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Measuring the Knowns to Manage the Unknown: How to Choose the Gate Timing Strategy in NPD Projects

Kim van Oorschot[1]
BI Norwegian Business School
Nydalsveien 37
0484 Oslo
Norway
kim.v.oorschot@bi.no

Katrin Eling
Eindhoven University of Technology
The Netherlands
k.eling@tue.nl

Fred Langerak
Eindhoven University of Technology
The Netherlands
f.langerak@tue.nl

[1] Corresponding author

Dr. Kim van Oorschot is Professor of Project Management in the Department of Leadership and Organizational Behaviour at the BI Norwegian Business School. Her current research focuses on decision making, trade-offs, and tipping points in dynamically complex settings, like new product development (NPD) projects. Her research projects are aimed at discovering so-called ‘decision traps': decisions that seem to be good on the short term, but have counterproductive effects on the long term. For this purpose, she develops system dynamics models based on actual project data. She also teaches project management and system dynamics to executive, master, and bachelor students. She has published in such journals as *Academy of Management Journal*, *Journal of Management Studies*, *Production and Operations Management, Journal of Product Innovation Management*, *Project Management Journal*, *Journal of the Operational Research Society,* and *International Journal of Operations and Production Management*.

Dr. Katrin Eling is Assistant Professor of New Product Development in the Innovation, Technology Entrepreneurship & Marketing Group of the School of Industrial Engineering at Eindhoven University of Technology in the Netherlands. She received her PhD from the same school, has an MSc in Strategic Product Design from Delft University of Technology, The Netherlands, and a Diploma in Industrial Design from the University of Wuppertal, Germany. Dr. Eling’s research focuses on the effective and efficient management of the front-end of new product development. For her PhD dissertation she received the Best Proposal Award in the 2011 Dissertation Proposal Competition of the PDMA and the Beta PhD Thesis Award 2015 for the best thesis in the Beta Research School for Operations Management and Logistics. She has published in the *Journal of Product Innovation Management,* in *Creativity and Innovation Management* and in the *International Journal of Market Research*.

Dr. Fred Langerak is Professor of Product Development and Management in the Innovation, Technology Entrepreneurship & Marketing Group of the School of Industrial Engineering at Eindhoven University of Technology in the Netherlands. He has a M.Sc. and Ph.D. from the Erasmus School of Economics. His research focuses on managerial interventions to improve the process of conceiving, designing, developing, and bringing new products to market, and managing these products post-launch. He has published in such journals as *International Journal of Research in Marketing*, *Journal of Product Innovation Management*, *Marketing Letters*, *IEEE Transactions on Engineering Management, R&D Management*, and *Creativity and Innovation Management*.

ABSTRACT

Stage-wise timing of new product development (NPD) activities is advantageous for a project's performance. The literature does, however, not specify whether this implies setting and adhering to a fixed schedule of gate meetings from the start of the project or allowing flexibility to adjust the schedule throughout the NPD process. In the initial project plan, managers and/or development teams often underrate the time required to complete the project because of task underestimation. Although the level of task underestimation (i.e., the unknown) is not identifiable at the start of the project, our study argues that project managers and/or teams can manage the unknown by measuring three project conditions (i.e., the knowns) during front-end execution, and use their values to select the best gate timing strategy. These project conditions entail: (i) the number of unexpected tasks discovered during the front-end, (ii) the willingness of customers to postpone their purchase in case the execution of these unexpected tasks would lead to a delayed market launch, and (iii) the number of unexpected tasks discovered just before the front-end gate. Together these conditions determine whether a more fixed or more flexible gate timing strategy is most appropriate to use. The findings of a system dynamics simulation corroborate the supposition that the interplay between the three project conditions measured during front-end execution determine which of four gate timing strategies with different levels of flexibility (i.e., one fixed, one flexible and two hybrid forms) maximizes new product profitability. This finding has important implications for both theory and practice as we now comprehend that the knowns can be used to manage the unknown.

Key words: Stage-Gate, front-end, task underestimation.

PRACTITIONER POINTS:

- The best gate timing strategy can be selected by project managers and/or teams at the end of the front-end based on the answers to the following three questions:
    - Did the team discover new tasks in the front-end stage?
    - Are all customers willing to postpone their purchase if the NPD process is possibly delayed due to the execution of unexpected tasks?
    - Were new tasks discovered just before the front-end gate?
- If no new tasks were discovered, the initial and tight gate timing can remain fixed. If tasks were discovered and all customers are willing to postpone, a completely flexible strategy is best. If new tasks were discovered and not all customers are willing to postpone, one of the hybrid strategies should be used, depending on whether or not new tasks were discovered just before the front-end gate.

INTRODUCTION

The majority of new product development (NPD) projects follow a phased or Stage-Gate® type of NPD process to reduce risk and decrease the costs of investing in a losing course of action (Barczak, Griffin, and Kahn, 2009; Chao, Lichtendahl, and Grushka-Cockayne, 2014). An additional, but often overlooked advantage of applying Stage-Gate types of processes is that they allow for a better time planning of NPD projects by dividing the overall process into easier-to-schedule short-term goals (Cooper, 1994, 2008). However, despite the popularity of research topics such as NPD cycle time reduction and market-entry timing over the last decades (e.g., Cankurtaran, Langerak, and Griffin, 2013; Langerak, Hultink, and Griffin, 2008), these potentially time-related advantages of Stage-Gate approaches have not received much attention in the product innovation and management literature (Krishnan and Loch, 2005).

Only a few studies have investigated the antecedents or consequences of cycle time for individual stages of the NPD process, and the more recent findings clearly underscore the importance of a stage-wise timing of NPD activities (Bendoly and Chao, 2016; Eling, Langerak, and Griffin, 2013). These studies show that stage-wise cycle times better explain new product performance than do aggregate cycle time from ideation to launch, which confirms the Stage-Gate idea of subdividing the NPD process into shorter and smaller work packages in project planning (Cooper and Sommer, 2016). However, what remains unclear from previous research is how *fixed* or *flexible* the schedule of gate meetings should be from the very beginning of the NPD project.

This is not surprising as it is often difficult, if not impossible, to make realistic time-planning schedules at the outset of an NPD project. From a cycle time reduction perspective, fixing the timing of all gate meetings a priori and strictly adhering to this schedule appears most advantageous, as this strategy emphasizes time reduction and increases goal clarity from the start of the NPD project (Kessler and Chakrabarti, 1996). Moreover, a completely fixed gate timing facilitates the consistent reduction of all stages' cycle times, which is necessary to realize aggregate cycle-time reduction advantages (Eling et al., 2013). However, the new product concept may not yet be known, or not be clearly defined at this early stage, and the exact nature of the NPD tasks that will need to be completed may also still be unknown (Kim and Wilemon, 2002).

As a result of this "fuzziness" at the beginning of a new project, in combination with mounting speed-to-market pressure, the amount of NPD work that needs to be done over the course of the entire NPD process is often underestimated at the start of the project (Tatikonda and Rosenthal, 2000; Van Oorschot, Langerak, and Sengupta, 2011). If insufficient time is scheduled, the development team runs the risk that some NPD tasks will not be proficiently completed before the launch date, which could lead potential customers to reject the new product because of reduced quality (Calantone and Di Benedetto, 2000; Crawford, 1992).

To account for such adverse consequences of task underestimation, allowing for a more flexible rescheduling of gate meetings while the NPD project is ongoing, may be more beneficial than strictly adhering to the schedule fixed at the outset of the project. However, there also are potential drawbacks of such a flexible approach. Specifically when gate meetings are postponed too easily and frequently, the time-to-completion may increase. As a result market-entry timing goals are compromised and customers that have anticipated and relied upon the timely introduction of the new product may be lost to competitors (Eisenhardt and Tabrizi, 1995; Van Oorschot, Akkermans, Sengupta, and Wassenhove, 2013).

These opposing arguments show that deciding on the right level of gate timing flexibility at the start of the project comes down to an educated guess, because the best level of flexibility to maximize project performance depends on the level of task underestimation, which is unknown.

Against this backdrop, our study proposes that three quantifiable project conditions (i.e., the knowns) can be measured before the end of the front-end stage and their values be used to manage this unknown. These conditions relate to: (i) the number of new, unexpected tasks discovered in the front-end stage, (ii) the willingness of customers to postpone their purchase in case the execution of these unexpected tasks would lead to a delayed market entry, and (iii) the number of new tasks discovered just before the front-end gate. The aim of this study is to answer the following research question:

> *How can these three project conditions be used by the project manager and/or development team to select the most profitable gate timing strategy (i.e., more fixed or more flexible) for the particular NPD project at hand?*

This question points at the objectives of this study which are: (i) to show that the profitability impact of a chosen gate timing strategy depends on the project conditions and (ii) to develop rules-of-thumb that allow project managers and/or teams to select the gate timing strategy that maximizes new product profitability. To realize these objectives this study distinguishes between, and tests the consequences of applying four gate timing strategies with different levels of gate flexibility (i.e., one fixed, one flexible and two hybrid forms) to NPD projects with varying conditions. The testing is conducted by means of a simulation based on system dynamics modeling to account for the complex system of feedback processes resulting from applying each gate timing strategy (Bendoly, Croson, Goncalves, and Schultz, 2010; Größler, Thun, and Milling, 2008). The model is extended from a calibrated and validated system dynamics model developed by earlier research (Van Oorschot et al., 2011) using NPD project data from manufacturers of industrial products gathered in previous studies by Eling et al. (2013) and Van Oorschot et al. (2011).

The simulation of 200 NPD project scenarios shows that the three project conditions jointly determine how much flexibility in gate timing is required, and therefore which gate timing strategy performs best. As such, our study shows that the most profitable gate timing strategy can indeed be selected by the project manager and/or team at the end of the front-end stage based on the three project conditions. These conditions can be monitored and measured during front-end execution. As such, the knowns (i.e., the project conditions) can be used to manage the unknown (i.e., degree of task underestimation) in NPD.

