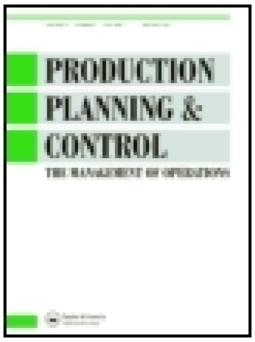

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Structuring a new product development process portfolio using decoupling thinking

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ABSTRACT
The purpose is to develop a structured new product development (NPD) process portfolio for manufacturing companies that facilitates the organization of NPD processes for both standardized products, focusing on time-to-market, and customized products, focusing on time-to-customer. The research combines different literature streams, enriching and advancing the understanding of decoupling thinking in NPD processes of manufacturing companies. It includes extensive empirical data from six manufacturing companies and presents testable propositions for further research. The resulting NPD process portfolio separates technology development from product development, acknowledges the different drivers and outcomes of processes and addresses the lead-time trade-offs. It provides an overview of potential options for NPD processes and shows different pathways through the processes. Companies can use the portfolio to support decisions related to the overall configuration of their NPD portfolios, the role and the range of different NPD processes, as well as to determine when and how to engage customers.

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New product development; aggregate project plan; decoupling thinking; customer order decoupling point; lead time

1. Introduction

Many manufacturers of customized products face the challenge of efficiently developing and producing individualized products for craft consumers, while also appealing to mass markets (Salvador, Rungtusanatham, and Forza 2004). To deal with this problem, some manufacturers have segmented their markets and differentiated their offerings, designing and producing a combination of standardized and customized products (e.g. Duray 2002; Fernandes, Gouveia, and Pinho 2012; Roy, Komma, and Kumar 2013). These manufacturers offer standardized products for the general market and customized products for specific customers, resulting in two interlinked problems regarding new product development (NPD).

The first issue involves deciding if, how and to what extent individual customer orders should drive NPD activities. The second entails understanding the lead-time trade-offs for customized products that are engineered-to-order or adapted-to-order while the customer waits. In these situations, compressing 'time-to-customer' becomes critical and represents a more apt description than time-to-market or ramp-up-time (Büyüközkan and Arsenyan 2012; Katana et al. 2017; Mahmoud-Jouini, Midler, and Garel 2004; Stalk and Hout 1990). Hence, such organizations must balance the need to provide new and unique products with the customer's willingness to wait. Traditionally, the customer order decoupling point (CODP), which is the point that decouples forecast-driven (FD) activities from customer-order-driven (CoD) activities, has been used to help in this balancing act (e.g. Giesberts and van der Tang 1992; Hoekstra and Romme 1992) but mainly when manufacturing products (Rudberg and Wikner 2004; Wikner et al. 2017). However, recent papers have shown how decoupling thinking applies to engineering designs (Gosling, Hewlett, and Naim 2017).

The marketing and innovation literature promotes the need for customer involvement in NPD projects and stage gates (Grönlund, Sjödin, and Frishammar 2010; O'Hern and Rindfleisch 2010; Sawhney, Verona, and Prandelli 2005). However, when customer involvement in NPD is discussed in the literature (e.g. in relation to customer participation, co-creation, co-innovation, knowledge integration and quality function deployment), it often focuses on involving customers that represent the product's market to generate ideas, test concepts, obtain market needs or test prototypes (e.g. Chang and Taylor 2016; Eslami and Lakemond 2016; Kathiravan et al. 2008; Kärkkäinen, Piippo, and Tuominen 2001; O'Hern and Rindfleisch 2010; Prahalad and Ramaswamy 2000; Song, Cao, and Zheng 2016). This should not be confused with customer involvement in NPD due to customers ordering products with specific requirements, that is, NPD 'to order' (Willner et al. 2016).

The above situation, when customers become intimately involved in NPD processes, is less discussed in the NPD literature but has been highlighted as an important topic requiring more sophisticated understanding (Brodie et al.

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2011; Chang and Taylor 2016). The NPD literature offers several processes and models for developing standardized products (e.g. Cooper 2014; Pahl et al. 2007; Ulrich and Eppinger 2012), emphasizing the market rather than specific customers, but theorizing for customer involvement, customer co-creation and customer input into the design process is still in its infancy (Hoyer et al. 2010; Saarijärvi, Kannan, and Kuusela 2013). For example, Wheelwright and Clark's (1992a, 1992b) classic categorization discusses different types of NPD projects within an organization but not including NPD 'to order'. Recent advances in understanding the engineer-to-order sector in the operations management domain offer some insights into potential structures for such interactions, but, thus far, these bodies of knowledge have proceeded independently of one another.

If manufacturers have to balance standardized and customized product requirements, then a portfolio of product development (PD) processes will be required. Several different models are available to guide decision making with respect to new product portfolios (e.g. Chao and Kavadias 2008; Cooper, Edgett, and Kleinschmidt 2001), as well as characterizations of different NPD projects (Wheelwright and Clark 1992b), but the literature often presents categorizations or typologies of NPD projects. The present study focuses on not only the balance or the range of NPD projects within an organization but also the organizational processes and the underlying structures that realize the new products. The latter topic has mostly been treated through the specific focus on the introduction of a specific NPD idea, for instance, through stage-gate approaches (Cooper 2014; Pahl et al. 2007). Hence, this study broadens the focus to a more system-wide view of the different NPD processes used in an organization and the portfolio that this enables.

The preceding discussion indicates gaps in the understanding of three points: first, the nature of customer interactions in NPD projects driven by specific customers; second, the fundamental range of organizational processes and structures that allow for a spectrum of NPD projects to be realized; and finally, the possibility of enrichment by decoupling concepts from the engineer-to-order body of knowledge. Collectively, addressing these gaps should allow for more effective management of the development of standardized products that focus on time-to-market while developing customized products that emphasize time-to-customer, both in the same manufacturing company.

Therefore, the purpose of this research is to develop a structured NPD process portfolio for manufacturing companies that facilitates the organization of NPD processes for both standardized products, focusing on time-to-market, and customized products, focusing on time-to-customer. In this regard, two research questions are asked. The first one seeks to obtain a more thorough understanding of manufacturing companies' NPD processes, not least concerning drivers (i.e. if processes are driven by the market or a specific customer). The second builds on this understanding, and in answering the question, a framework for structuring NPD processes is developed.

1. What are the similarities and the differences among manufacturing companies' NPD processes in terms of drivers, activities, outcomes and lead times?
2. How can organizations structure a portfolio of NPD processes using decoupling thinking, incorporating customer-driven NPD projects?

