper, 2014; Wysocki, 2014; Van Oorschot *et al.*, 2018). We identify chronic limitations of stage-gate and suggest that it is inadequate to deal with many contemporary innovation challenges, such as big data and open innovation, and that NPD needs innovation if it is to remain effective. In some projects, a new hybrid model is recommended. In other projects, a much looser, less structured approach seems to deliver better team communication, improved development productivity and a faster-to-market response. Above all, we show stage-gate overstates its applicability by claiming to be suitable to all firms and all NPD projects.

The paper is organized as follows. The next section reviews the evolution of stage-gate, discussing historical development and current status and providing an overview of the criticism of the different generations of stage-gate models. We then discuss challenges to stage-gate, after which we focus on three problems that the stage-gate model needs to deal with in addressing these challenges: the planning fallacy, the rise of open innovation and the scope of stage-gate use. Finally, we describe how NPD could cope with these challenges and could innovate its own approach.

The historical development and criticism of stage-gate

The stage-gate model has its origin at the macro level; that is, in science, technology and innovation studies (STS). It was considered one of the process models, along with technology push and pull models, and distinguished from the category of system models (Godin, 2017, p.4).[1] Process models are concerned with the unfolding of activities over time, which means they constitute stages of activity whereas a system model comprises actors and their interaction at a specific moment (Godin, 2017, p.5).

At the micro level, the stage-gate approach was originally presented as a description of best NPD practices as applied in multiple industries. These industry practices were found to be highly varied; when evaluated according to a stage-gate method, they ranged from four to seven stages. This broad approach had already been in use for a long time; the earliest cited example was based on company practice from 1964 (Cooper, 1990). The model was recommended because firms which had performed well in NPD tended to operate distinct stages with clear gate reviews. The initial description of the approach followed a manufacturing paradigm within which quality control takes place between stages, following the principle that ‘the stages are where the work is done; the gates ensure that the quality is sufficient’ (Cooper, 1990, p.46). This approach is in direct contrast to the right-first-time philosophy of ‘lean’ (Karlsson and Åhlström, 1996; León and Farris, 2011).

Phased review process models have evolved over time. This is partly because of their emerging disadvantages, and partly because the economic and social contexts of companies using these models have changed (cf. Ortt and Van der Duin, 2008). Cooper’s (1994) stage-gate approach in

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[1]One could go even further back by positioning the start of the linear stage-gate approach in the works of Vannevar Bush just after World War II, developing national, technology and science-based innovation policies and processes.

particular distinguishes among three generations. The first generation was developed by NASA in the 1960s. It was called the staged review process and contained a detailed scheme for working with contractors and suppliers of space projects. This type of product development consisted of discrete phases with a review point at the end of each phase. It was engineering-driven and applied mainly to the physical design and development of the product. In response to criticisms of this first-generation model, several clarifications were issued. For instance, stage-gate is not intended to be functional as a relay race, but rather as an integrated, concurrent approach involving cross-functional teams (Cooper, 2008). It is not designed to be rigid, with all stages used in every project. Instead, the stage-gate model should be adapted to suit the project (Cooper, 2008). And it should not be interpreted as a linear process operating in one direction only. Instead, backwards movement may occur, stages may be repeated and there is scope for iteration within phases (Cooper, 2008).

The responses to the above criticisms led to the second-generation model. The second generation, in an attempt to adapt and improve, included eight success factors that were identified after studying innovation projects (Berkhout *et al*., 2006):

1. Cross-functionality: at each stage players from different functions, such as marketing, R&D, engineering and manufacturing, take part in the project team
2. Integrating marketing and manufacturing with the product development process
3. Decision points or gates are also cross-functional: managers from different functions collectively decide about the progress of an innovation project
4. Approaching the innovation process from a more holistic point of view: focusing not only on the development stage, but trying to capture the entire process (from idea to launch)
5. Much more emphasis on up-front homework or pre-development work: putting great effort into defining the scope of the project and conducting a more detailed investigation before starting development
6. Much stronger market orientation
7. Introducing parallel or concurrent engineering
8. Improved decision-making process with clear go/kill criteria.

Significant criticism was again levelled at the second-generation stage-gate process. This criticism came from users who question its applicability for all industries and for all projects. Criticism has also come from researchers who have put forward alternative models to stage-gate's phased sequential architecture. As a response to this criticism, a new generation of the model was again proposed. This focused on speeding up and improving the efficiency of the process by incorporating overlapping stages with fuzzy conditional-go decisions. Indeed, Cooper himself noted some disadvantages, such as that projects must wait at each gate until all tasks have been completed, the overlapping of stages is all but impossible and projects must go through all gates and stages. To overcome these disadvantages and to formulate third-generation product development projects, the focus was put on efficiency and speed by allocating the required resources more efficiently. Cooper (1994, p.9) defined four Fs to characterize the third-generation product development processes:

1. Fluidity: 'it is fluid and adaptable, with overlapping and fluid stages for greater speed'
2. Fuzzy gates: 'it features conditional go decisions (rather than absolute ones), which are dependent on the situation'
3. Focused: 'it builds in prioritisation methods that look at the entire portfolio of projects (rather than one project at a time) and focuses resources in the "best bets"'
4. Flexible: 'it is not a rigid state-and-gate system: each project is unique and has its own routing through the process'.

The stage-gate model has evolved by adapting to changing social and economic circumstances and thereby taking away the disadvantages of each generation. These adaptations were made by companies applying NPD models and were therefore based on practical experience. These disadvantages were determined by management scientists through critical studies of the quality and effectiveness of stage-gate models in each generation. Table 1 summarizes the criticism of the various generations of stage-gate and subsequent responses.