These findings contribute in a number of ways to different streams in the product and innovation management literature. First, the findings contribute to the literature on the implementation rigidity and/or flexibility of the Stage-Gate approach as this study shows *how much* flexibility is required in terms of *when* gate meetings will be held. Second, adding to the literature on cycle time reduction, the current study provides additional explanations for the trade-off between quality and speed in maximizing new product profitability, and lends additional support to the notion that NPD cycle time should be managed in a stage-wise manner (Bendoly and Chao, 2016; Eling et al., 2013). Finally, a contribution is made to the front-end management literature by delivering a new explanation for prior contradicting claims about taking time or speeding the front-end stage (Burchill and Fine, 1997; Smith and Reinertsen, 1997) and by showing that the end of the front-end stage indeed is a good point to finalize the timing of the remaining NPD trajectory (Kim and Wilemon, 2002).

The next section outlines the study's theoretical foundations, and the subsequent section explains the model and structure of the system dynamics simulation. Then, we present and discuss the simulation results and point out the managerial and theoretical implications of the findings. The article closes with a discussion of the study's key limitations and suggestions for further research.

THEORETICAL BACKGROUND

Stage-Wise Time Planning

A Stage-Gate type of process is characterized by multiple stages in which NPD activities are executed, each followed by a gate meeting in which the project is reviewed and a go/no-go decision for continued investment in the project is made (Barczak et al., 2009; Cooper, 2008). Although projects differ in terms of the adeptness with which NPD activities are performed, the structure according to which the activities are performed is basically the same for all projects (Cooper and Kleinschmidt, 1986) and comprises three main stages: (i) the front-end, (ii) development, and (iii) commercialization, with in-between gates (Crawford and Di Benedetto 2011).

The *front-end* consists of idea generation, concept development, and project planning activities (Khurana and Rosenthal, 1998; Reid and de Brentani, 2004). This “fuzzy” beginning stage of a project starts with the identification of an opportunity or idea, and ends with the front-end gate when the final go/no-go decision for physical development of the resulting new product concept is made. To pass the front-end gate the project’s fuzziness (i.e., what is developed, why, and how) must be reduced to an acceptable level (Kim and Wilemon, 2002). The subsequent *development* stage consists of product design and testing activities and ends with approval for mass production of the new product at the development gate (Crawford and Di Benedetto, 2011). Afterward, the launch planning and manufacturing scale-up of the new product begins in the *commercialization* stage, which ends with the commercialization gate that determines whether the new product is ready to enter the market (Crawford and Di Benedetto, 2011).

These three stages facilitate easier and more precise time planning by dividing the overall idea-to-launch process into several short-term steps and goals (e.g., in terms of costs, quality, and time), and the evaluation at each gate ensures that the in-between time goals are met (Cooper, 1994, 2008) before a go decision is made. Distinguishing among, and using these three main stages for the time-planning aspect of an NPD project, allows for the successful implementation of a speed-to-market strategy (Eling et al. 2013).

New product idea-to-launch cycle time reduction is an important objective in NPD management (Cankurtaran et al., 2013). The key rationale underlying firms' efforts to reduce cycle time are the first-mover advantages attributed to faster product development (Langerak and Hultink, 2006; Van Oorschot et al., 2011). However, the exact consequences of cycle time reduction are still not fully understood (Cankurtaran et al., 2013). Some studies have found positive effects of cycle time reduction on NPD outcomes (e.g., Chen, Reilly, and Lynn, 2005; Kessler and Bierly, 2002), while others have found no significant effects (e.g., Griffin, 2002; Meyer and Utterback, 1995).

A recent meta-analysis shows that several methodological design artifacts may help explain these inconsistent findings, such as the use of objective versus subjective measures of new product idea-to-launch time (Cankurtaran et al., 2013). Another possible explanation comes from studies investigating the stage-wise effects of NPD cycle time reduction. For example, Eling et al. (2013) use objective measures of the cycle times of three main NPD stages (i.e., front-end, development, and commercialization) to show that new product performance is increased only when cycle time is consistently reduced across all three stages. In contrast, simply reducing overall idea-to-launch cycle time, with inconsistent acceleration across the three stages, had no significant effect on NPD performance. Bendoly and Chao (2016) also show that the reduction of time spent in individual stages of the NPD process may better explain project performance than the reduction of the overall NPD process cycle time. Using a stage-wise time planning can also reduce the risk of back-loading (i.e., being inefficient and taking too much time at the beginning of the project, so that NPD tasks pile up and time pressure increases toward the end of the NPD project) (Van Oorschot et al. 2011). Together these findings highlight the importance of managing cycle time in a stage-wise manner.

Need for Balancing Rigidity & Flexibility of Stage-Wise Time Planning

To date no research has paid attention to the question of how rigid or flexible such a stage-wise timing of an NPD project should be. From a cycle time reduction perspective, making a tight initial time plan for all gates (i.e., a plan to bring to market the new product as fast as possible based on the known tasks at hand) at the very beginning of the NPD project, and sticking to this time plan throughout the project, would be most advantageous (Zhang, 2016). An advantage of keeping the gate timing fixed is that the time goal for the project is clear from the very beginning, which has been shown to increase NPD project performance (Kessler and Chakrabarti, 1996; Langerak, Hultink, and Robben, 2004; Stockstrom and Herstatt, 2008). Having and adhering to clear time goals nurtures a culture of speed and improves the efficiency and effectiveness of the team (Kessler and Chakrabarti, 1996; Meyer and Utterback, 1995). Keeping the gate timing fixed also ensures consistent and balanced time pressure throughout the project, which should already start at the beginning of the front-end stage (Eling et al., 2013; Kim and Wilemon, 2010). As a result, a decrease of product quality due to mistakes made under unanticipated time pressure, or even due to leaving NPD tasks uncompleted, is less likely (Burchill and Fine, 1997). Consequently, when deciding on a tight gate timing at the very beginning and adhering to this schedule through project execution, positive consequences of NPD cycle time reduction may accrue, such as lower development costs through a more effective use of resources (Cankurtaran et al. 2013), achieving pioneer or fast-follower advantages through early market-entry (Lilien and Yoon, 1990), and/or increased new product quality through a better match of forecasted and actual market, environmental, and technical forces (Kessler and Bierly, 2002).

Despite these advantages, the initial timing of the stages and gate meetings is often made too tight. The number of tasks that must be executed is regularly underestimated at the beginning of the project, resulting in overly optimistic initial time planning (Buehler, Griffin, and Ross, 2002; Lyneis and Ford, 2007). Task underestimation occurs at the outset because the product concept and the tasks that need to be completed to develop the concept into a new product are simply not known (Pich, Loch, and Meyer, 2002; Van Oorschot, Sengupta, Akkermans, and van Wassenhove, 2010). Task underestimation also happens because teams focus on the more visible individual components of the new product concept when planning the project, and often overlook tasks resulting from the connectivity among these components. These tasks only emerge as the project proceeds through the NPD process (Abdel-Hamid and Madnick, 1991). In addition, NPD team members often forget the amount and complexity of work that needed to be completed in similar prior projects, and thus tend to be overly optimistic about their ability to complete the current project in a short time (Kahneman, Slovic, and Tversky, 1982). Another reason that task underestimation in NPD project planning occurs is the team's overconfidence in its ability to interpret available market, environmental and technological information (Bendoly et al., 2010).

Adequately accounting for unexpected tasks in the initial planning of an NPD project has proven difficult, regardless of the project's characteristics (Roy, Christenfeld, and McKenzie, 2005). For example, categorizing an NPD project as incremental or radical does not reliably account for a potential underestimation of tasks when making the time planning at the beginning of the NPD project. The reason is that if more tasks are already expected at the very beginning of the project due to a higher uncertainty, the tasks are no longer 'underestimated'. Furthermore, although underestimation of tasks is likely to be higher for more innovative projects, it may also occur in incremental projects because of a higher likelihood of feeling overconfident in such projects.

Keeping the initial gate timing fixed when task underestimation occurs may initiate a vicious circle (or reinforcing feedback loop) of negative cycle time reduction effects (Burchill and Fine, 1997). Development costs may increase because the team must work beyond the predicted hours or additional members need to be hired to perform all the unexpected tasks (Van Oorschot et al. 2010, 2011). Mistakes are also likely to occur when time pressure increases, leading to increased costs and additional delays due to the need to work through certain problems again to ensure the product is of desired quality (Crawford, 1992). New product quality may ultimately be compromised from these inflexibilities, which in turn can reduce sales, particularly when unexpected tasks are postponed or when some tasks cannot proficiently be completed before the scheduled launch date (Sethi, 2000).

In contrast, including "slack" or time buffers to account for planning mistakes should also be avoided by development teams in the initial time planning of any type of NPD project. The reason for this is that slack can become a self-fulfilling prophecy (Kessler and Chakrabarti, 1996; Pich et al., 2002). Loose deadlines may lead to a decline of workers' performance and to a delay of the activity (Gutierrez and Kouvelis, 1991). This should be avoided because cycle time reduction is important for all types of NPD projects as earlier studies have shown (Barczak et al., 2009; Griffin, 1997, 2002). This explains why the gate timing schedule should be tight from the very beginning of all type of projects, while some flexibility may be required to account for unexpected tasks being discovered.

However, too much flexibility in scheduling gate meetings can also have drawbacks. A lack of rigid commitment to time goals due to repeated postponement of gate meetings can be inefficient because the awareness of making planning mistakes, discussions of whether to reschedule upcoming gate meetings, and agreement on new dates consumes a great amount of energy and time from the development team (Denis, Dompierre, Langley, and Rouleau, 2011; Pich et al., 2002). Without definite time goals and hence less time pressure, the task completion efficiency of the team decreases, and as a result, precious time and resources may be wasted in each stage of the project's NPD trajectory (Kessler and Chakrabarti, 1996; Meyer and Utterback, 1995). In addition, product quality goals may become a higher priority than time-to-market goals. Customers who are not willing or able to wait for the delayed new product, may be lost, leading to a situation in which new product sales are lower than expected despite higher quality (Langerak and Hultink, 2006). The additional time and resources spent on developing a higher-quality product may consequently not pay off.