In investigating and answering these research questions, the study makes three main research contributions. First, it enriches and advances the understanding of decoupling thinking (e.g. Dekkers 2006; Rudberg and Wikner 2004; Wikner and Rudberg 2005) in the NPD processes of manufacturing companies by applying an engineering decoupling point (EDP) framework (Gosling, Hewlett, and Naim 2017), giving empirical insights in a largely conceptual research area. Second, the decoupling thinking approach developed offers an alternative perspective to the literature relating to co-creation and knowledge integration (e.g. Chang and Taylor 2016; Song, Cao, and Zheng 2016), focusing on specific customer involvement in NPD processes with individual requirements, rather than involving customers that represent the product's market to generate ideas, test concepts, obtain market needs or test prototypes. Third, the study adopts Wheelwright and Clark's (1992a, 1992b) holistic view on aggregate project plans, but through the use of our decoupling thinking approach we focus on individual customers as drivers for NPD projects, which extends the original work to include new considerations and results in a holistic approach to the structuring of a firms NPD processes. The structured NPD process portfolio developed enables practitioners and stakeholders in NPD processes to visualize and reflect more deeply on the configuration and the aims of an organization's approach to innovation and customer involvement.

The paper is organized as follows: Section 2 provides a review of decoupling thinking in engineering and several aspects of NPD, ending with a synthesis. Section 3 describes the research design, focusing on methodology choice, case selection, data collection and analysis. Six case companies' NPD processes are thoroughly presented in Section 4 and summarized in a table. In Section 5, the NPD processes are analyzed, focusing on similarities and differences, which results in a structured NPD process portfolio being proposed in Section 6. The portfolio separates technology development (TD) from PD, acknowledges the different drivers and outcomes of processes and addresses the lead-time tradeoffs. Finally, in Section 7, conclusions and theoretical and practical implications are presented, where testable propositions and further research are proposed.

2. Literature review

2.1. Decoupling thinking in engineering management

Decoupling thinking is frequently applied when manufacturing products (Rudberg and Wikner 2004; Wikner et al. 2017),

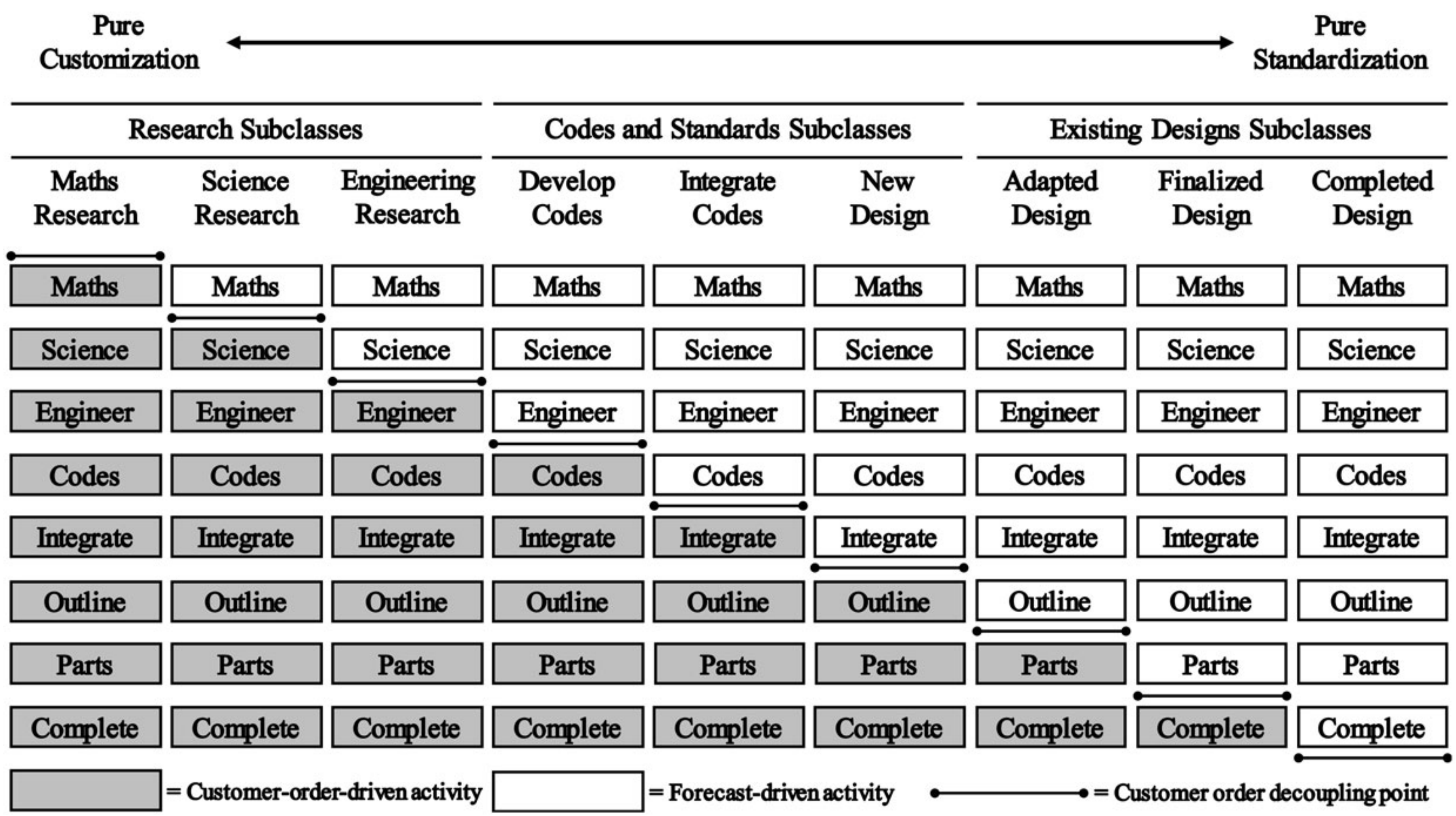

Figure 1. The EDP framework (adapted from Gosling, Hewlett, and Naim 2017, 412).

such as by using a CODP in the form of a stock point somewhere in the manufacturing system that decouples activities based on forecasts from those based on customer orders, that is, commitment (Giesberts and van der Tang 1992; Hoekstra and Romme 1992; Olhager and Wikner 2000). Nevertheless, decoupling thinking can also be used in NPD; for example, Rudberg and Wikner (2004) and Wikner and Rudberg (2005) extend the concept of decoupling thinking to include the engineering dimension, besides the production dimension. The CODP in the engineering dimension, thus, decouples FD from CoD engineering activities (Wikner and Rudberg 2005), in other words, decouples those based on aggregated product requirements from those based on customer orders with specific individual product requirements.

Following Wikner and Rudberg's (2005) consideration of the CODP's engineering dimension and Gosling and Naim's (2009) discussion of engineer-to-order supply chains, Gosling, Hewlett, and Naim (2017) introduce an EDP framework for classifying different EDPs. The framework was conceived and developed in the context of complex civil and structural engineering, as well as scientific equipment projects, drawing on the philosophy of engineering concepts (e.g. Bulleit et al. 2015) and engineering management literature (e.g. Dekkers 2006). Through an extensive co-operative inquiry, Gosling, Hewlett, and Naim (2017) identify nine engineering subclasses, extending from pure mathematical research (with unclear theoretical principles) to using existing complete and finalized designs for solutions. This framework covers a continuum of nine structures to describe to what extent the activities are CoD, as shown in Figure 1.