One of the intriguing debates within NPD is the extent to which stage-gate can continually evolve to be relevant and useful for all firms. The benefits of stage-gate models for NPD have been well documented (Cooper and Kleinschmidt, 1996; Griffin and Hauser, 1996; Cooper, 2008). It has been shown to increase product success and decrease development time because it lowers integration barriers and improves team communication (Griffin and Hauser, 1996; Chen et al., 2010). It helps facilitate the need for negotiation and reconciling divergent perspectives (Adolph *et al*., 2012).

More recently, hybrid product development systems have emerged that claim to solve many of the limitations of stage-gate by including agile methods, such as scrum (Sommer *et al.*, 2015; Cooper and Sommer, 2016; Conforto and Amaral, 2016). These evolutions (or third-generation models) are designed to make the process more flexible, more agile and more adaptive. They have been developed in the light of now well-understood manufacturing techniques, such as lean manufacturing and six sigma, and build on the project management revolution in the software industry represented by agile (Smith, 2008). But these third-generation models do not account for uncertainty, which is a central consideration in emerging models of entrepreneurship, such as lean start-up (Ries, 2011) and effectuation theory (Read and Sarasvathy, 2005; Chesbrough, 2010). It is also unclear how stage-gate models operating at the level of the firm account for open (Chesbrough, 2003) and networked innovation (Berasategi *et al.,* 2011; Hoholm and Olsen, 2012) that span firm boundaries.

It is clear that senior managers within firms use the stage-gate model as an analytical tool to provide an overview of NPD project progress, and it has ceremonial value in such settings. The extent to which it can always be used as an operational tool to manage highly uncertain innovative NPD projects remains questionable, though it remains a ubiquitous phenomenon within the NPD literature. Andrew Van de Ven's Minnesota studies (Van de Ven and Poole*,* 1990) showed us that innovation projects are not well ordered and are in fact messy. Other studies investigating NPD practice have also concluded that plan-driven methods are inadequate in isolation and that informal and soft management approaches are essential to project success (Hobday and Brady, 1998). Significantly, stage-gate seems to be the dominant model for NPD within firms, yet research and literature continue to underscore the uncertain and messy characteristics of Van der Ven's innovation journey.

Stage-gate fails to provide guidelines for how to incorporate these new approaches to managing projects. For example, with gate timing strategy, the literature does not specify whether firms should adhere to a fixed schedule of gate meetings from the start of the project or allow flexibility to adjust the schedule throughout the NPD process (Van Oorschot *et al.*, 2018). In an innovation

Table 1. Evolution of stage-gate

Criticism	Response	Generation of stage-gate
Hard gates with defined criteria not suitable for all types of projects	Fuzzy gates	1
One size does not fit all projects	The collapsing of two or more stages into one: SG (full), SG (xpress), SG (lite)	1
Absence of end customer in the development process	'Build-test-feedback-revise' loops at each stage that connect to the end customer	2
Does not apply when new technology is being developed	Technology stage-gate	2
Rapidly changing market and technology environments	Agile/stage-gate hybrid models	3

network, it is unclear how to incorporate learning and change, or how to deal with project governance. The willingness to respond to criticism is laudable (see Table 1), but is this simply an attempt to maintain the relevance of the stage-gate model in an NPD environment that is now fundamentally different from the time of its origins? For example, computer-aided manufacturing has radically transformed both engineering design and manufacturing supply chains. Computing technologies have transformed every element of the design process, from customer insight (where digital methods are now core business) to workplace collaboration in the design function, to digitally integrated manufacturing and delivery (Yoo *et al.,* 2012; Davenport and Ronanki, 2018).

The stage-gate model is (or has been recently) defined as a macro-process which also requires project management methods (Cooper, 2008). Specifically, 'project management methods are applied within the stages of the Stage-Gate' (Cooper, 2008, p.217). One major problem with this macro view is that project management as a professional discipline has its own stages and gates (e.g., Schindler and Eppler, 2003), not to mention professional qualifications, and this presents a conflict. Another problem is the recent inclusion of agile and hybrid methods (Cooper, 2016; Cooper and Sommer, 2016, 2018), which seem to be beyond the scope of a macro-level stage-gate model since a major focus of agile is team level and in-stage activity. The stage-gate is also not usually described as a macro-level model, but as a blueprint, or a playbook that 'maps out what needs to be done, play by play' (Cooper, 2008, p.214): 'play by play' is not macro.

Recent adaptations to the stage-gate model also refer directly to current industry practices. This deferral to current practice reinforces our critique that the stage-gate lacks any clear conceptual foundation. If industry practice defines what the stage-gate is, and if industry practice is divergent and evolving, then does the stage-gate have any identifiable characteristics beyond the label? Stage-gate seems to suffer from the paradox that in order to stay relevant to today's industry practice, it has to change (adapt), but without ever ceasing to be a stage-gate approach. It has been noted that 'today's version is almost unrecognizable from the original model' (Cooper, 2008, p.216). The question of when it has diverged sufficiently to warrant a new identity might be considered as a speciation debate (e.g., Safran and Nosil, 2012). The issues of process scale and the level of change also raise the question of identifiability: when is an NPD process not stage-gate? If all NPD involving any element of formal process management is included, then perhaps its foundations (definition, boundaries) should be revisited.

Stage-gate and social and technological challenges

As illustrated by the different generations, the stage-gate method has adjusted to changes in industry brought about by various social and economic changes. In this section, we describe three such 'challenges'. The critical remarks made in the former section on stage-gate can be considered 'internal criticism', whereas the challenges presented here are 'external criticism'. Later we go into more detail with regard to the possible impact of these challenges for future NPD models and practices.