These opposing arguments show that a balance needs to be struck between flexibility and rigidity in determining the appropriate gate timing strategy.

The Knowns at the End of the Front-End

From the discussion above it can be seen that different factors determine the need for flexibility versus rigidity in the gate timing of an NPD project. When unexpected tasks are discovered during the project, more flexibility in the gate schedule is required to allow the proficient completion of these tasks. This would likely lead to a delayed market entry. However, when a timely completion of the project is important because customers are unwilling to postpone their purchase in case of a delayed market introduction, more rigidity may be more advantageous to complete the project faster.

Unfortunately these factors are unknown when making the initial time planning of the project. However, by the end of the front-end the manager and/or team should be able to determine the need for flexibility and rigidity and select the most appropriate gate timing strategy. This point in the project's development trajectory is most suitable because at the front-end gate meeting the authorization decision is made as to whether to actually develop the new product, and if so considerable resources will be committed (Chang, Chen, and Wey, 2007; Kim and Wilemon, 2002). The up-coming front-end gate meeting thus forces the team to reduce the project's fuzziness to the authorization level set by the gate committee. This means that the NPD team must clearly describe what new product will be developed, how it will be developed, and what the definitive timeline for the development will be (Kim and Wilemon, 2002; Reid and de Brentani, 2004).

The project manager and/or team should be able to assess three project conditions just before the front-end gate to find the right balance between flexibility and rigidity that could not be determined while setting the initial time planning of the project. First, the team knows the number of unexpected tasks that were discovered during the front-end stage (condition 1). Second, the development team has, at the end of the front-end stage, a better understanding of potential customers as well as knowledge about the characteristics of the new product's window of opportunity so that the number of customers that are willing to postpone their purchase can be assessed (condition 2). Finally, at the end of the front-end, the development team is able to determine the likelihood that more unexpected tasks may still be discovered in the remainder of the NPD process by observing the number of tasks discovered just before the front-end gate (condition 3).

The rationale of assessing project condition 3 is that the discovery of unexpected tasks, just as the reduction of fuzziness in the front-end of an NPD project, follows a pattern of a gradually flattening curve (Kim and Wilemon, 2010), also known as an adaptive expectation or exponential smoothing (Sterman, 2000), that ends at zero (when all unexpected tasks are discovered). With this assumption we follow the dominant view in the literature (e.g., Kim and Wilemon, 2002), although other studies have also argued for different patterns of task discovery (e.g., Chang et al. 2007). When new tasks are still being discovered just before the front-end gate, it is likely that the team is not finished yet with reducing the fuzziness of the project. This indicates that more flexibility in the time planning is needed for not only the future stages (i.e. development and commercialization), but also for the front-end stage.

Waiting until all tasks are discovered (i.e., at a later point in the NPD process) to determine the right balance between flexibility and rigidity in the timing of the gates is not realistic because even in the development and commercialization phases, unexpected tasks are often still discovered (Kamoche and Cunha, 2001). As such, the market launch date is likely to be delayed too much. An earlier point in the NPD process (i.e. before the end of the front-end) is also not feasible because the team is unlikely to have discovered the majority of unanticipated tasks or to know enough about the potential customers to correctly estimate their willingness to wait for a possibly delayed market introduction (Kim and Wilemon, 2002).

Gate Timing Strategies: Trade-off between Time and Quality

Following the reasoning above, we propose a stage-wise timing approach for NPD projects that allows choosing the gate timing strategy with the appropriate level of flexibility for the project at hand just *before* the front-end gate meeting. This approach requires starting the project with a preliminary and tight gate timing schedule that is suitable for those tasks known or expected by the NPD team at the very beginning of the project (depicted with number 1 in Figure 1). During the front-end stage, the team can monitor the three project conditions (number 2 in Figure 1). Just before the initially planned front-end gate meeting, one of four theoretically distinguished gate timing strategies is then selected based on the project conditions (number 3 in Figure 1). This gate timing decision point is placed just *before* and not *at* the front-end gate meeting so that the development team can also postpone the front-end gate meeting if necessary. The four gate timing strategies that are distinguished in this study (explained on the right side of Figure 1) are: (i) the fixed strategy, (ii) the flexible strategy, (iii) the fixed front-end strategy, and (iv) the flexible front-end strategy.

<<< Insert Figure 1 about here >>>

Choosing the *fixed gate timing strategy* (Figure 1, row 1) just before the front-end gate means strictly adhering to the tight initial time plan made at the very beginning of the NPD project for all gates. Gates are not allowed to be postponed in this strategy. However, when task underestimation is high, the initial timing of the stages and gate meetings is often made too optimistically. This is why it is often argued that flexibility is required to account for unexpected tasks being discovered in an NPD project (Biazzo, 2009; Verganti, 1999). Re-planning and postponing gate meetings whenever this is deemed necessary throughout the project is what we call the *flexible gate timing strategy* (depicted with extra gate timing decision points in Figure 1, row 4). This flexible gate timing strategy allows the team multiple decision points in which gate meetings can be postponed if necessary.

These opposing strategies illustrate that in making a decision about the gate timing strategy, a trade-off has to be made between gate timing rigidity and flexibility (Bayus, 1997; Tatikonda and Rosenthal, 2000) in order to:

(i) plan extra time to adeptly complete the unexpected tasks discovered throughout the NPD trajectory to avoid compromising new product quality and sales;

(ii) keep as close as possible to the initial time planning of gate meetings in order not to lose customers unwilling or unable to wait for the delayed introduction of the new product.

The fixed gate timing strategy is at one extreme of this trade-off. By keeping all gate meetings fixed, time-to-market is chosen over new product quality. The flexible gate timing strategy is at the other extreme. By allowing the development team more time whenever unexpected tasks are discovered, product quality is prioritized over time-to-market.

Between these two incompatible strategies, we position two hybrid gate timing strategies. These allow the team to re-plan the gate meetings, but - in comparison to the completely flexible strategy where re-planning is possible before every gate meeting of the project - only *once* before the initially planned front-end gate. The first hybrid form is the *fixed front-end gate timing strategy* (Figure 1, row 2), which keeps the front-end gate timing fixed, but allows *one* re-planning of the development and commercialization gates to allocate extra time for the execution of new tasks that were discovered during the front-end stage. The second is the *flexible front-end gate timing strategy* (Figure 1, row 3). Here, at the end of the front-end stage, all three gates including the front-end gate are allowed to be re-planned *once* to give more time for the discovery and execution of unexpected tasks also in the front-end. One re-planning possibility thus allows the team to schedule additional time to complete unexpected tasks (hence protecting new product quality), but at the same time does not grant the team the opportunity to keep postponing the due date whenever a new task is discovered (hence protecting market entry timing).

The difference between the two hybrid strategies is that the fixed front-end strategy emphasizes cycle time already in the front-end, which has been argued to be important for a successful time-to-market strategy (Kim and Wilemon, 2002; Smith and Reinertsen, 1997). The flexible front-end strategy, in contrast, emphasizes new product quality by allowing more time for the completion of unexpected tasks during the front-end (Burchill and Fine, 1997; Crawford, 1992; Thomke and Fujimoto, 2000).

Selecting the Right Gate Timing Strategy Based on the Knowns

Which of these four gate timing strategies is the best to maximize project performance should be determined by measuring and assessing the three project conditions, the 'knowns', at the initially-planned end of the front-end stage. For the individual project conditions, theoretical inferences about their effects on the performance of each strategy can be made. These will be discussed below. How the interaction between the conditions affects the performance of each strategy is theoretically much less clear, and therefore not discussed.

First, knowing the number of tasks that has been discovered during the execution of the front-end stage determines whether or not a postponement of gate meetings will actually be necessary to ensure that the newly discovered tasks can competently and timely be completed without compromising new product quality (Lukas and Menon, 2004). When many unexpected tasks have been discovered during the front-end stage, a more flexible strategy that allows some kind of rescheduling is likely to be more appropriate than a completely fixed gate timing strategy.

When (almost) no unexpected tasks are discovered, the team could adhere to the initial gate timing (i.e., fixed gate timing strategy).

Second, having an idea of how many potential customers would be lost if the execution of the unexpected tasks would result in a delayed market entry (Lilien and Yoon, 1990), and how many customers would be willing to wait for a possibly delayed introduction of the new product, allows the development team to understand the importance of a timely market introduction. If the majority of customers are willing to wait, the team could consider a more flexible gate timing strategy. If most customers would be lost, a more rigid gate timing strategy should be considered to reach the market in time, and avoid losing customers to the competition (Langerak et al., 2008).

Finally, when new tasks are still being discovered just before the front-end gate, the team clearly needs more time for reducing the fuzziness of the project. Hence, it is likely that more new, unexpected tasks will be discovered at a later point in the project’s NPD trajectory (Chang et al., 2007). The higher this likelihood, the more gate timing flexibility will be required.

Although we have made some initial theoretical inferences about the need for rigidity versus flexibility depending on the individual project conditions, it likely is the interactions between, and importance of each of these conditions that explain which gate timing strategy maximizes new product profitability. Assessing this from a theoretical perspective is, as mentioned before, profoundly difficult. Therefore we will simulate the consequences of applying each gate timing strategy (i.e. the fixed, flexible and two hybrid forms) for new product profitability under different levels and combinations of these three project conditions to fully understand their role in choosing the appropriate gate timing strategy.

METHOD

We use system dynamics simulation because our research involves multiple interacting feedback processes, time delays, nonlinear effects, and a fundamental trade-off or tension (Bendoly et al., 2010; Davis, Eisenhardt, and Bingham, 2007; Größler et al., 2008) between new product quality and cycle time. In addition, simulation helps overcome the difficulty of observing the consequences of applying different gate timing strategies in practice, in which many other factors that differ across NPD projects may intervene with the effects.