The nine subclasses are organized into three broader categories. The first, *Research Subclasses*, comprises *Maths Research*, *Science Research* and *Engineering Research* and refers to situations where customer orders penetrate the furthest upstream development projects, including research and development. This category may include proof of concept, testing or even fundamental research to establish principles for a solution. Under *Maths Research*, the theoretical principle is unclear, and it is not obvious that a solution exists. Under *Science Research*, a theoretical foundation likely exists, but the application is uncertain. *Engineering Research* requests testing of materials, principles or applications.

In the next three structures (*Develop Codes*, *Integrate Codes* and *New Design*) under *Codes and Standards Subclasses*, a project's purpose can be defined, but there is an open brief regarding the solution. It requires some interaction with an established set of codes, codified knowledge or standards (Gosling, Hewlett, and Naim 2017). For instance, in the construction industry, governments issue building codes (e.g. Eurocodes) to establish and enforce minimum standards for construction quality, structural integration, durability, liability, accessibility and especially fire safety (Allan and Iano 2009; Carswell 2012) to ensure public health and safety. In this study, codes and standards are separated. Codes are regulations by local, state, national or other governmental bodies to control the goods produced through a set of acceptable minimum requirements. Standards are usually technical documents that standardize the quality of a product, its size or the production procedure (e.g. Society of Automotive Engineers and International Organization for Standardization) (Foliente 2000). Under *Develop Codes*, codes should be developed to articulate any new standards. Under *Integrate Codes*, new codes have to be modified or integrated with existing ones for market acceptance. Such acceptance may take the form of standards (e.g. British Standards or Highway England Standards). Under *New Design*, novel and unique designs may be developed, using existing codes and standards as starting points (Gosling, Hewlett, and Naim 2017).

Under *Existing Designs Subclasses* (comprising *Adapted Design*, *Finalized Design* and *Completed Design*), the principal challenge is to utilize available knowledge and bring standard designs together for a project's needs; for example, form, layout and integration should be considered on an order-by-order basis. Under *Adapted Design*, a design's individual parts may be customized on a project-by-project basis. Under *Finalized Design*, existing items can be assembled for a solution. Finally, under *Completed Design*, existing designs are perfectly suited to customers' requirements (Gosling, Hewlett, and Naim 2017).

The aforementioned framework develops logic for understanding the potential points for customers to penetrate engineering designs, but some areas require further clarity. First, it is unclear how these CODPs apply in mainstream manufacturing companies. Second, the linkages with the NPD body of knowledge are unclear and have much potential to enrich the framework.

2.2. New product development: project portfolios, characterizations and customer engagement

NPD research addresses the processes, approaches and strategies that lead to the development of product portfolios that will maximize the fit of new products with customer needs and minimize the time-to-market (Schilling and Hill 1998). Such development will often involve balancing tensions between market changes, customer requirements and value, NPD goals and strategies, as well as resources and competencies (Cooper, Edgett, and Kleinschmidt 1997; Schilling and Hill 1998). To manage this balancing act, firms must engage in NPD portfolio planning and management. Several different models are available to guide decision making, including using strategic buckets or smaller chunks of resources (Chao and Kavadias 2008), financial methods, business strategy, bubble diagrams and scoring models (Cooper, Edgett, and Kleinschmidt 2001), as well as characterizations of different NPD projects to develop a balance (Wheelwright and Clark 1992a, 1992b). The present study is directly concerned with structuring the project portfolio to balance standardized and customized products (and its lead-time implications), so the focus is on the latter category to inform characterizations of NPD projects and customer interactions.

Wheelwright and Clark (1992a, 1992b) emphasize that companies should form an aggregate project plan to ensure that the collective set of projects will accomplish the development goals, as well as build the organizational capabilities needed for each company to succeed. This plan should ensure that the development resources are used for the appropriate types and combinations of projects. Wheelwright and Clark (1992a, 73–74; 1992b, 49–50) therefore introduce four categories, which are well established and have been widely cited (e.g. Davies and Brady 2016; Jarzabkowski and Kaplan 2015; Schilling and Hill 1998):

- *Research or advanced development projects* are often conducted by a research and development group that is separate from the main development organization. These projects aim to investigate new science or capture new know-how so that this knowledge can be available and incorporated into specific development projects. As such, research or advanced development projects are the precursors to product and process development.
- *Breakthrough development projects* involve creating the first generation of completely new products or processes and often incorporate new technologies or materials. These projects break new ground for the organization. If successful, the core concepts and technology will likely constitute a whole new product family or process.
- *Platform or generational development projects* are used for developing platforms or core development projects that provide the bases for product families and processes, with a design life of several years. They establish the basic architecture that can then be adapted and expanded by follow-on projects.
- *Derivative development projects* are used for refining and improving selected performance dimensions to better meet the needs of specific market segments. They thus tend to be much narrower in scope and resource requirements and are often referred to as incremental.

Schilling and Hill (1998) plotted these four categories against the scale of required product and process changes, where at the extreme, necessitate new core products and processes. They note further that the categories should be managed as a balanced portfolio of projects at different stages of development.

When conducting the above NPD projects, researchers have advocated for the benefits of gathering input and joint value creation by different stakeholders and members of the supply chain. For example, van Echtelt et al. (2008) find positive results of innovation performance in the co-creation of new products with suppliers, but only if long-term relationships are developed with suppliers, emphasizing shared learning routines and aligned capabilities. Mahr, Lievens, and Blazevic (2014) argue that customer co-creation is a major source of competitive advantage; however, they find that the benefits are contingent on the communication channels enabling co-creation. Hence, the ability to manage collaborative PD projects is becoming more important (Eslami and Lakemond 2016).

The democratizing innovation movement has promoted a vision of user-centric innovation, based on 'lead-user' innovation patterns and pioneering work of innovation communities, rather than manufacturer-centric development of new products (von Hippel 2005). To enable this vision, users and user communities must somehow become actively engaged in the design processes of new products, and new conditions and mechanisms for user participation in design, as well as producer–consumer interactions, are needed (Franke, Keinz, and Steger 2009; Lundvall et al. 2002). Such changes include using technology to enable self-design (Franke and Piller 2004), as well as creating policy and societal shifts in relation to the transparency and the openness of knowledge (von Hippel 2005).