Social challenges

Social challenges such as 'climate change, resource depletion, energy transition, internet of things, etc.' (Gorissen *et al.,* 2016) can be relevant to changes in NPD practice. The wider impact of environmental change on NPD includes 'shorter product lifecycles, increasing competition and growing customer demands' (Duehr *et al.*, 2019). In these conditions, changes in both the customer requirements and the technologies can take place between successive product generations (MacCormack *et al*., 2001). A multidimensional approach to understanding the present nature of the changing global business environment is VUCA: volatility, uncertainty, complexity and ambiguity. The term originated in the US military (USAHEC, 2019) and has since been applied in a general management setting (Bennett and Lemoine, 2014) and in innovation studies (Millar *et al.,* 2018). To discuss the important but varied role of the environment in NPD process we address these four dimensions in turn.

VOLATILITY: RAPID ENVIRONMENTAL CHANGE

The increasing volatility of organizational environments forces organizations to become more agile. Agility can be defined as the ability to change rapidly, and in particular as the ability of the product development process to change products, platforms or process rapidly in response to a range of environmental triggers (Conforto *et al.*, 2016). Change is therefore viewed as both an opportunity to improve, and a major source of problems in the NPD process (Jarratt *et al.,* 2011). One rather extreme argument is that phased development was created to inhibit this costly and difficult change problem (Smith, 2008). As a competitive strategy, this might improve process efficiency, but it would not support the need to adapt to environmental change and may reduce competitiveness. The need to change rapidly relates to the need to respond in a competitive setting.

UNCERTAINTY: UNPREDICTABLE FUTURES

Uncertainty refers to an unpredictable future, which includes the future state of competitors, customers and technology pathways. Uncertainty is also experienced when exploring new areas, such as the need to create new knowledge of customers in international markets (Duehr *et al.,* 2019). Adapting to uncertainty and change is considered 'a major strategic challenge faced by organizations' (Du and Chen, 2018). One proposed solution to uncertainty is improvisation, which 'complements traditional planned actions and helps organizations respond to emergent opportunities and threats' (Du *et al.*, 2019). NPD projects in the electronics industry were shown to perform better when they were flexible and able to respond to new information within the development cycle (MacCormack *et al.*, 2001). The linear nature of the stage-gate reduces the capability to incorporate new information that requires meaningful change. This makes it less suitable in uncertain environments. A second problem with applying stage-gate in an uncertain environment is that under-resourcing the early phases might make a project look worse than it would have done with higher resources, meaning that adhering strictly to the stage-gate philosophy may well kill off viable projects (Van Oorschot *et al.*, 2010).

COMPLEXITY: EMERGENT INTERACTIONS

In a complex environment, informal and soft approaches to managing projects are essential to project success, but rational systems for managing projects are thought to be fundamentally inadequate (Hobday and Brady, 1998). Large and complex systems will always rely on human communication and coordination. If flexible and human-centred design approaches are more often required in complex projects, the suitability of the stage-gate method is questionable. For example, in a study of integrated circuit design, the use of a flexible approach to design outperformed projects using inflexible technologies by a factor of 2.2 (Thomke, 1997). Much of this difference was attributable to the considerable effort required to create the detailed specification in the first place. Specifying any design in detail requires that the design is well understood. In complex projects, this requires a great deal of effort. Whether and to what degree a detailed early specification is desirable should be carefully considered. The stage-gate model does imply early specification.

AMBIGUITY: MULTIPLE INTERPRETATIONS ARE POSSIBLE

Experimentation is proposed as a suitable response to overcoming the challenges of ambiguity (Kaivo-oja and Lauraeus, 2018), allowing the NPD team to learn about and better understand the situation. In new venture creation (i.e., an uncertain project), practitioners were found to define radically new product–market pairs by defining their product and market progressively (Mahmoud-Jouini *et al.*, 2017). In the context of the stage-gate process, this incorporates almost all stages (0–4), and the 'gated' nature does imply that any experimentation that requires moving between stages multiple times would be difficult. Therefore, ambiguous situations would not be well suited to stage-gate methods.

The challenge of big data

The availability of data in huge quantities, and the capability to process these data has started to impact many arenas of organizational work. For example, the so-called 'internet of things' (IoT) offers significant opportunities for firms to develop their business models. Exploratory research by Tesch *et al.* (2017) investigated the underlying decision criteria applied at gates in IoT ecosystems and identified two main decision points. Within the context of NPD, customers are able to specify their changing needs with ever greater assurance and speed (Davenport, 2010). In a recent study of using big data in new product development Tan and Zhan (2017) discern three key principles to accelerate NPD using big data: autonomy (of NPD teams), customer connection and being part of a fast launch and improved ecosystem.

Inevitably and unsurprisingly, stage-gate has been adapted to incorporate the agile process loop of 'build-test-feedback-refine'. However, this adaptation leaves the process spine of the stage-gate untouched. These adaptions propose multiple agile learning loops connected to standard stage-gate. It is argued that such loops allow the development to respond to fluid market conditions. However, anchoring a customer-responsive development loop to a fixed internal stage-gate system seems problematical. What is to stop gate decisions being paced to an internal metronome even while the technical development proceeds at the pace required by the customer? The need for a periodic realignment of internal and external pace inevitably introduces inefficiencies. This begs the question of the advisability of restricting the responsiveness of agile development by tethering it to a slower internal stage-gate system (or process). Stage-gate may continue to have a role to play in such circumstances for the strategic management of product portfolios, but the key claim that it accelerates innovation (Cooper, 2008) seems outdated.