Our model is grounded in both theory and practice, as we use a system dynamics model built in previous research and calibrated and validated from real NPD project data (Van Oorschot, et al. 2011). However, the projects modeled in Van Oorschot et al. (2011) consist of only one overall NPD stage, followed by a period in which the new product is sold in the market. To test the effect of different gate timing strategies, we extend this model to accommodate for multiple stages, their interdependence, and their gates before new product launch. To this end we draw on the work of Eling et al. (2013) who distinguish three main NPD stages: front-end, development, and commercialization. We use their objectively measured duration of each stage and additional characteristics of 46 NPD projects to calibrate our model.

Because our model structure and equations are grounded in literature and parameter values are based on empirical data from prior studies, the evidence level of our model is at least medium, according to the classification scheme for system dynamics models suggested by Homer (2014). It is difficult for our model to exactly replicate behavior of previous NPD projects, because we do not have access to projects that have experimented with hybrid gate timing strategies. However, the generic behavior that fixed strategies lead to new products that are introduced in the market earlier, albeit with lower quality, and that flexible strategies lead to the introduction of new products with higher quality that are delivered to the market later, is supported by our model and corroborated by the extant NPD literature.

The Model Structure and Definition

Figure 2 depicts a high-level overview of our model. For the purpose of readability and clarity we only present this synopsis of the model consisting of its main causal relationships and the resulting trade-off between cycle time and new product quality. A more detailed view of the model, a description of all equations, a list of variables, values of constants, and the sources for these values appear in an online supplement (following Rahmandad and Sterman's (2012) guidelines for simulation-based research). The variable definitions and their interrelationships are derived from the review of extant NPD management literature and are fully described in Van Oorschot et al. (2011; Tables 2 and 3; p. 854) and therefore not repeated here.

<< Insert Figure 2 about here >>

We model each stage as a set of NPD tasks that flow from one stock (accumulation of tasks) to the next. Four stocks are distinguished per stage in the NPD process: unexpected tasks (*UT*), tasks in execution (*TE*), tasks finished (*TF*), and tasks pushed to the next stage (*TP*). These four stocks and their flows are presented in Figure 3. All stocks are defined as the integral of their net flows (inflows minus outflows) added to their initial value; see Equations (1)-(4). Subscript *i* refers to a particular stage (i.e., front-end, development, commercialization) in the NPD process:

$$UT_i(t) = UT_i(0) + \int_0^t \left(tir_i(s) - tdr_i(s)\right)ds. \quad (1)$$

$$TE_i(t) = TE_i(0) + \int_0^t \left(tdr_i(s) + tsr_i(s) - tmr_i(s) - tfr_i(s)\right)ds. \quad (2)$$

$$TP_i(t) = TP_i(0) + \int_0^t tmr_i(s)ds. \quad (3)$$

$$TF_i(t) = TF_i(0) + \int_0^t tfr_i(s)ds. \qquad (4)$$

<< Insert Figure 3 about here >>

The task inheritance rate (*tir*) defines the number of tasks that are transferred, unfinished, from a previous stage. The task discovery rate (*tdr*) is the rate in which new unexpected tasks are discovered. The task start rate (*tsr*) indicates the rate in which the development team starts working on tasks when a new stage begins. The task finish rate (*tfr*) defines the rate in which tasks are finished. Finally, the task move rate (*tmr*) equals the rate in which unfinished tasks are pushed to the next stage when there is not sufficient time to finish them.

The Unknown: The Level of Task Underestimation

In the front-end stage, all tasks that need to be completed are initially either in the stock of unexpected tasks (unknown to the team) or in the stock of tasks in execution (known to the team), depending on the task underestimation percentage of the project. When task underestimation is 0%, no tasks are in the unexpected stock and all tasks start in the stock of tasks in execution. So, the higher this task underestimation percentage, which is unknown to the team at the start of the NPD project (see left side of Figure 2), the more tasks are initially unknown and in the unexpected stock. During front-end execution, the majority of unexpected tasks are discovered and defined, which means that they flow into the stock of tasks in execution.

The Knowns: The Project Conditions

As explained in the theory section, we identified three project conditions that the team can monitor and measure at the end of the front-end stage, and that likely influence the performance of each gate timing strategy. The three conditions are depicted in Figure 2 (in the box labeled "knowns"). As such, we can simulate which timing strategy works best under which (knowable) project conditions. The way we modeled these three conditions, and how they can be measured by the NPD project team, is explained below.

1. *The number of new, unexpected tasks discovered in the front-end stage*: The number of unexpected tasks in the project is influenced by the task underestimation percentage. This percentage is unknown to the team at the start of the project and can only be known when the project is completely finished. However, the team can keep track of the total number of unexpected tasks discovered in the front-end. In the model this number is derived by calculating the sum of the task discovery rate during the front-end stage, from the start in week 1 until the scheduled completion time (*SCT*) of the first gate: $\sum_{t=1}^{SCT_1} tdr_1(t)$.

   We simulate scenarios that vary in the number of new, unexpected tasks being discovered in the front-end for 0%, 25%, 50%, 75%, and 100% for each of the four gate timing strategies. These percentages are based on underlying levels of task underestimation from 0% to 40% because an upper-bound of 30%-40% is not uncommon (Roy et al., 2005). The total number of new tasks discovered in the front-end stage can be compared to the initial number of expected tasks. So when 75 extra tasks are discovered and 100 tasks were initially known to the team, 75% extra tasks were discovered, which relates to task underestimation of about 40%: 75 new tasks divided by 175 tasks in total.

2. *The number of customers willing to postpone their purchase*: Customers' willingness to postpone their purchase in case that the execution of unexpected tasks leads to a delayed market entry is defined by a percentage, *wp*. When this percentage is 100%, all customers are willing to postpone their purchase. In other words: a short time-to-market is not important.

When this percentage is 0%, no customers will postpone their purchase if the new product introduction is delayed due to the discovery of unexpected tasks. This implies that all customers will be lost. We simulate scenarios with five different percentages of customers' willingness to postpone: 0%, 25%, 50%, 75% and 100%.

3. *The number of tasks discovered just before the front-end gate*: Not only the sum of the tasks discovered is important, but it is also important to observe *when* these tasks are discovered. In our model this is reflected by the variable task discovery rate. We model this task discovery rate (*tdr*) in the front-end stage as an adaptive expectation (exponential smoothing, Sterman, 2000), where *ddt* is the discovery delay of tasks, or in other words, the average time it takes to discover a task (Equation (5)):

$$tdr_1(t) = UT_1(t)/ddt. \quad (5)$$

The shorter the discovery delay, the higher the task discovery rate, which means that new tasks are discovered faster. In most NPD projects this task discovery rate is high in the beginning of the front-end stage but decreases during the stage and eventually flattens out. This means that eventually, the task discovery rate will drop to (almost) zero. When this happens, it is unlikely that many unexpected tasks will be discovered in the future (stages) of the NPD process, which means that the team knows how much workload (tasks) remains.

The team can keep track of this task discovery rate and the way it behaves over time. It is especially important just before the front-end gate meeting to measure how many unexpected tasks are still being discovered. In the model this value is given by $tdr_1(SCT_1)$ which is the task discovery rate at the initially scheduled completion date of the front-end stage (i.e., the front-end gate).

We simulate scenarios with two different discovery delays: a short one (4 weeks) and a long one (10 weeks). When the discovery delay is 4 weeks, it means that all unexpected tasks will be discovered during the front-end stage and hence the number of tasks discovered just before the front-end gate is zero. When the discovery delay is 10 weeks, it takes the team more time to discover tasks, which means that some unexpected tasks are still being discovered just before the front-end gate.

We therefore simulate 200 scenarios (5 different values for unexpected tasks discovered, 2 different values for tasks discovered just before the front-end gate, 5 different values for willingness to postpone, and 4 different gate timing strategies).

Decision Point: Trade-off between Cycle Time and Product Quality

The actual number of tasks in execution and the productivity of the development team determine what a feasible completion time for each stage could be. If this feasible completion time is longer than the initially scheduled completion time, the team is under time pressure because it may not be able to finish all tasks before the gate meeting takes place. When this happens, team members will first choose to work overtime (Tatikonda and Rosenthal, 2000). The model allows for a maximum of 25% of overtime work. Assuming that a normal working day is 8 hours, this means that the team can work a maximum of 10 hours per day. But, when working overtime is insufficient to close the gap between the feasible completion time and the scheduled completion time, the team has to choose between two other options. These options are dynamic because they initiate behavior that can influence the current stage at the current time, but also future stages, and the profitability of the NPD project through changes in costs, cycle time, quality, and sales. We model these options as feedback loops:

1. In line with the concept of fuzzy or conditional gates (Biazzo, 2009; Cooper, 1994), the model allows uncompleted tasks at the time of the gate meeting to be moved to the stock of *tasks pushed to the next stage*. This means that the timing of the gate is protected, but tasks that are not yet finished move from, for example, the front-end to the development stage. As such the team solves their time pressure problems by reducing the workload in the current stage. Thus, pushing tasks to the next stage will set off a balancing loop (B1) within the stage, labeled *trading-off time for quality* in Figure 2. Product quality is likely to be compromised in this option, because tasks that are pushed from, for example, the front-end to the development stage, were initially not part of the project plan for this development stage. As a result, the time pressure for this stage will increase and the team will need to find a way to deal with this pressure as well. This dynamic behavior is also known as "shifting the burden" (Wolstenholme, 2003). The balancing loop indicates a quick fix (i.e., a solution that works well in the short run). By pushing tasks to the next stage, fewer tasks remain in the current stage, which makes it easier to finish this current stage on time.

   However, for the entire project, this quick fix is likely to make matters worse in the long run. Pushing tasks to the next stage leads to more scheduling problems in the following stage. Tasks not completed at the end of the commercialization stage will compromise the quality of the new product launched in the market.[i] The possibility to push tasks to the next stage has similar consequences as making errors. Once errors are discovered they require rework, and this rework is added to the normal, planned tasks that need to be executed.[ii] This increases work pressure for the team, which can create problems in finishing the project in a timely manner. When there is no time to correct errors or errors remain undetected, new product quality may also be compromised and the next stage will suffer more. This is in line with the findings from Parvan et al. (2015).