Due to the above factors, there is increasing attention on the role of customer engagement in such activities, where users actively participate or are somehow involved in NPD processes (Brodie et al. 2011; Chang and Taylor 2016). The logic is that by directly involving the customer, needs, solutions and value can be more accurately captured, which may be undertaken at various phases and levels of the NPD process (e.g. ideation, design, commercialization or launch; see Chang and Taylor 2016; Hoyer et al. 2010; Saarijärvi, Kannan, and Kuusela 2013). Mahr, Lievens, and Blazevic (2014) argue that there are multiple determinants and channels for the success of such customer engagement and co-creation in terms of the value of relevance, novelty and costs. They distinguish among face-to-face, voice-to-voice and bit-to-bit channels, finding that the channels vary in their abilities to facilitate co-creation value. Customer contributions may also vary by role, for instance, technological experience or new ideas, and timing, for instance, throughout the NPD process or at its specific stages (Eslami and Lakemond 2016).

However, this area of research is in its infancy and requires increased understanding about outcomes, challenges and approaches, as well as further clarifications of definitions to guide theory and practice (Hoyer et al. 2010; Saarijärvi, Kannan, and Kuusela 2013). For the purpose of this study, the potential for customer engagement in the design engineering aspects of NPD is of interest, especially for NPD projects undertaken for a specific customer. Hence, the concept of the user as subject versus user as a partner (Sanders and Stappers 2008), the customer as an information source versus customer as co-developer (Cui and Wu 2017), or customer as co-creator, user or resource (Eslami and Lakemond 2016) in the design process is pertinent.

2.3. New product development: processes, practices and interfaces

Traditional stage gating of processes has been well described and explained in the literature. These concepts provide a blueprint for moving through the different stages of development, for instance, idea generation and business case, along with gate decision criteria for proceeding from one phase to the next (Cooper 2014; Pahl et al. 2007; Schilling and Hill 1998). However, its use may be limited to certain types of NPD projects; customer involvement, in the decoupling thinking sense outlined in Section 2.1, has not traditionally been factored into the phase management. Additionally, there is growing consensus that the 'waterfall' approach (i.e. the linear, fixed and plan-driven approach to project management) needs to be replaced by more flexible approaches (Blank 2013; Cooper 2016).

More recently, the stage-gate approach has been extended to include agile project management methodologies in NPD. It is argued that integrating these concepts makes it possible to include the customer's voice and manage resources more effectively (Cooper 2016; Cooper and Sommer 2016; Sommer et al. 2015). This will involve incorporating practices, such as sprints, scrums, unfinished product testing and customer feedback, 'on-the-fly' planning, flexible structures and strategies, and modular platforms and product architecture (Cooper and Sommer 2016; Thomke and Reinertsen 1998). Similar messages can also be found in the lean start-up literature, where iterative phases of development and customer interaction are envisaged, including pivot points if things do not proceed as planned (Blank 2013).

A further challenge in the management of NPD projects is the problem of interfaces between different phases. In particular, the interface between fundamental TD and more traditional PD processes has been identified as an important problem area (e.g. Lakemond et al. 2013; Nobelius 2002; Säfsten et al. 2014). Here, TD is perceived as a process where new technology is developed, whereas, in the PD process, ideas are developed into viable new products or reconfigurations of existing ones. Hence, PD links TD with production by incorporating technology into product concepts (Lakemond et al. 2013). Nonetheless, TD and PD are often separated in both practice and academia (Säfsten et al. 2014). In the manufacturing industry, TD is often carried out in separate research and development departments, whereas PD is undertaken in development projects (Säfsten et al. 2014). One of the reasons for this division involves the numerous challenges that a TD project faces, such as technology uncertainties, referring to the technology's readiness for commercialization. It is argued that having TD within a PD project increases risks (Lakemond et al. 2013; Säfsten et al. 2014). Moreover, PD tends to have sharp deadlines compared with TD, which is characterized by diffuse competence needs, resulting in more uncertainty. Thus, separating TD from the critical path of PD projects decreases their complexity and risk, thereby enhancing precision (Nobelius 2002).

2.4. Decoupling thinking and configuration of NPD processes: a synthesis

Based on the foregoing literature review, the following summaries can be established from the different literature streams:

- Decoupling thinking in engineering management (via the EDP framework) shows that the CODP can be positioned across a spectrum of customization and standardization in engineering designs (Gosling, Hewlett, and Naim 2017). The CODP body of knowledge can be used to reflect on managerial approaches to be used at pre- and post-decoupling points and the extent of customer involvement, along with competitive trade-offs of those penetration points. However, empirical work in the engineering domain has focused on each project as the unit of analysis, rather than overall NPD processes and portfolios. It is also unclear how this thinking, taken from the operations management domain, fits with contemporary NPD theory and practice.
- Different NPD project types exist (e.g. Wheelwright and Clark 1992a, 1992b), and these will need to be considered and configured as part of a portfolio of projects (Cooper, Edgett, and Kleinschmidt 2001; Schilling and Hill 1998). Traditionally, such projects have been approached through stage gates and waterfall-type models, but there is increasing pressure to develop the understanding of customer engagement, value co-creation and the use of more flexible approaches to NPD (Sommer et al. 2015). Interfaces in NPD projects can be problematic and are particularly acute in TD projects (e.g. Lakemond et al. 2013).

This study intends to integrate these different research streams for a more sophisticated approach to managing an NPD process portfolio. The concepts outlined in Section 2 establish the foundation for the research design and protocols and directly provide the methods; the protocols are informed by the extent of customer penetration and involvement with NPD processes, the management of the NPD process, the portfolio of the NPD projects, and the interfaces between different phases. Since a portfolio approach is taken, the focus is on the firm-level processes employed.

3. Research design

As argued in this paper, the existing literature on NPD – where manufacturing companies develop both standardized products, focusing on time-to-market, and customized products, focusing on time-to-customer – is regarded as inadequate. In such instances, Eisenhardt (1989) finds a case study suitable for building a theory. Rich descriptions of manufacturing companies' NPD processes, as well as the contexts in which they are used, are required to deepen the understanding, and this research therefore follows a case study methodology where the established theoretical concepts serve as a foundation and inform the research design. Here, Gosling, Hewlett, and Naim's (2017) EDP framework is used as a starting point and applied to manufacturing companies to distinguish between FD and CoD activities, visualize and analyze NPD processes (i.e. project portfolios; e.g. Wheelwright and Clark 1992a, 1992b), study interface challenges and differentiate between TD and PD (e.g. Lakemond et al. 2013; Säfsten et al. 2014).

This work can further be described as a holistic multiple-case study (Yin 2009) since it includes six companies, and the same issues are addressed in each company. The study combines research activities from funded programmes in Sweden and Wales and draws on engaged and extensive joint research with industry collaborators. For the purpose of confidentiality, the six selected companies' products in

Table 1. Case companies and sources of evidence.