The challenge of digitization and artificial intelligence

Yoo *et al.* (2012) argue that the increasing incorporation of digital technologies within physical products has profound implications for innovation. Such technologies enable innovation in an open and flexible manner that is shifting innovation processes in various ways. These authors identify three traits of innovation with pervasive digital technologies (Yoo *et al.,* 2012): the emergence of technology platforms as the central focus of innovation; the increasingly distributed nature of innovation processes; and new product development through the combination of modules with digital functionality. These open and flexible traits incorporating pervasive digital technologies imply an innovation process that is emergent and distributed. Efforts to manage such emergence with a system of management that corrals innovation into stages and gates seems untenable. Nambisan *et al.* (2017) have broadened the scope of digitization of innovation by conceptualizing digital innovation as 'the creation of (and consequent change in) market offerings, business processes and models that result from the use of digital technology' (Nambisan *et al.*, 2017, p.224). These authors argue that digital innovation represents a fundamental challenge to ingrained assumptions of extant theories and practices of innovation. In relation to organizational processes, they draw attention to the shifting spatial and temporal boundaries of digital innovation, as well as a more complex relationship between those processes and innovation outcomes. Stage-gate systems, which arrange innovation activities in a particular sequence, seem irrelevant in a digital world.

Of all digital innovations, then, those involving artificial intelligence (AI) technologies are increasingly attracting the attention of policymakers (e.g.,Heaton, 2019) and innovation practitioners (e.g., Davenport and Ronanki, 2018). The potential implication of AI for business management is a subject of much debate. Some scholars have argued that all management activities are under threat from AI systems, and competitive advantage will be realized by those businesses with the most powerful AI systems (Ferras-Hernandez, 2018). Other writers are more circumspect and observe a tendency to over-hype the contemporary benefits of AI-enabled technology. However, in a spirit of early adoption, AI is already having an impact on the way firms manage innovation.

Through improved productivity, it has created space for innovation. It has also enabled more people within the firm to engage with datasets and thus help generate novel patterns and democratize creativity. It is clear the way innovation is managed is changing, driven by powerful incentives for firms to acquire and control critical large datasets and application-specific algorithms (Cockburn *et al.*, 2019). This will reshape the nature of the innovation process and the organization of R&D. AI has been presented as a transformational approach to project management since the 1980s (Levitt and Kunz, 1987), and many years on whilst we can now automate several project management tasks, 'today's situation is more like a car with early assistance systems such as ABS' (Auth *et al.,* 2019, p.34) than a fully autonomous vehicle. What is clear is that with the potential to augment and automate the analysis, validation and completion of NPD project tasks, the underlying process will also need to adapt.

Digitization is also a major force of change in innovation. For example, digital design combined with additive manufacturing enables the production of prototypes, tools and final parts directly from computer-aided design (CAD) data. 3D-print injection moulding is especially useful to test the design, fit and function of products before mass production. If changes are required, new mould iterations can be 3D-printed in just a few hours at minimal cost. 3D-printed tools enable both prototype testing and the manufacturing of low volumes of final parts. Additive manufacturing enables the digitally created part to be formed layer by layer. Thus, complex geometries and sophisticated features are now possible that would be difficult to produce using traditional manufacturing methods. 3D-printing offers the potential to reduce production costs and delivery times. It also offers manufacturers the opportunity to exploit new features based on novel material properties (Poelma and Rolland, 2017). The use of novel methods and materials has a major influence on the design process. The stage-gate process specifies a test and validate stage following the develop phase, and this is not suitable for novel materials. This problem is amplified in the context of regulated or safety-critical products. A recent example in the construction industry describes a 3D-printed concrete bridge being developed within a new paradigm of design by testing (Salet *et al.,* 2018) to overcome the limitations of traditional NPD processes in creating new products based on emerging technologies.

Challenges for developing fourth-generation stage-gate models

The internal criticism to stage-gate which fuelled its development has been seen as three successive (historical) generations. In the previous section, we discussed three external challenges that cause serious problems to the suitability and effectiveness of stage-gate. In this section we discuss two more general challenges that need to be overcome by stage-gate to innovate itself and stay relevant and effective to today's companies. The first is that stage-gate somehow – and despite all its evolutionary changes – remains a formal, linear and rational process. The second challenge is that firms need to recognize and be more transparent about when and where it is suitable. Indeed, we suggest that firms should recognize that while stage-gate may be ideal in some NPD settings, in others it may not.

The fallacy of planning

The stage-gate process has been described as linear (Sommer *et al.,* 2014). While this point has been addressed (Cooper, 2008) and later generations are described as iterative, the traditional stage-gate model clearly indicates that project outcomes should be defined in advance. The reference model (or properly the 'typical system') (Cooper, 1990) identifies two pre-development phases. The pre-development phases (initial screening and market assessment) can be broadly conceptualized as 'specify'. Specifying the project up-front requires that both goals and solutions are known in advance, and under these conditions a traditional project management approach can be applied to good effect (Wysocki, 2014). Where either goals or solutions are not known, different methods are required. A number of alternative methods are emerging that address this problem.

Company practice is adapting to different situations, thereby varying idea-to-launch systems (Cooper, 2014). In one study of a very large company, MacCormack *et al.* (2012) show how HP have adopted three different NPD processes, called emergent, agile and efficient. Only the efficient level (where project outcomes are established in detail and in advance) adopts well-defined stages and gates. Agile and emergent projects both define the process as they go.

Evidence from a small number of case studies in early-stage firms indicates that the NPD process is often applied informally (Marion *et al.*, 2012). This is not surprising given that early-stage firms operate in an environment of extreme uncertainty about products and markets. Small empowered teams can be very effective with expanded roles, power to take decisions and with little emphasis on a defined process (Marion *et al.*, 2012). However, it is also argued that early-stage firms should spend time developing NPD process expertise – but with a particular focus on enabling cross-functional teams (Durmusoglu *et al.,* 2013). In entrepreneurship, the lean start-up process begins with 'build' (Ries, 2011), prototyping an initial idea in order to gain feedback and to evaluate whether to continue. In contrast, effectual logic, a model of entrepreneurial decision-making, starts with a given set of means (i.e., the circumstances and characteristics of the decision maker, including personal preferences, abilities and networks) before specifying goals (Sarasvathy, 2001). These studies show a range of situations in which detailed early planning is either not possible or not desirable.