The way we modeled this is as follows. The number of tasks moved to the next stage is given by the task move rate, which is modeled as an adaptive expectation (Equation (6)). The flow is proportional to the stock, and the average delay time is the minimum time required to move a task to the next stage (*mint*):

$$tmr_i(t) = PG_i(t) * TE_i(t)/mint. \quad (6)$$

The variable *PG* (Passed Gate) can have only two values: 0 if the gate is not passed yet and 1 if the team is at the gate meeting (or if the gate meeting has passed).

2. The second option to reduce time pressure and solve the discrepancy between feasible and scheduled completion time is to give the team more time to finish uncompleted tasks. This scenario also sets off a balancing loop (B2), labeled *trading off quality for time* in Figure 2. This loop describes a goal adjustment. The original goal is to finish all tasks on time, but when the team realizes that it is running out of time, the time goal is adjusted (the gate is postponed). By postponing the scheduled completion time and re-planning the gates, the team will have more time to finish all tasks, which reduces the time pressure, thus closing the loop. The scheduled completion time (*SCT*) is modeled as a stock that can adapt to the feasible completion time (*FCT*) during a certain delay (*dtad*) (see Equations (7) and (8)). In the scenario with flexible gates, for example, the equations in the front-end are as follows (in the scenario with fixed gates, there is no adaption possible because the gates are fixed):

$$SCT_1(t) = SCT_1(0) + \int_0^t SCTar_1(s)ds. \quad (7)$$

$$SCTar_1(t) = (-SCT_1(t) + FCT_1(t))/dtad. \quad (8)$$

Resulting Gate Timing Strategies

The trade-off that the team makes between cycle time and new product quality determines which gate timing strategy is chosen, and thus which loop is activated and how (Figure 2). When cycle time is prioritized over quality and all gates are completely fixed, only loop B1 is activated (fixed gate timing strategy). When quality is prioritized over time and all gates are completely flexible, only loop B2 is activated (flexible gate timing strategy). The two hybrid strategies activate both loops B1 and B2, but not in the same way. By keeping the front-end gate fixed, the fixed front-end gate timing strategy focuses more on time than the flexible front-end strategy. However, this strategy also focuses on quality by allowing more time in the development and commercialization stages. The flexible front-end strategy focuses more on quality than the fixed front-end by allowing more time in all stages (including the front-end) to discover and execute new tasks. But, this strategy also protects market entry timing by allowing the gates to be rescheduled only once (as opposed to the flexible gate timing strategy in which gates can be rescheduled as often as deemed necessary).

New Product Profitability

To evaluate the performance effects of the four gate timing strategies, we calculate (stage-wise and total) cycle times, new product quality, developments costs, and new product sales for each of the 200 scenarios defined above. We define the ultimate measure of interest, new product profitability (Equation (9)), as the difference between the revenues or sales benefits (*SB*) (the sales rate [*sr*] times sales price [*sp*]; see Equation (10)) and the development costs (*DC*) (total number of FTE person weeks [*TPW*] expended, including overtime, times the labor costs per FTE person week [*lcp*]; see Equation (11)) (Cankurtaran et al., 2013).

$$P(t) = SB(t) - DC(t). \quad (9)$$

$$SB(t) = SB(0) + \int_0^t (sr(s) * sp(s))ds. \quad (10)$$

$$DC(t) = lcp * TPW(t). \quad (11)$$

NPD projects finished late are likely to have lower profitability when early market-entry timing is important. Customers will be lost when market entry is delayed from the initially planned introduction date because they instead buy competitors' products rather than waiting for the delayed new product to be finished and launched (Langerak and Hultink, 2006; Lilien and Yoon, 1990). Projects that are finished on time but have lower quality, because NPD tasks are not completed, are also likely to have lower profitability because: (1) more customers are lost to competitors as they are not interested in buying a new product with inferior quality and: (2) customers who are still willing to buy the lower-quality product pay a lower price for it (Lukas and Menon, 2004). These effects of cycle time and new product quality on the number of customers, and in turn new product profitability, are depicted on the right in Figure 2.[iii] In the next section, we present and discuss the profitability effects of the four gate timing strategies under different project conditions.

SIMULATION RESULTS & DISCUSSION

The simulation results in terms of the new product's profitability are presented in eight graphs in Figure 4. We simulated 200 scenarios in which we varied the values for the three project conditions and the gate timing strategies: five different levels for the number of new (unexpected) tasks that were discovered during the front-end stage, five different levels for the willingness of customers to postpone their purchase, two different levels for the number of new tasks that were discovered just before the front-end gate, and the four different gate timing strategies.

The graphs on the left-hand side of Figure 4 present the 100 scenarios in which no new tasks were discovered just before the execution of the front-end gate. This indicates that the team has discovered all new tasks during the front-end stage and no new tasks are expected to appear in the other two stages. On the right-hand side of Figure 4, the 100 scenarios are depicted in which new tasks were still being discovered just before the front-end gate. This indicates that the project's fuzziness has not been sufficiently reduced and that more new tasks are expected to be discovered in the next stage(s). The detailed results on all outcome measures (e.g., cycle time, new product quality, costs and sales) for each of the 200 scenarios can be found in an online supplement. Below we will provide a discussion of the impact of the three project conditions on the performance of the different gate timing strategies.

<< Insert Figure 4 about here >>

Number of New Tasks Discovered in the Front-End Stage

In general, the results show that the higher the number of new, extra tasks discovered by the team during the execution of the front-end stage, the higher the need for some flexibility in the gate timing strategy. Only when there are no extra tasks discovered (0%), do all gate timing strategies perform about equally well with a new product profitability between 3.80 to 3.83 million euros, regardless of the other two project conditions (number of tasks discovered just before the front-end gate and willingness to postpone). In Figure 4 this situation of 0% extra tasks is depicted with a black solid line.

Therefore, only in the extreme situation when no new tasks are discovered is the team able to deliver the right quality within the right time. There is no need to make a trade-off between cycle time and new product quality, and as such there is no need to change the initial gate timing plan.

All gates can be kept fixed. In all other situations, new unexpected tasks are discovered and a cycle time versus quality trade-off must be made. As a result, one of the three more flexible gate timing strategies will outperform the fixed gate timing strategy. Which of the three flexible strategies performs best, depends on the other two project conditions that are described below.

Customers' Willingness to Postpone Purchase

Not unexpectedly, Figure 4 shows that, in general, when more customers are willing to postpone their purchase when unexpected tasks are discovered, new product profitability increases. This is not surprising because without a penalty for being late, the team can take more time to focus on and improve new product quality without losing customers, which enhances new product profitability (trading-off quality over time). Only in the extreme situation in which all customers are willing to postpone their purchase (100%) is the flexible gate timing strategy clearly better than the two hybrid strategies. This situation is depicted in Figure 4 with a black dotted line. When unexpected tasks are discovered, but not all customers are willing to postpone, one of the two hybrid gate timing strategies is better (this situation is depicted in Figure 4 with a black dashed line). The value of the third project condition, the number of tasks discovered just before the front-end gate, determines which of the two hybrids is best.

Number of New Tasks Discovered Just Before the Front-End Stage

It is not only important whether or not new tasks are discovered during the front-end stage, but also when these tasks are discovered. In our model this is determined by the discovery delay of tasks. The longer this delay, the more time it takes the team to discover these unexpected tasks and the higher the probability that not all unexpected tasks will be exposed during the front-end stage. It is not possible for the team to know how many unexpected tasks they will discover in the project, but they can measure how many tasks they have discovered earlier in the front-end stage relative to the number of tasks discovered just before the front-end gate meeting.

When the team stops discovering new tasks just before the front-end gate (depicted by the graphs on the left-hand side of Figure 4), the likelihood of discovering even more tasks in the remaining stages of the NPD process is low. In these situations the fixed front-end timing strategy performs best. With this strategy time pressure is more consistently applied throughout the NPD project (Eling et al., 2013). As a result, the new product will likely reach the market timely enough not to lose too many customers unwilling to wait. With the flexible front-end strategy, in contrast, time pressure is released too much through the rescheduling of all three stages. Time and resources are subsequently also wasted in the early stage of the NPD process (Kim and Wilemon, 2002; Smith and Reinertsen, 1997). As a result, the market launch date may be pushed back too much, with negative effects on development costs and new product sales.

When the team continues to discover new tasks, also just before the front-end gate (depicted by the graphs on the right-hand side of Figure 4), it is likely that more tasks will still be discovered in the future. Under these circumstances the flexible front-end timing strategy performs best because this strategy grants the NPD team more time in the front-end (compared to the fixed front-end strategy) to complete more unexpectedly discovered front-end tasks before actually starting the development stage. This also allows the team to complete more unexpectedly discovered tasks in the development and commercialization stages, thereby positively affecting new product quality and sales (Reid and de Brentani, 2004; Verworn, Herstatt, and Nagahira, 2008). In contrast, when keeping the front-end gate fixed, unexpected tasks that are not discovered in the front-end, will be discovered and completed in the development stage (in line with the notion of fuzzy or conditional gates) (Biazzo, 2009; Cooper, 1994). The revised time plan would thus be much too optimistic as the workload is underestimated once more. This would ultimately harm new product quality and sales.

Conclusion

The findings of the system dynamics simulation show that each of the four gate timing strategies can outperform the others in specific situations defined by the three project conditions (i.e., the knowns). Thus by measuring the knowns during front-end execution project managers and/or teams can select the most profitable gate timing strategy at the end of the front-end stage. It is important to note that the completely fixed and flexible gate timing strategies only work in extreme situations. The fixed strategy only leads to the highest project profitability when *no* new unexpected tasks are discovered. The flexible gate timing strategy only works best when new tasks are discovered and *all* customers are willing to postpone their purchase. The hybrid gate timing strategies (fixed front-end and flexible front-end) will therefore lead to the highest new product profitability in most situations.

THEORETICAL IMPLICATIONS

Our findings have important implications for several research streams in the product innovation and management literature. First, the findings contribute to the literature on the implementation rigidity and/or flexibility of the widely used Stage-Gate approach, thus responding to a call for further research in NPD management on the use of Stage-Gate processes (Krishnan and Loch, 2005). In support of other research (Biazzo, 2009; Sethi and Iqbal, 2008; Tatikonda and Rosenthal, 2000), our study finds that a too rigid approach performs worst when unexpected tasks are discovered and that using a more flexible approach is more advantageous.