Case and Country	Founded	Products	Employees[1]	Turnover thousand EUR (€)[1]	Company size[1]	Source of evidence		
						No. of interviews and respondents (R)		Archival documents
TurbineCo, Sweden	1913	Gas turbines	2597	1,201,030	Very large	2	Product developer (R1) Purchasing manager (R2) Demand planner, sales & operations planning (R3)	Stage-gate models, process charts and process descriptions, company webpage searches, workshop documents, list of codes and standards
						2[2]	Product developer (R1)	
LuminaireCo, Sweden	1943	Luminaires	586	137,678	Large	1	Project leader for product development (R4)	In and out phasing documents (generational shifts), stage-gate models, process charts and process descriptions, company webpage searches, workshop documents
						1	Logistics manager (R5) Master planner & planning team leader (R6) Manufacturing manager (R7)	
						1	Customer design manager (R8)	
						1	Project leader for product development (R4) Logistics manager (R5)	
FurnitureCo, Wales	1998	Furniture and task seating	361	75,817	Large	2	New product introduction manager (R9) Continuous improvement manager (R10)	Company webpage searches
						1	Continuous improvement manager (R10)	
PumpCo, Sweden	1967[3]	Hydraulic pumps and motors	230	36,464[4]	Medium	2	Inbound/outbound manager (R11) Product developer (R12)	Stage-gate models, process charts and process descriptions, company webpage searches, workshop documents
FoilCo, Sweden	1945[3]	Plastic foils	107	25,665	Medium	2	Product manager (R13)	Stage-gate models, company webpage searches, process charts and process descriptions, organization chart, company presentation
ChimneyCo, Wales	1997	Prefabricated chimneys and brick arches	70	5110	Medium	3	Product development and marketing manager (R14)	Stage-gate models, process charts and process descriptions, workshop documents, product hierarchy diagrams
						1	Managing director (R15)	
						1	Production director (R16)	

[1]The information concerning the number of employees, turnover and company size are from the Amadeus (2018) database, where the company size is based on the European Commission's (2018) definition.
[2]The interviews were conducted using video chat.
[3]The companies were founded earlier, but this was the year they started producing the type of products that are currently manufactured.
[4]The turnover presented here is an estimate for the specific site studied in this research. This is 50% of the turnover for the whole Swedish organization.
Note: See Appendix 1 for the list of acronyms and their meanings.

Table 2. Research protocol for the case studies.

Stages	Research activities and key areas of discussion
Case selection and initiation	• Identify each company based on the selection criteria. • Gather an initial sense of NPD processes. • Discuss any potential interest in decoupling concepts.
Stage 1 – Establish scope and background	• General introductions and explain purpose. • Discuss general developments in the case company in relation to NPD.
Stage 2 – Presentation of initiatives	• Present the EDP framework, either electronically or through printed handouts. • Provide an opportunity for the interviewees to register their first impressions and ask any initial questions. • Give the case company the opportunity to present or explain any structures that they may have in place for NPD.
Stage 3 – Discussion of frameworks and structures	• Are the engineering subclasses recognizable, understandable and complete? • How do the NPD processes in the case company relate to the framework? • How far do individual customers penetrate NPD activities?
Stage 4 – Discussion of implications	• How do ongoing NPD activities relate to the EDP framework? • Where do different products and processes from the case company start and finish with respect to the engineering activities outlined in the framework?
Stage 5 – Site tour	• Relate back to other stages and, if possible, directly observe relevant products and projects for the NPD processes discussed. • Further clarify any details in relation to CODPs and the implications.
Stage 6 – Analysis	• The research team discusses the findings from different data types. • Visualization of NPD processes. • Offer the interviewees the opportunity for further comments and clarifications.

Note: See Appendix 1 for the list of acronyms and their meanings.

combination with 'Co' (abbreviation of the company) are used as pseudonyms to identify the companies in this paper (see Table 1).

3.1. Unit of analysis and case selection

The unit of analysis comprises the development processes in each case company, by which new technology, new product designs or reconfigured product designs are realized. In a multiple-case study design, the selection of cases should be guided by theoretical interest, suitable for illuminating and extending relationships and the logic among constructs (Eisenhardt and Graebner 2007; Yin 2009). In line with this approach and based on the research purpose, the following criteria were used for case selection: (1) manufacturing companies; (2) having internal NPD processes, as well as enthusiasm and willingness to study them in a research setting; (3) developing relatively complex products, including both standardized and customized products; and (4) representing different industries, sizes and maturity levels. TurbineCo, LuminaireCo, PumpCo and ChimneyCo are involved in research programmes in Sweden or Wales, with purposes related to this study. Two more cases were added, FurnitureCo and FoilCo, to reach Eisenhardt's (1989) recommended number of total cases and in total, include three very large to large companies and three medium companies (based on the European Commission's [2018] definition).

3.2. Data collection and analysis

Since this study is based on comprehensive research programmes, extensive data were collected from interviews, observations, archival documents and workshops. Although differing slightly among the companies, the case studies' main stages and their order are described in Table 2. In total, 20 semi-structured interviews were conducted (18 face-to-face and 2 video chats) and audio recorded (except for ChimneyCo). The interviews ranged from 40 minutes to 3 hours each, with one, two or three participants at a time (Table 1). Follow-up questions were asked via email. The observations were performed via site tours and focused on products and material flows to obtain an overview. The archival documents mainly described NPD processes and provided details (Table 1). During the workshops, the companies' representatives presented their NPD processes.

The audio recordings were transcribed shortly after each interview. The documented empirical data (from interviews, documents and observations) were then codified using codes deduced from the purpose and the EDP framework (i.e. case, context, NPD processes, type of development activities, drivers, codes and standards, lead times, outcomes and illustrative examples). The data were mainly analyzed by positioning the companies' NPD processes into Gosling, Hewlett, and Naim's (2017) EDP framework, taking into account interface challenges and differentiating between TD and PD (e.g. Lakemond et al. 2013; Säfsten et al. 2014), classifying them according to Wheelwright and Clark's (1992a, 1992b) four categories and visualizing their lead times. This analysis was first done for each company before juxtaposing them. This process can be considered a within-case analysis (Eisenhardt 1989), whose output is summarized in Table 3 and Figure 2. The results of the within-case analysis were then used to compare the case data to one another (i.e. a cross-case analysis), where the analysis focused on revealing similarities and differences among the NPD processes and the suitability of different configurations. This analysis made it possible to distinguish the processes used by the different companies, aggregating and simplifying them, where a summary of the cross-case analysis emerged, as illustrated in Figure 3.

Method and source triangulations, as well as investigator triangulation (Torrance 2012), were applied to the data obtained from different collection methods, among the participants in the same case companies and among the three

Table 3. Summary of the case companies' contextual factors and NPD processes.