There is also evidence dating back to the 1990s showing that detailed early planning requires a major time investment (Thomke, 1997). This is related to the issue of trading off project goals, which dates back much further in the project management triangle. While the project management triangle (the 'iron triangle') might offer unsuitable metrics for many projects (Atkinson, 1999), it does embody a long-held view that decisions about time, cost and quality represent a trade-off in which two objectives may be met at the expense of the third. This trade-off is not acknowledged and addressed by the stage-gate process. If specification (quality) is fixed, then either cost or time will suffer; indeed, this is an extremely common outcome. Agile methods, such as scrum, typically fix the cost and time requirements with specification (quality) as a flexible outcome. The stage-gate process does not offer this degree of flexibility (Smith, 2008). Indeed, Cooper (1990, p.7) notes how the third-generation stage gates have rigorous criteria and metrics that test a number of quantitative and qualitative criteria at the same time. Yet, the key problem is identified by Sethi and Iqbal (2008), who argue that rigorous gate review criteria limit increased project inflexibility, which shows that stage-gate also suffers from trade-offs that every innovative company faces.

Early discussion of the need for a stage-gate process showed that the pre-development phases were critical to project success and that they were often weakly managed (Cooper, 1990). The stage-gate process clearly indicates that a project should be designed in detail first, and then built. Company practices are now evolving to apply different methods in cases where either the project goal or the solution is not known. The third-generation stage-gate system is adaptive, incorporating iteration and early build-test-revise loops, referred to as 'spiral' development. These developments are described in contrast to traditional stage-gate methods (Cooper, 2014). They claim to allow a degree of flexibility, which may be overstated. Company practice and guidance from the project management profession currently indicate that multiple distinct project management methods are required.

The challenge of open innovation

The philosophy that management is a rational activity is foundational to stage-gate systems. Such rationality is most easily enacted in contexts when the innovating organization controls the resources and process required to take an innovation from idea to launch. Increasingly, innovation is occurring in open contexts involving knowledge and activity flows that cross organizational boundaries. Innovation management in such circumstances requires organizational actors to solve the challenges of cooperation (i.e., the decision to participate and contribute) and coordination (the integration of independent activities). Perhaps inevitably, stage-gate has been adapted to accommodate the challenges of open innovation (OI) (Chesbrough, 2003).

Docherty (2006) has imposed the standard stage-gate model on the open innovation funnel of Chesbrough (2003) – with little apparent regard for the complex dynamics of cooperation and coordination. In this conception (Docherty, 2006), a focal firm appears in control of both the stages and the gates. The knowledge and skills external to the firm are simply treated as resources to be purchased, with the gates apparently under the complete control of the focal company. This is a limited concept of open innovation and does not reflect the effects of power (e.g., Hansen and Mattes, 2018) or cultural dynamics (e.g., Caccamo, 2020) on collaborative innovation. On a very practical level, what happens if different OI partners operate their own stage-gate systems? There is a risk of inefficiencies caused by an administrative need to align stage-gate systems to ensure stages and gates in different organizations have the same scope. Interaction between OI partners is not simply transactional; collaborative innovation is much more strategic and subtle than this. Partners may have different institutional logics (Beck *et al.,* 2022) that require meaning-making at every turn. The differences caused by the various institutional logics evident in such organizations are well-established (Bjerregaard, 2010). This challenge of continuous meaning-making cannot be resolved with any credibility to stages and gates. Carlile's typology of knowledge boundaries (semantic, syntactic and pragmatic) in NPD explains the complexity of knowledge transfer in OI contexts (Carlile, 2002). Good criteria for go/kill decisions are not necessarily knowable, and structuring OI projects as a series of rational steps is to make light of the differences among innovation actors.

An approach to management based upon rationality requires an organization of resources founded upon agreed standards of evidence and definable goals. This is motivated to ensure that the evaluation of a prospective course of action (e.g., a go/kill decision) may be resolved objectively. In contrast, contemporary research in behavioural economics has questioned the continued value of the rational economic actor (Kahneman, 2003) and paved the way for non-rational modes of behaviour modification, such as nudges (Thaler and Sunstein, 2008). Such challenges to rationality do not deny a role for reasoning in decision-making about innovation. Rather, in accepting that there are innovation contexts where there is so much that is unknown the response might not be to build ever more complex stage-gate systems in pursuit of cold objectivity, but to treat our organizational ignorance (Roberts, 2013) as an opportunity for inquiry into our very management of innovation; an inquiry that runs in tandem with the technical matters of R&D. Stage-gate systems, with their foundation in rationality, restrict the possibilities for such inquiry into management and thereby limit their applicability to project contexts where goals and solutions are clear.

The overstatement of stage-gate

It is claimed that the stage-gate model can be applied to a wide scope of new product development projects:

> Whether a company is developing game changing technologies and products that alter competitive landscapes and create new markets, or it is introducing new-to-company products to generate new revenue streams, or whether it is defending market share by releasing improved versions of products, the Stage-Gate model improves performance and reduces your risk of failure. (Edgett, n.d.)

Yet, for over 40 years firms have recognized that different management styles are required for the different levels of knowledge uncertainties that exist within R&D projects. Current arguments in the project management domain suggest that stage-gate's one-size-fits all approach 'simply doesn't work' (Wysocki, 2014; see also Van der Duin and Ortt, 2020). In response, different project management methods are recommended based on an analysis of the project type. Firms know from experience that the innovation process may follow a number of different paths. The challenge for the firm is how to organize and plan resource allocation for those innovation processes that do not easily fit into traditional models. For instance, in a study of 132 innovation projects in 72 companies, Salerno *et al.,* (2015) propose a taxonomy of eight different innovation processes with specific rationales that depend on a project's contingencies.