Previous research has focused on flexibility in terms of *what* will be developed until the gate meeting takes place (i.e., tasks, gate deliverables) and *how* it will be developed (i.e., resources allowance). The current study, in contrast, focuses on flexibility in terms of *when* the gate meetings will be held, while keeping the level of task (what) and resource (how) flexibility fixed. Additionally, we provide a much more fine-grained picture of *how much* flexibility is required. We find that new product profitability can be increased by selecting a gate timing strategy at the end of the front-end stage that fits specific project conditions that can actually be monitored and measured during the execution of the front-end stage. As a next research step, it would be worthwhile to investigate how *varying* combinations of rigidity versus flexibility of tasks, resources and timing conditions when applying Stage-Gate processes affect NPD performance, and which levels of flexibility are most appropriate for task and resource conditions.

Second, from the perspective of the cycle time literature, our findings provide additional explanations for why a focus on only cycle time or only new product quality, cannot suffice to maximize new product profitability. Instead, making a careful trade-off between these two important metrics and finding the optimal balance between them seems the most advantageous approach to successful NPD project execution (Bendoly and Chao, 2016; Swink, Talluri, and Pandejpong, 2006). Teams that adhere to an idea-to-launch plan that is too tight, get caught in the vicious cycle of negative cycle time reduction consequences. As a result, many tasks remain uncompleted, compromising new product quality and hurting sales. In contrast, teams allowed to postpone gate meetings to perform unexpected tasks and maintain high levels of product quality can miss the window of opportunity with a delayed market introduction.

As such, the findings confirm the existence of a trade-off between cycle time and quality, which can successfully be managed by choosing the right gate timing strategy. Development costs, which are an important consequence of cycle time reduction and a driver of new product profitability (Cankurtaran et al., 2013), are of lesser importance here because, just like in reality, team resources and the associated costs are constrained to a certain threshold (a maximum of 25% overtime). Further research might investigate whether different levels of resource constraints have differential impacts on the performance of different timing strategies.

Third, our findings lend support to the notion that managing NPD cycle time in a stage-wise manner, rather than in a process-wise manner, better contributes to achieving an optimal cycle time reduction level (Bendoly and Chao, 2016; Eling et al., 2013). Adding to Eling et al.'s (2013) findings, the current study shows that only a feasible, consistent acceleration of NPD cycle time across all stages leads to the highest new product profitability. The best-performing scenario when new tasks are discovered during the front-end stage (extra tasks > 0%), when not all customers are willing to postpone their purchase (wp < 100%), and when no extra tasks were discovered just before the front-end gate, is the fixed front-end gate strategy. This strategy leads to consistent time pressure (i.e., working overtime) on the team throughout the project, as exemplified in Figure 5. For the fixed gate timing strategy, the amount of overtime is also constant throughout the project, but the overall timing is just too short to complete all tasks on time. For the other two strategies, the workload is less consistently distributed along the stages of the NPD process because it gets either increased (flexible front-end) or relaxed (completely flexible) only shortly before the gate meetings take place.

<< Insert Figure 5 about here >>

Finally, our findings have implications for the front-end management literature. When task underestimation is high and the task discovery rate just before the front-end gate is low, which means that many new tasks have been discovered during the front-end stage, the fixed front-end strategy performs better than the flexible front-end one. In contrast, when the task discovery rate just before the end of the front-end stage is still high, the flexible front-end strategy maximizes project profitability as this strategy grants the team more front-end time to discover and complete unexpected tasks. This finding delivers a new explanation for prior contradicting claims about the timing of the front-end stage. Some authors have posited that enough front-end time should be taken to proficiently complete this important stage (Burchill and Fine, 1997; Crawford, 1992; Thomke and Fujimoto, 2000). This is indeed the case when too much uncertainty (i.e., undiscovered tasks) remains at the end of the front-end stage and a flexible front-end strategy outperforms the fixed front-end one. In contrast, other scholars have claimed that no precious time should be wasted in this important beginning stage (Kim and Wilemon, 2002; Smith and Reinertsen, 1997), which is confirmed by our findings when the task discovery rate just before the end of the front-end stage is low, so that a fixed front-end strategy performs best.

Next, the high performance of both hybrid strategies also confirms theoretical arguments that the end of the front-end stage is indeed a good point in the NPD process to finalize the timing of the remaining NPD trajectory. As such, our findings emphasize the importance of the front-end stage in determining the most appropriate gate timing strategy. Although this finding corroborates prior research (Kim and Wilemon, 2002), some important research questions remain. After the completion of what front-end activity can the revised timing decisions best be made, and which front-end tasks can be moved to the development stage without harming product quality or running the risk of getting rejected at the gate?

MANAGERIAL IMPLICATIONS

Most NPD projects, if not all, suffer from task underestimation (i.e. the unknown) which makes it extremely difficult to predict at the very beginning of the NPD project how much time is needed to complete each stage, and when gate meetings should be scheduled. Therefore, we proposed a gate timing approach that uses three distinct project conditions that can be measured during the execution of the front-end stage to choose the final gate timing strategy that maximizes new product profitability. Our simulation results deliver empirical support for this approach. Consequently, for the optimal time planning of an NPD project the project manager and/or team should make an initial and tight gate timing schedule at the very beginning of an NPD project and then answer the following questions right before the front-end gate meeting takes place:

1. Did the team discover new tasks in the front-end stage?
2. Are all customers willing to postpone their purchase if the NPD process is possibly delayed due to the execution of unexpected tasks?
3. Were new tasks discovered just before the front-end gate?

The most appropriate gate timing strategy that should then be chosen for the remaining project follows from the answers to these questions as depicted in the decision tree in Figure 6. When *no* unexpected tasks are discovered in the front-end stage, the timing can remain fixed as it was made at the very beginning of the project. When new tasks are discovered and *all* customers are willing to postpone their purchase until these tasks are completed, the gate timing schedule should remain flexible until the end of the project. This means that the NPD team can reschedule gate meetings whenever deemed necessary. When new tasks are discovered and *not all* customers are willing to wait for a delayed market introduction, the strategy choice depends on the number of tasks discovered just before the front-end gate. When the discovery of new tasks stops just before the gate, the NPD team should keep the front-end gate fixed as initially scheduled and only reschedule the development and commercialization gates according to the amount of discovered tasks. When the discovery of new tasks continues right before the front-end gate, also the front-end gate should be rescheduled to account for more unexpected tasks that will be discovered in the remainder of the NPD process.

Since the majority of, if not all, NPD projects involve some level of task underestimation (Roy et al., 2005) and it is unlikely, due to competitive pressures, that all customers would be willing to wait for a delayed market entry induced by the execution of unexpected tasks, a safe rule-of-thumb is to always deploy one of the hybrid gate timing strategies. This means rescheduling the gate timing of the (front-end,) development and commercialization gates once at the end of the front-end stage.

<< Insert Figure 6 about here >>

LIMITATIONS AND RELATED FURTHER RESEARCH

By definition models are simplified representations of reality, and therefore all models are fallible (Sterman, 2000). We also made several simplifying assumptions that make our model less applicable to all NPD projects and/or omitted some real-life characteristics of innovation projects. First, we assumed that the majority of tasks that are underestimated will be discovered using adaptive expectation theory (Sterman, 2000). Although this assumption is well grounded in the front-end literature (Kim and Wilemon, 2002), other discovery patterns (e.g., with the majority of unexpected tasks being discovered in later stages) may also be possible. Our model could be extended to accommodate such patterns.

Second, the model is based on the assumption that all projects apply Stage-Gate processes with fuzzy gates in which tasks may be moved to the next stage. Future studies should consider the effects of gate timing strategies for other forms of phased NPD projects, such as with rigid or agile gate criteria, concurrent processing of stages (Krishnan, Eppinger, and Whitney, 1997), or spiral approaches to organizing NPD (Garnsey and Wright, 1990).

Third, this study only uses data related to NPD projects from manufacturers of industrial products that received go decisions at the different gates, and thus only included projects that successfully made it to the end of the NPD pipeline. Further research might investigate whether different timing strategies are more appropriate for NPD projects that receive other (e.g., recycle or hold) decisions or use data related to NPD projects from manufacturers of consumer products or services. Moreover, different timing strategies may have an impact on the likelihood of actually receiving go/no-go decisions at the gates. Despite these limitations, our results provide many valuable new insights into the causal relationships and feedback loops that exist in NPD projects, and how different gate timing strategies impact new product profitability.