Company	Context	NPD process	Outcome	Lead times/midpoint[1] and time interval
TurbineCo	Customers request shorter time-to-customer without any compromise regarding customization. TurbineCo is therefore considering modularizing the customer-specific options and segmenting the market to handle the requirements for both customization and reduced time-to-customer.	FDTD	New software codes, technology, calculation and optimization methods and new production methods	6–24 months/15 months ± 9 months
		FDPD/CoDPD (major)	New standard or bespoke products	FD: 60–84 months/72 months ± 12 months CoD: 12–24 months/18 months ± 6 months
		FDPD/CoDPD (medium)	Reconfigured or customized products based on existing standard products	FD: 2–24 months/13 months ± 11 months CoD: 2–12 months/7 months ± 5 months
		FDPD/CoDPD (minor)	Outlined design, reconfigured or customized individual components	FD: 2–24 weeks/13 weeks ± 11 weeks CoD: 2–24 weeks/13 weeks ± 11 weeks
		CoDPD package	Customized package	2–10 months/6 months ± 4 months
LuminaireCo	The market and LuminaireCo have undergone and are still undergoing a technology transition, resulting in a generational shift (i.e. the need for updating and redesigning the current product portfolio), as well as new technological opportunities for designing and developing new products.	FDTD	New technology	1 month–several years/N/A
		FDPD (major)	New standard products	12–18 months/15 months ± 3 months
		FDPD (medium)	Reconfigured standard products	8 months/8 months ± 0 month
		FDPD (minor)		4–5 months/4.5 months ± 0.5 month
		CoDPD (major)	Bespoke products	10–20 weeks/15 weeks ± 5 weeks
		CoDPD (minor)	Customizations of standard products	1 week/1 week ± 0 week
FurnitureCo	Some of the current challenges faced by FurnitureCo are the extent to which it should focus on 'shifting the market' versus 'following the market', making progress in capturing the customer's voice and meeting the needs of different generations (e.g. baby boomers and millennials). FurnitureCo finds it desirable to use a more customer-driven approach. However, to realize this, FurnitureCo needs a more strategic approach to customer interaction, including the management of interaction points with suppliers and different internal teams in the NPD process.	FDPD	New standard products	6–12 months/9 months ± 3 months
		CoDPD (major)	Bespoke products based on standard products	1–18 months/9.5 months ± 8.5 months
		CoDPD (minor)	Customizations of standard products	A few weeks to many months, to a large extent dependent on the project's complexity/N/A
PumpCo	Due to a combination of market maturity and technology maturity, PumpCo is considering other innovative solutions, such as identifying other areas for application, as well as customizing different solutions.	FDTD	New technology, production processes and calculation and simulation methods	To a large extent dependent on the project's complexity/N/A
		FDPD	New and reconfigured standard products	6–36 months/21 months ± 15 months
		CoDPD	Customizations of standard products	2 hours–6 months/≈ 3 months ± 2.99 months
FoilCo	Both the technology and the production process are mature. FoilCo has therefore become more CoD and customizes its products for specific customers, estimating that 85% of all projects are customer driven.	FDTD	New technology and production methods	6–60 months/33 months ± 27 months
		FDPD/CoDPD	New standard products with options, as well as bespoke and customized products	FD: 1–38 weeks/19.5 weeks ± 18.5 weeks CoD: 1–32 weeks/16.5 weeks ± 15.5 weeks
ChimneyCo	Traditionally, ChimneyCo has had a CoD focus. Due to a combination of market maturity and advances in technology, it decided to embark on larger and speculative, marketplace innovations. It wishes to continue with a combination of FD and CoD processes, acknowledging the need for speculative market-driving innovations. Company changes are undertaken to include the formation of cross-functional teams, formalized NPD stage gates and management systems.	FDPD	New standard products with options	6–24 months/15 months ± 9 months
		CoDPD (major)	Bespoke products based on standard products	6–7 weeks/6.5 weeks ± 0.5 weeks
		CoDPD (minor)	Customizations of standard products	4 weeks/4 weeks ± 0 week

[1]The midpoint is calculated as the average value of a process' shortest and longest lead times.
Note: See Appendix 1 for the list of acronyms and their meanings.

researchers. The participants were provided with initial interpretations of their interviews, mostly by feedback on their processes that were mapped into the EDP framework, together with the written data. Further along, the results were also sent back to the companies for their review of the data presented, as well as whether they recognized the emerging account as fair and reasonable.

The case companies' NPD processes are thoroughly described in the next section, including the contextual factors from which the results are deduced to enable the readers to assess how the results can be applied in their contexts, in line with Guba and Lincoln's (1989) suggestions.

4. The case companies' NPD processes

This section explains the different NPD processes and lead times in the six case companies, following the case order presented in Table 1. The NPD processes' names are normalized for the purpose of confidentiality and for ease of comparison. This is done through the use of the concepts highlighted in the literature review, where the description distinguishes between FD and CoD engineering activities in combination with TD and PD activities. Table 3 summarizes the case companies' contextual factors and NPD processes.

4.1. TurbineCo

TurbineCo develops and produces gas turbines, which are built out of a core engine that is assembled with auxiliary systems as a package. The packages are the customer-specific and the site-specific options used for different applications. TurbineCo excels at accommodating and fulfilling customers' requests for customizations. However, these customizations tend to prolong the time-to-customer, and for some time, TurbineCo has perceived that some customers have been requesting shorter time-to-customer. TurbineCo has therefore started to question its way of achieving these customizations and is considering segmenting its offerings and modularizing the packages to handle requirements for both customization and reduced time-to-customer. TurbineCo uses five main NPD processes: forecast-driven technology development (FDTD), forecast-driven and customer-order-driven product development (FDPD/CoDPD) – major, medium and minor – and a CoDPD package.

According to Respondent 1 (R1; see Table 1), the FDTD process *'is more considered a strategic development [process] aimed at developing certain programmes, new codes and methods, etc.'* Hence, the outcomes of such a process are new software codes, technology or optimization models, as well as new production methods. These outcomes can then be incorporated into FDPD/CoDPD or a CoDPD package process. However, there can be several drivers of the FDTD process, such as a market need, as perceived by a technology manager: *'what is out there, and what do we need to develop? The technology managers also look at world trends . . . , go to different exhibitions, visit different universities and so on . . . . Then you also have customers' expectations; there could also be some requests from specific customers. What is valuable for them?'* (R1).

The process can thus start with research, where either the theoretical or the practical application is unclear, or even by testing principles and materials' mechanical properties. This research is sometimes conducted in collaboration with different universities, consultants and suppliers, especially for those supplying highly advanced technical components. R1 further argues for the need to separate the FDTD from the PD processes. This opinion is shared by the manager for sales and operations planning – *'[In TD], you do not know what you will get in the end. Time is one thing, and then you might not know the result or the area of use. In all the other projects [PD], there is almost always some kind of market driver.'*

The FDTD process can take from 6 months to about 2 years. All activities are driven by forecasts and normally end when a new technology or production method is developed, and the principles and the applications are tested.