A recent survey of senior R&D leaders found that that they are still wrestling with many of the challenges that stage-gate was supposed to alleviate. Top of this list is communicating the return on investment of R&D. For example, Christiansen and Varnes (2009) note that projects may pass all gates and yet fail commercially. Some of the problems emanate from the desire to make stage-gate suitable for all. Cooper (2008) described it as a macro-process, yet it is also sometimes described as a portfolio management tool that helps senior managers direct resources towards the right projects at the right time (Van Oorschot *et al.*, 2010). Stage-gate does not provide specific support for tracking project progress within stages, and detailed guidance for project managers within projects is lacking. Significantly and unsurprisingly, in a study of innovation management practices across industry sectors, Tidd and Thuriaux-Alemán (2016) find that the use and effectiveness of innovation tools varies by industry. In a study of service-specific characteristics and their implications for innovation management Schultz *et al*. (2019) discover that firms with a strong focus on service are less likely to use stage-gate systems.

There is an element of tautology when one looks at what is required for successful stage-gate practice. Strong NPD capability (defined in terms of opportunity analysis, technical development, product testing and commercialization) enhances the success of new product offerings, but also enhances the ability of the organization to be flexible, defined in terms of rapidly adapting market offerings (Arnett *et al.*, 2018). Finally, some of the identified success factors seem hollow and self-evident. For example, the argument that 'a well-defined preliminary product concept allows for a better understanding of many important matters, including development time, costs, technical expertise, market potential, risk, and organizational fit' (Florén *et al.,* 2017) is obvious to practitioners in the field, but is also very difficult to achieve. The time and cost of producing a well-defined concept is a strategic consideration (Thomke, 1997) which should influence the decision of whether a detailed product concept is actually desirable. Our review of the literature identifies further limitations of stage-gate which we have summarized in Table 2.

Table 2. Limitations of stage-gate

Limitations of stage-gate	**Source**
The process is sequential and can be slow	Sethi and Iqbal (2008)
The whole process is focused on end gates rather than on the customer	Jespersen (2012)
Product concepts can be stopped or frozen too early	Ettlie and Elsenbach (2007)
The high level of uncertainty that accompanies discontinuous new products makes the stage-gate process unsuitable for these products	Sethi and Iqbal (2008); O'Connor (1998); MacCormack *et al.* (2001)
Risk of stage-to-stage information dependency	Jespersen (2012)
At each stage within the process, a low level of knowledge held by the gatekeeper can lead to poor judgements being made on the project	Cooper (1994)
Inflexible and too rigid	Smith (2008); Thomke and Reinertsen (1998); Verganti (1999)
Does not prevent failure Projects may pass all gates and fail commercially, according to previous empirical studies	Christiansen and Varnes (2009)
Does not utilize flexible software product development methods More flexibility through introduction of the agile methods that are now common practice in software development	Smith (2008); Sommer *et al.* (2015)
Detailed planning in a project, a necessary component of the stage-gate process, is extremely time consuming	Thomke and Fujimoto (2000)
No single approach is suitable for every project type	Turner and Cochrane (1993); Wysocki (2014)

Towards innovating the stage-gate approach

The previous sections have described many disadvantages and limitations of the stage-gate approach. Its development makes clear that stage-gate has coped with many problems, both theoretical and practical, and that it has constantly tried to overcome these by making adaptations and extensions to its underlying model and approach. External challenges suggest that stage-gate has difficulty dealing with current and (expected) future social and business changes that will alter the way companies develop new products and services. Despite the changing nature of stage-gate over time, its essence (namely linearity, rationality and acclaimed universalities) remains a very serious problem. This does not mean that stage-gate has lost its value altogether, but that we put forward the notion that the expectations of users of stage-gate should be managed and that it should be clear in which situations it can be used effectively.

In particular, and in addition, our analysis suggests that proponents of the stage-gate approach continue to overstate its suitability for all sectors and all firms. The stage-gate process is not presented as one option within a suite of process types, but rather as an always-suitable process framework that can be adapted. This is in direct contrast to current industry practice, such as the varied approach taken by HP (MacCormack *et al.,* 2012), and with current guidance on project management (Wysocki, 2014). There is general agreement that stage-gate is well suited to new product development in known markets with known solutions. The major debate within the field is whether the limitations of the stage-gate approach are caused by poor implementation or whether there is a more fundamental issue. The literature identifies that effective stage-gate implementation involves cross-functional teams, concurrent engineering and periodic business reviews. Arguably this is exactly where the difficulties arise. While it is a useful tool for new product management, stage-gate does not adequately address the interrelated elements that promote successful innovation. High levels of uncertainty about technology in combination with high levels of uncertainty about the market require a different approach (MacCormack *et al.*, 2012). Recognition that different approaches are required for different product innovation processes and that there are some situations where stage-gate is not appropriate (such as rapidly growing small firms in dynamic environments) would contribute much to the debate.