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Figure 1: Overview of the Four Gate Timing Strategies

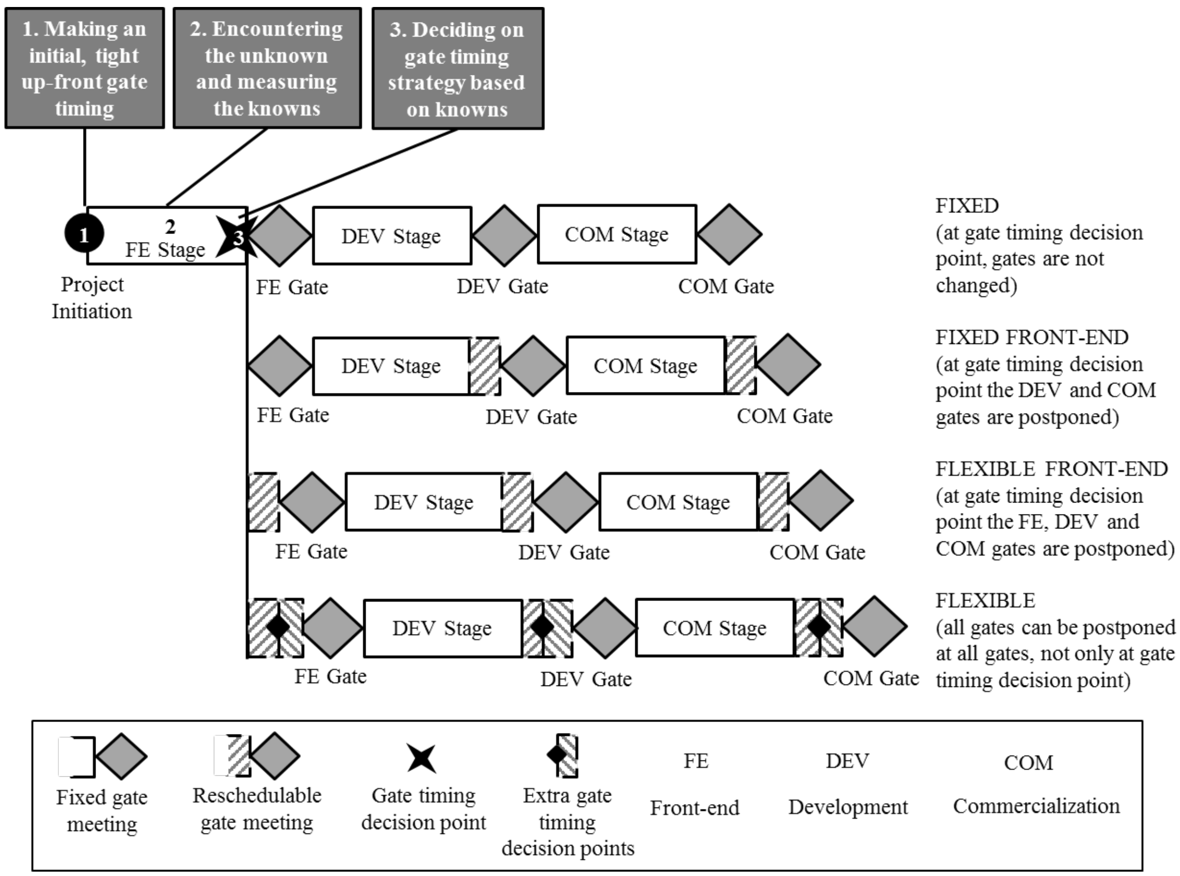
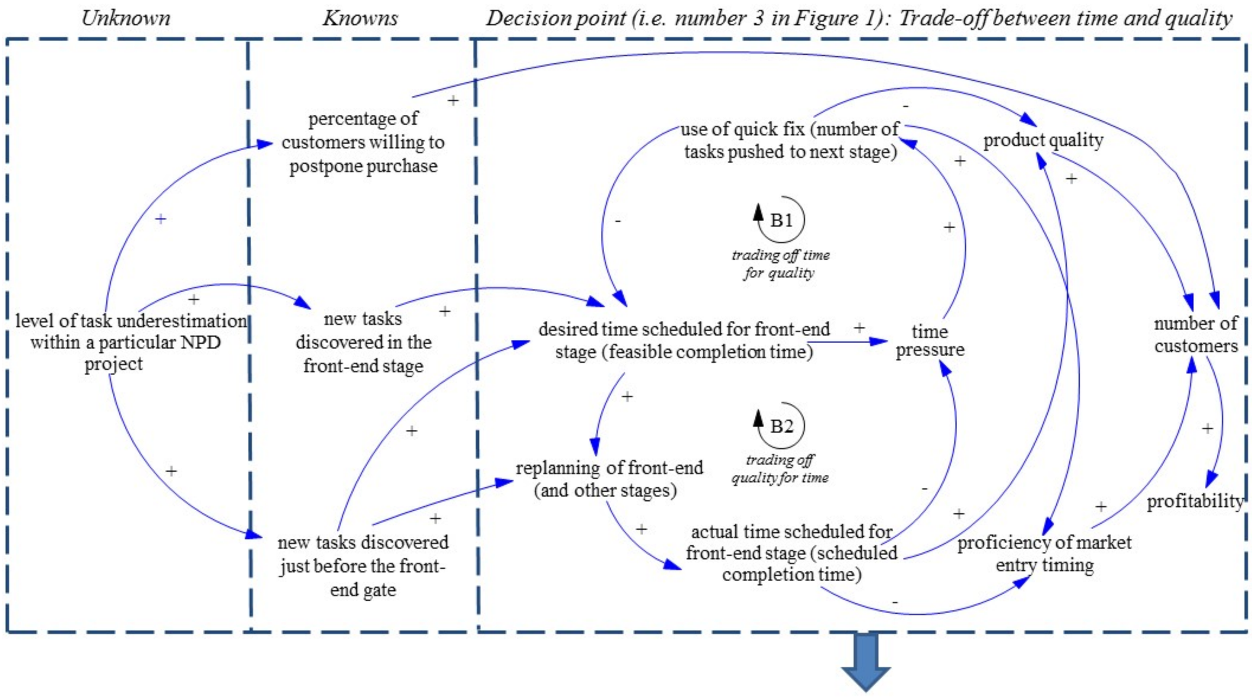


Figure 2: High-level Overview of the System Dynamics Model



Resulting Gate Timing Strategies:

Fixed gate timing strategy (only loop B1)

Fixed front-end gate timing strategy (loop B1 and B2)

Flexible front-end gate timing strategy (loop B1 and B2)

Flexible gate timing strategy (only loop B2)

Figure 3: Stocks and Flows of Task Execution in an NPD Stage

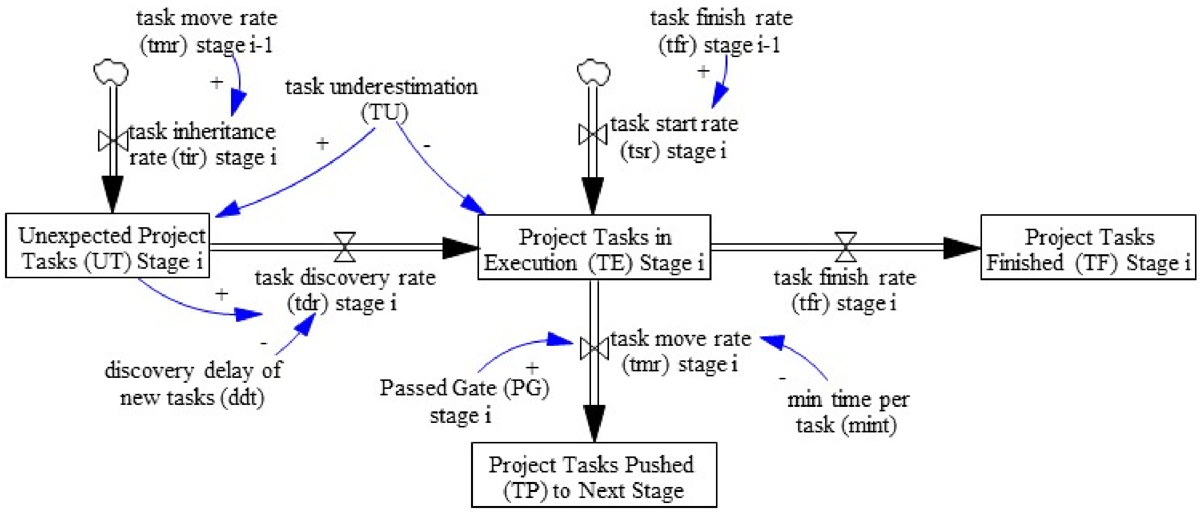
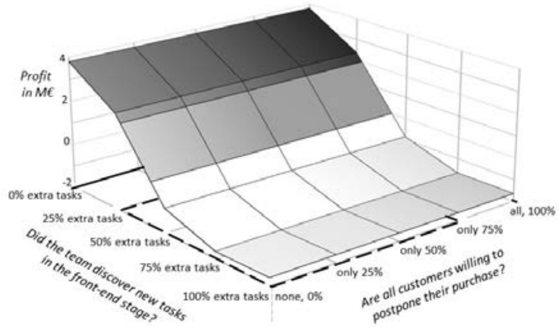


Figure 4: Simulation Results

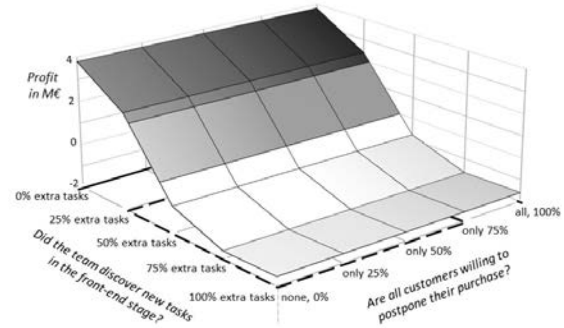
Were new tasks discovered just before the front-end gate? No