The FDPD/CoDPD process is used for developing standard products for the general market or bespoke 'one-off' products for a specific customer and is mainly used for developing core engines, with standard parts and options for packages. According to R1, all FDPD/CoDPD processes *'start off with a product requirement specification, that is, what should the final outcome be? This depends a bit on if we should develop a new gas turbine or if we only are to customise a part of the gas turbine.'* Hence, the choice of the variant (major, medium or minor) depends not only on a task's difficulty but also on the consequences of not meeting a target. As a result, the three variants differ in the engineering activities performed; for instance, *'in a major [variant], you go through the whole process, and for a medium [variant], you skip or clump together different reviews and stages'* (R1). The major FDPD/CoDPD is used for developing new products and may take off in testing materials and applications, developing new codes or articulating new standards. Since the core engine consists of thousands of items and can be sold to different parts of the world, an array of different codes and standards should be considered (e.g. for the European market, Pressure Equipment Directive 97/23/EC, ATmosphères EXplosibles 94/9/EC and International Organization for Standardization 21789:2009, covering the safety requirements for a gas turbine). Other examples include the State Standard of the Soviet Union in Russia and the American Society of Mechanical Engineers and the Boiler and Pressure Vessel Code in the US. The process would, therefore, start with the activities under Engineer or Codes (see Figure 1; e.g. testing materials or applications to determine their compliance with codes and standards). Although the medium FDPD/CoDPD entails the same activities carried out in the major FDPD/CoDPD, it is not used for developing completely new products but for reconfiguring existing products for new applications. According to R1, *'an example is adapting a gas turbine to a cold climate. This means that we can start from given premises for some parts [of the core engine], and some have to be implemented from things we* *have developed [in the FDTD process]'*. Hence, some parts of the turbine must be reconfigured and tested, or codes have to be developed or integrated to function better under such conditions. The minor FDPD/CoDPD could then start by outlining the design using existing codes or by customizing the design's individual components for a specific customer. However, the activities performed under Parts and Complete (see Figure 1) are always included in the three processes. The differences between the three processes are also reflected in the development lead times (Table 3).

The CoDPD package is less complex than the three FDPD/CoDPD variants, with a development lead time of about 2–10 months. It is mostly used for auxiliary system configurations according to customers' demands. *'There can be some differences in the customers' layouts. Where does the fuel come in, how does the air intake look like, do you need to adjust the pipes … ?'* (R1). These are some of the questions asked in such a project, and the CoDPD package is thus mostly used for customizing individual components and involves incremental changes, such as in materials or adjusting the package to the setting where it will be used.

4.2. LuminaireCo

LuminaireCo develops and produces professional lighting solutions for public environments, such as offices, schools, retail areas, industries and hospitals. LuminaireCo develops and produces standard modular catalogue products, as well as customized and even bespoke one-of-a-kind products. During recent years, LuminaireCo has undergone and still undergoes a technology transition, where the traditional light sources are replaced by the light-emitting diode (LED) technology. This transition has resulted in a generational shift (i.e. the need for updating and redesigning the current product portfolio), as well as new technological opportunities for designing and developing new products. R4 explains that '*there is a furious pace on the component side at the moment*'; R5 follows up that they *'have more than 80 generational changes only this year'*, and as a result, all products, including these components, have had to be redesigned. To develop its products, LuminaireCo uses six main processes: FDTD; major, medium and minor FDPD; and major and minor CoDPD.

The FDTD process *'is not actually defined but still a way of working that can be compared with a process … meaning to develop fundamental technology that later can be introduced in future product concepts/projects'* (R4). Hence, the process is regarded as an informal and organic approach to building fundamental technology to be incorporated into FDPD when developing future products. It is sometimes conducted in collaboration with different universities (e.g. researching how humans are affected by light in different contexts). The FDTD work can start by researching theoretical or practical solutions to a problem or even by testing materials, applications or principles. The FDTD process can take from one month to several years, depending on the characteristics of the project undertaken, and all activities are FD.

The FDPD process is used for developing or reconfiguring standard products and is based on anticipated market needs (i.e. forecast). The major FDPD is used for new standard products, while the medium and the minor variants are used for making changes to existing standard products (e.g. changing the luminaire suspensions or the LED cards). The differences among the three processes are not necessarily observed in the engineering activities but in the project scope and the lead time; for example, a minor variant, in relation to a major or a medium variant, *'should go more rapidly; that is the basic idea'* (R4). Depending on the nature of the project, the three variants can start by testing materials, principles or technical applications or even by updating or changing a design's individual components, for instance, due to a component becoming obsolete at the supplier's end or a new technology being developed (e.g. the LED technique). R4 cites a typical example of a minor project where *'we [LuminaireCo] have a complete luminaire, which is a LED luminaire, and what happens is that a supplier calls and lets us know that [regarding] these LED motors which are in the luminaire, we [the supplier] will stop producing them now. So, within half a year, we [LuminaireCo] cannot buy these anymore. But we [the supplier] have this new card [LED motor] that looks the same but emits more light; that's good, right? But then, we [LuminaireCo] might get dots in the cup; that's not good … . This leads to the initiation of a development project instead of just an upgrade project. So, what could have been a logistics project is now a [FDPD] minor … where we are forced to make loads of tests, visual assessments and so on.'* The point of departure for the three FDPD processes therefore depends on the nature of the project and the required activities, meaning that they could start anywhere in between Engineer and Parts. However, the processes always end with a new design completed and ready to be produced. The differences are also reflected in the development lead times (Table 3).

The major and minor CoDPD are used for developing bespoke or customized products based on customer orders. However, these new customized products build on existing products and available solutions, meaning that the major and the minor CoDPD are less complex than FDPD, with fewer phases and people involved. In the major CoDPD, the theoretical principles are always clear, and the application is certain. Nevertheless, the process can also start by testing materials and applications in specific environments (e.g. temperatures and surroundings) or checking if the products comply with the codes and the standards regulating them. Since LuminaireCo's products are used in public spaces and sold in different countries, some codes and standards that they should follow are *Conformité Européenne* and the European standard for quality aspects of lighting workstations (EN12464) and China Compulsory Certificate. Most of the light sources and the roofing systems in which the luminaires are fitted are produced by other companies; therefore, the company's luminaires should comply with their standards. The major CoDPD can also start by using existing codes and standards or customizing individual parts of the design for a specific customer, meaning that it can begin with any of the activities in between Engineer and Parts. However, the process ends when the project is handed over to production. The minor CoDPD is used for reconfiguring standard products based on customer orders, through incremental changes, such as changing control drives or a component's colours. For instance, R4 and R5 currently observe a surge in demand for copper-coloured luminaries, so a typical CoDPD minor project at the moment could be *'to develop [product X] with a copper-coloured decoration'* (R5). The process can thus start from bringing existing knowledge together, applying existing codes and legislation or using existing components with known characteristics for a particular solution. The development lead time for the major CoDPD takes no longer than 10–20 weeks, depending on whether new tools are needed. In contrast, the minor CoDPD is primarily guided by system support, with a one-week development lead time.