Having identified a number of theoretical and practical issues with the stage-gate process, we propose a defined scope of application for stage-gate. Against this backdrop, we recognize the rapid technological change which has affected all areas of new product development. When it comes to managing new product development projects themselves, it is the level of uncertainty which determines the scope of the challenge. Incorporating change and flexibility into new product development projects can deliver the innovation firms desire. Yet, NPD is frequently too rigid for today's increasingly turbulent environment (Smith, 2008). In a major study of R&D managers, Magnusson and Lakemond (2017) find that project managers use product architectures to interpret their tasks and devise appropriate responses to perceived challenges. So, uncertainty seems to be the key factor in deciding to what extent stage-gate is indeed suitable for companies as a method to manage their new product development processes. This uncertainty relates both to how to manage new product development (the process) as well as to what the outcome of the new product development process could be (the product). Uncertainties in the product will emerge from both new technologies and new markets. Uncertainties in the process will be influenced by emerging technological opportunities, including big data, digitization and artificial intelligence. Figure 1 represents a new product development project typology based on these two types of uncertainties. We argue that high uncertainty in either process or product dimensions make stage-gate an unsuitable choice.

Having argued that stage-gate is appropriate only in situations with low uncertainty about the process and about the product, we think that a more fundamental choice needs to be made when dealing with stage-gate. Stage-gate has to reconsider its conceptual nature to be useful to firms in the future. This means that the ontology of stage-gate is a matter to which researchers and practitioners alike should attend: What is stage-gate assuming about the nature of innovation? We have

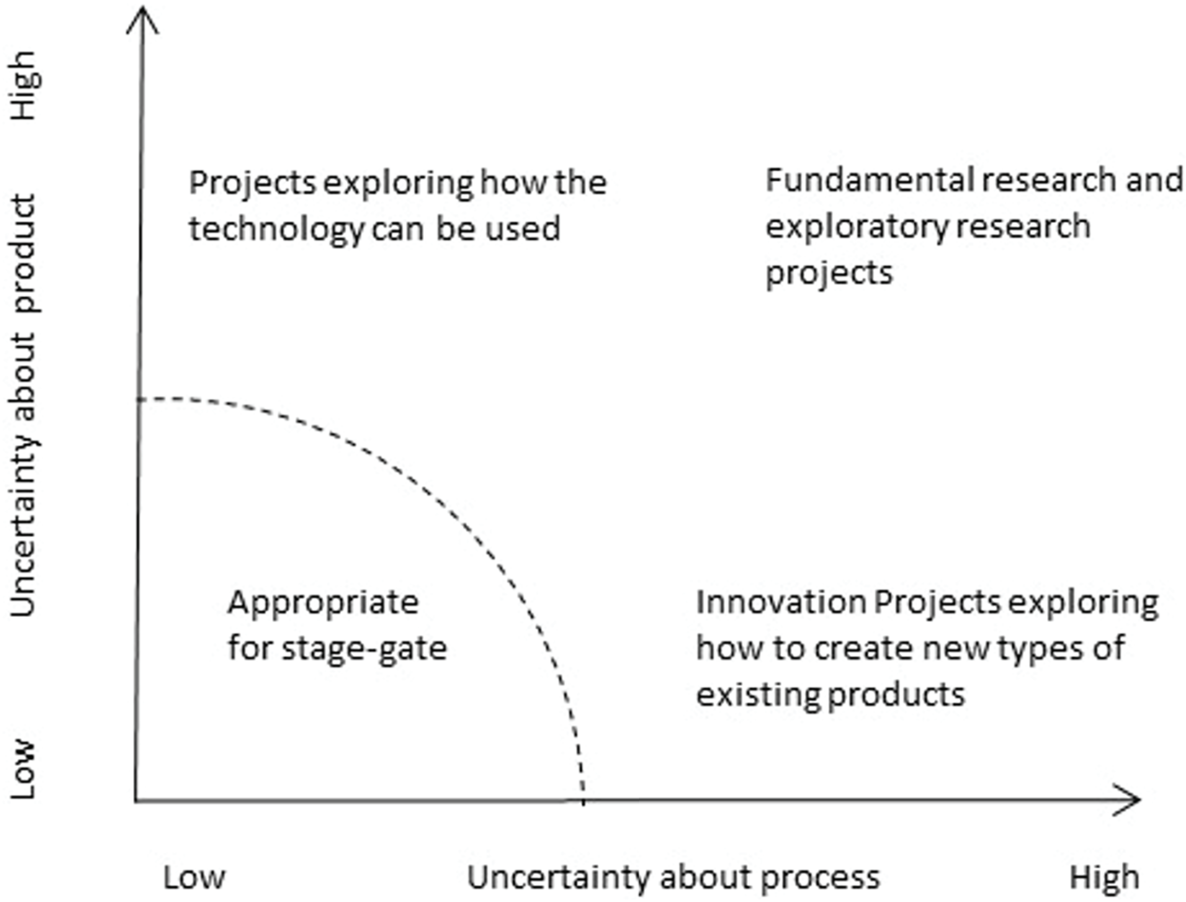

Figure 1. A project typology

argued that the advent of digitization (cf. Yoo *et al.*, 2012; Nambisan *et al.*, 2017) has accentuated the emergent nature of innovation outcomes. Stage-gate models, with their predefined arrangements of innovation activities, are founded on the ontological assumption that there are regular and repeatable patterns in the generation of novelty. This position seems increasingly untenable given the rapidly shifting temporal and spatial boundaries of digital innovation. The practice of innovation in firms has evolved, with more emphasis on creative, entrepreneurial, open, systemic and digitized activities in developing new products and services. Thus, NPD has become more like an innovation process characterized by 'multiple temporal rhythms and experiences rather than by a single linear conception of time' (Garud *et al.*, 2013, p.795). Stage-gate models, with their predefined organizational arrangements, cannot accommodate this temporal complexity. This conceptual distinction between innovation as a matter for project management (i.e., stage-gate) and innovation process is therefore of significant practical importance (Table 3).