Were new tasks discovered just before the front-end gate? Yes

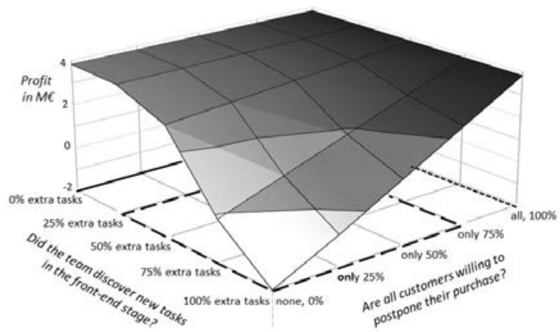
Fixed Gate Timing Strategy



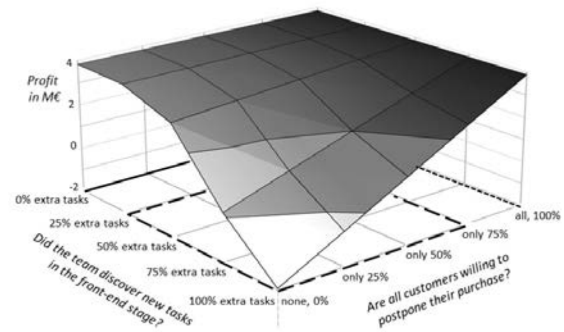
Fixed Gate Timing Strategy



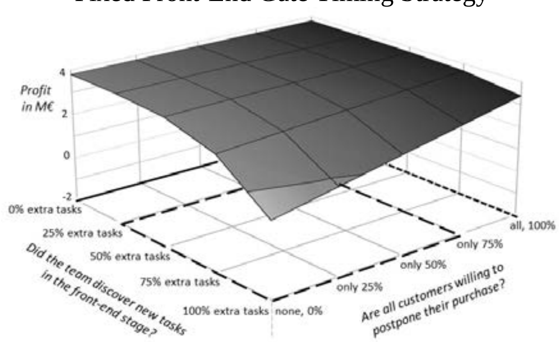
Flexible Gate Timing Strategy



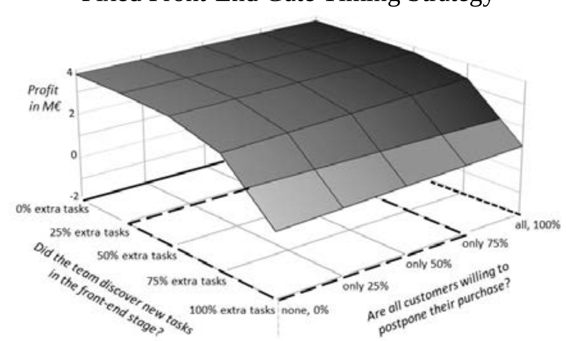
Flexible Gate Timing Strategy



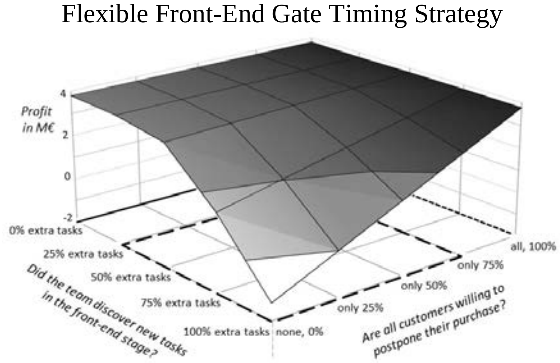
Fixed Front-End Gate Timing Strategy



Fixed Front-End Gate Timing Strategy



Flexible Front-End Gate Timing Strategy



Flexible Front-End Gate Timing Strategy

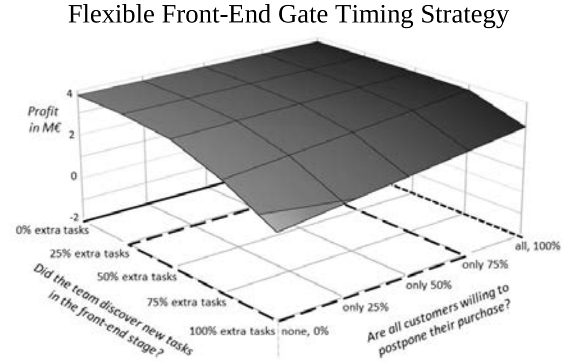


Figure 5: FTEs in Different Gate Timing Strategies under 75% extra tasks (in addition to initial known tasks), 0% willingness to postpone purchase, and no new tasks discovered just before the front-end gate and

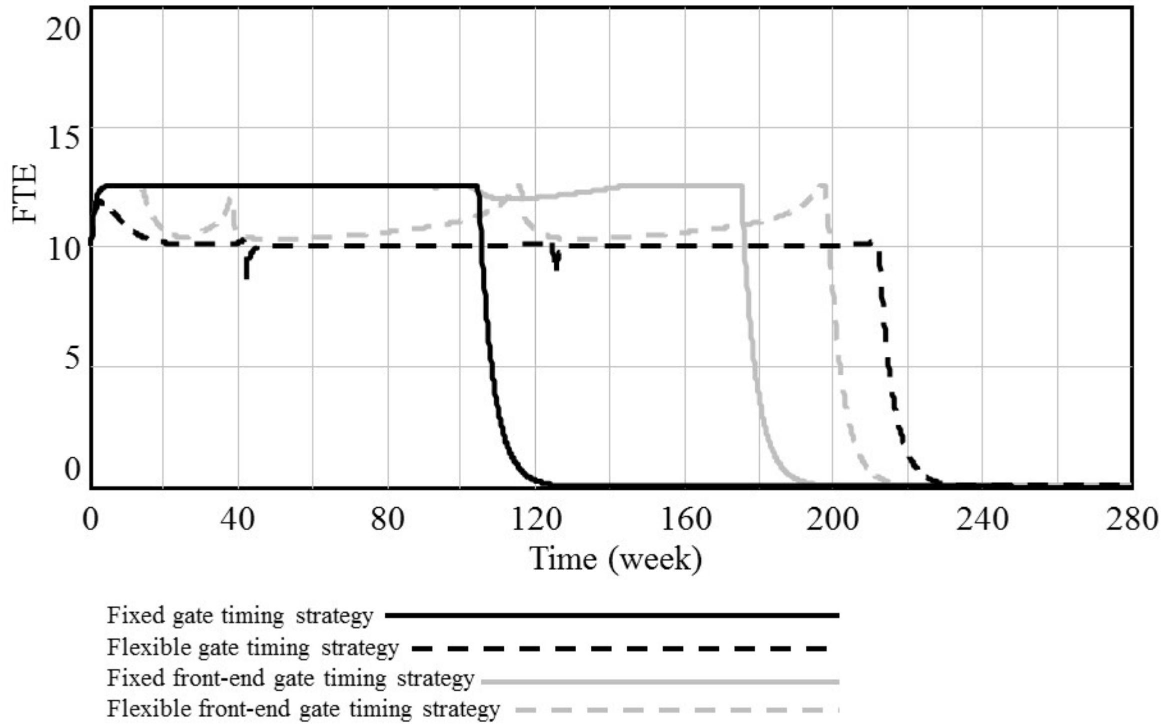
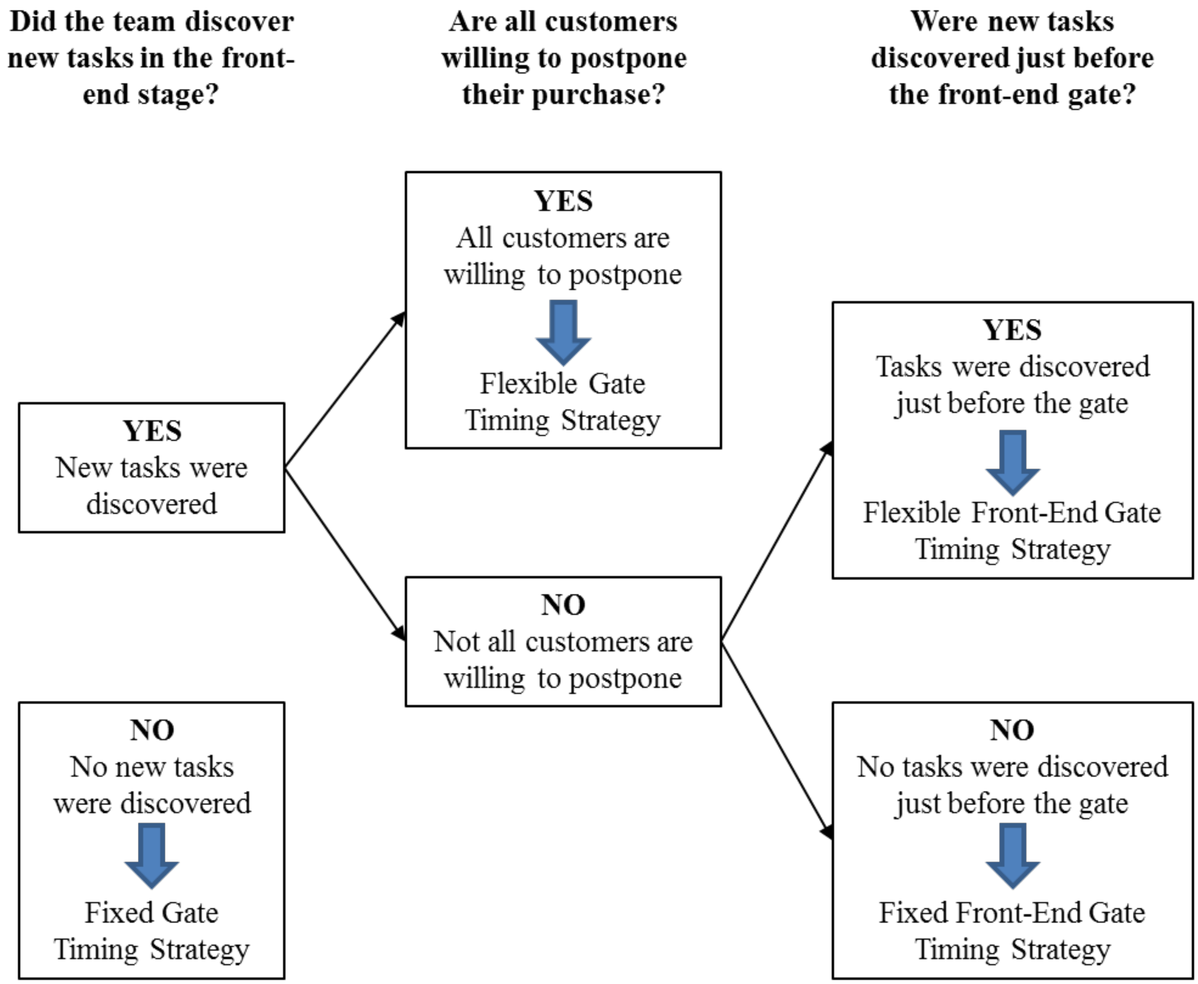


Figure 6: A Decision Tree for Managers Selecting the Appropriate Gate Timing Strategy



[i] To stay close to the previous model of Van Oorschot et al. (2011) we did not model making errors and rework in a way that Lyneis and Ford (2007) did in their model.

[ii] Errors made in the current stage can also be discovered in the next stage (Parvan, Rahmandad, and Haghani, 2015), thereby adding to the workload of the next stage.

[iii] For reasons of readability we have not included development costs in this figure.