Of course, this distinction should really be seen as a continuum. Early in the new product development process, these strategic decisions should be clear. Is the company (or group of companies in the case of collaborative innovation) going to develop a radically new product, or an incremental, improved version? This initial vision need not be fixed. After all, many radical innovations started as a minor idea for improvement (and vice versa). Making this decision upfront, nevertheless, allows the project to be positioned somewhere in the typology of Figure 1. That is, if the company aims to develop a radical new product, it will be both uncertain about how to develop it and about the precise nature of the product, meaning that its new product development process will be in the upper right corner of Figure 1. But if the project aim is rapidly to develop an improved version of an existing product, the lower left corner of the typology applies. We have argued that

Table 3. Differences between project management and innovation processes (Van der Duin and Hermeler, 2014)

	Project management	**Innovation process**
1	Reducing uncertainties	Managing (and accepting) uncertainties
2	Stakeholders are known	Stakeholders unknown
3	Final goal is clear	Final goal is vague
4	Significant repetition	Unique elements
5	Focus on goal	Focus on process
6	Project time is well organized	Time horizons long
7	Often formalized and planned	Often spontaneous and informal
8	Operational by nature	Strategic by nature
9	Internally focused	Externally organized

NPD would benefit from a contingency approach (see Van der Duin and Ortt, 2020) thereby making it clearer where the stage-gate is a wise and useful tool (i.e., in situations with low uncertainty about process and product) and where it is not (i.e., in situations with high uncertainty about process and product). Given the changes in technology and society, we expect that this zone of uncertainty will become larger and therefore the applicability of stage-gate will diminish.

Concluding remarks

Stage-gate systems have unquestionably been successful and are, in themselves, an example of management innovation (cf. Birkinshaw *et al.*, 2008). However, stage-gate systems originated in what now seems a different era of business, an era without the internet, mobile computing and international networks of collaborating colleagues able to exchange data instantly. The philosophy of rational management underpinning stage-gate seems increasingly unsuited to the complexity of contemporary innovation challenges. For instance, it is often claimed that AI is drastically changing the management of innovation. Innovation in a VUCA world which is rapidly being transformed by digitization is even less able to be seen as stages and gates. The Minnesota Studies, arguably the most rigorous ever processual studies of innovation, concluded after 17 years and multiple innovation contexts that:

> our research of a wide variety of innovations has found no support for a stage-wise model of innovation development and no support for a linear (cyclical) model of adaptive trial-and-error learning, particularly during highly ambiguous and uncertain periods of the innovation journey. (Van de Ven *et al.*, 2008, p.2)

The chaotic representation of the innovation journey observed and investigated by these researchers seems the very opposite of the ordered world of stage-gate systems.

This paper offers a comprehensive critique of stage-gate new product development models. It pulls together the limitations of the approach into one classification and illustrates how these limitations have been addressed. The implication of this study for firms and managers is that they need to make a more realistic assessment of the suitability of stage-gate to new product development projects using a project typology (Figure 1). We note that in response to widespread criticism, advocates of the stage-gate system have adopted two core strategies: first, they have presented these criticisms as myths born of misunderstandings about the fundamental nature of the model; secondly, stage-gate systems themselves have adapted and evolved into multiple forms that offer a practical riposte to the critics. In a briefing note, Robert Cooper (2008) introduces nine myths about stage-gate systems, which he then proceeds to debunk. Drawing upon his substantial experience, he articulates six common errors in the application of stage-gate and offers advice on how they may be avoided. Despite the wealth of Cooper's experience and the undoubted success of the model, these same criticisms remain. In such circumstances, it is reasonable to ask why the criticisms persist; and whether the fault really does lie with myth and faulty implementation.

The second response to critics is evident in the multiple forms into which stage-gate systems have evolved. The stage-gate idea appears impervious to criticism offered for a particular innovation context: the model simply morphs into something that responds to the specific needs. Why might this be? At its core, stage-gate systems have a very simple and rational foundation. Stages comprise some project team activity about which information is generated, analysed and presented in a defined manner. Gates are decision points allied to certain criteria. The sequence that describes the flow of activity of stage-gate (project action–information generation–analysis–decision) is the core of any rational management activity. This building block of all stage-gate systems might come in different sizes depending on the scope of the activity, but the rational nature of the flow of activity remains the same. The robustness of the core building block gives stage-gate systems their strength, but it also means they are infinitely adaptable: they can be fitted to any organized endeavour. This is also a problem, since if it is adaptable to all situations, it is no longer an identifiable or a unique offering. When confronted with a particular new product development context, a solution can be designed with a creative reconfiguration of the stage-gate building blocks. There appears to be no innovation context to which a system comprising these building blocks cannot be designed.

In this paper, we have challenged the idea that organizing the complex and creative endeavour inherent in the development of an innovation may be achieved by the combination of a series of rational stage-gate building blocks. Stage-gate systems have unquestionably been extremely successful in many contexts. However, we strongly doubt whether contemporary currents in innovation management are best approached by yet another recombination of stage-gate building blocks. It seems as if the innovation of stage-gate suffers from the famous (perhaps notorious) innovator's dilemma of Christensen (1997). Stage-gate has indeed renewed itself, but only in an incremental way which works for a certain period until new, more radical and different ways of innovation are developed and used. The dominance of stage-gate in terms of usage by organizations and managers has somehow suggested that it still has sufficient value to its users, but new technological and business changes now occur so quickly that they diminish the value of stage-gate. The changing context of innovation management has outdated the stage-gate approach and its limited innovation has not caught up with new requirements. In addition, the dominance of stage-gate has not been replaced by the dominance of yet another innovation paradigm, but has given way to a situation in which different innovation contexts (brought about by different interplays of these technological, business and social changes) require different ways of innovation. With Figure 1, we have attempted to illustrate four innovation contexts with different approaches to innovation. Only one would be suitable for stage-gate. This contingency approach to innovation is not only more modern, but also provides innovation managers with an alternative to an approach to innovation whose best days are perhaps in the past.

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