4.3. FurnitureCo

FurnitureCo develops and produces specialized contract 'task' seating solutions, tabling products and meeting pods. Since designs are subject to contemporary tastes and fashions, as well as advances in ergonomics and lifestyles, FurnitureCo prioritizes the sensing of social and demographic changes. This includes trying to anticipate the changing world of work, and many product lines revolve around meeting the needs of different generations (e.g. baby boomers and millennials). This approach can be seen in the discussion by R9 – *'we are just about to change how we capture the voice of the customer, etc. So traditionally, we have developed products from within, knowing simple things like a gap in the portfolio or a shift in the market, so how back sofas are really popular from an acoustics perspective. Acoustics products like that, pods, for instance, because of the open plans, … like mobile generations, how technology is influencing the workplace, and then also booms in millennials in terms of, you know, the age groups are affecting the working environment as well, so that is feeding into that, but that is you know, the majority is internally generated information.'* However, much of this sensing is undertaken intuitively, based on insights from people who have been in the business for a long time. The company's three NPD processes are FDPD and major and minor CoDPD. FurnitureCo has an internal code of practice, including design codes, with a document that specifies codes and standards for engineering designs and expectations to fulfil.

Typically, FurnitureCo outsources TD projects or works in partnership with key system suppliers. R10 suggests that this makes sense when suppliers *'technically have a greater understanding of the existing designs and specifications'*.

The FDPD process is used for standard products targeting a broad market, which is typically undertaken on an annual cycle. It starts with market research, followed by testing materials, principles or applications. FurnitureCo seeks to capture the customer's voice early in the process and includes intuitive judgements about market shifts (e.g. a preference for natural materials or age-related shifts). The supplier input on specialized parts may also be incorporated at this stage. Once a product is launched, the project team gathers customer feedback to determine if modifications or new variants need to be investigated, meaning that the process can start by using codes and standards as starting points for changing existing products. These include British, European and international standards relating to usage and flammability, which can take months to complete. Examples include the National Fire Protection Standards and International Organization for Standardization standards for burning behaviour. The project concludes with a finished design/drawing of the product, ready to be ordered by a customer. Ongoing requirements are then managed through a material requirement planning system. The development lead time normally takes 6–12 months.

The major and minor CoDPD are used for developing customized products for specific customers. The major CoDPD is used for bespoke designs (e.g. high-end, fully integrated glass meeting rooms for a commercial client). In such a project, the glass used, its scale and size, as well as the internal finishes, would be bespoke. Designers, engineers and standards specialists typically work together on such a project, which may involve engineering work, such as calculating structures and air-flow testing. This also entails rethinking codes and standards from derivatives or using existing codes and standards, which is particularly the case with an international client. The minor CoDPD is used for incremental changes to existing standard products, whose individual parts should be customized on a project-by-project basis. Such changes may include a modified feature, such as electronics or media, the size or even customers' wishes to specify their own materials. The major CoDPD normally takes 1–18 months, whereas the development lead time for the minor CoDPD depends on the nature of the changes, lasting from a few weeks to many months.

FurnitureCo has suddenly become an international exporter. Sales in the US and the Far East have grown considerably, particularly over the last two years. *'We are getting to the point now where we are having to have almost a dedicated resource for looking at the changing world of standards… we seem to have [become] an international company overnight, literally. We have been selling abroad, don't get me wrong, for sort of a decade, but I do not know what happened in the last two years. But internationally, it has taken off'* (R9).

Hence, a more co-ordinated approach to managing international codes and standards is under development. According to R10, the challenge for FurnitureCo is the extent to which it will focus on 'shifting the market' versus 'following the market' and making progress in capturing the customer's voice. *'It is desirable to have a more customer-driven approach. Early input/feedback from customers is key. It makes customers feel like they own the process'*, but this should be made *'in a way that does not stop some of our fluidity'* (R10). To realize this, FurnitureCo needs a more strategic approach to customer interaction, including the management of interaction points with suppliers and different internal teams in the NPD process.

4.4. PumpCo

PumpCo develops and produces hydraulic pumps and motors for machine manufacturers and industries worldwide.

Due to a combination of market maturity and technology maturity, PumpCo is considering other innovative solutions, such as identifying other areas for application, as well as customizing different solutions. Their three main NPD processes are FDTD, FDPD and CoDPD.

The FDTD process is considered an informal and organic approach to developing new technology solutions to be used in future products; new production processes; testing materials, principles and applications; developing new ways for calculations and simulations, as well as investigating theoretical or practical opportunities and solutions to problems, where solutions may not even exist. The process is separated from the PD processes and is based on exploratory research where the technology developed is unknown or unfamiliar to PumpCo, as expressed by R12: *'[…] because you cannot control it [TD] in the same way. If you are going to research something completely new, you do not know how long it will take. Doing things that you do not know that there is a solution to within a product development project… then you might design a solution, and when one year has passed, you realize that this does not work, and then it is rather painful to go back. Furthermore, if the fundamental technology is already complete when you start a product development project… then you are able to compress the time span [time-to-customer].'* In many cases, an FDTD process is conducted in collaboration with local universities, sometimes also with suppliers, consultants and research institutes, all depending on what the project is about. The lead time largely depends on the project's complexity, as well as on the given resources in terms of time and money, and could thus take several years. If there is a solution to the problem, the process ends when a new technology is developed, the principles and the applications are tested, and the result can be incorporated in an FDPD or a CoDPD process.

The FDPD process is used for developing standard products based on forecasts. The process usually picks up where FDTD finishes, by incorporating new technology and knowledge into an FDPD project and testing the materials, principles or applications. In some cases, minor reconfiguring of the technology is included in the FDPD process although building on already existing technology, where the practical application should be tested. This step could still be regarded as comprising the activities under Engineer: testing materials, principles or applications. Nevertheless, the process ends when a new design is complete and ready for the production ramp-up. The FDPD process uses cross-functional teams, with the development lead time taking about 6 months to 3 years.

The CoDPD process is less complex than FDPD and is used for developing customized standard products based on customer orders. It can involve following new legal requirements and integrating new codes with existing ones (e.g. offshore applications). The process can also entail incremental changes to a standard product, such as changing the hydraulic flow by altering displacements or changing a component. According to R12, when altering the displacement of a hydraulic motor, there is a need for traceability. Therefore, *'this "product development" means that a new item number is made… it is a case for the CoDPD process and takes a few hours from request until completion'.* Furthermore, individual parts can be customized on a project-by-project basis, but the overall design rules have already been established in earlier projects. Since the products are used in vehicles and the mining industry, for instance, they must follow the directives of End-of-Life Vehicles, ATmosphères EXplosibles, and the Registration Evaluation and Authorization of Chemical Substances. Moreover, to make their products compatible with those of their customers, the company uses items that follow the International Organization for Standardization and Society of Automotive Engineers' standards. The development lead time for the CoDPD process takes from 2 hours to 6 months.

4.5. FoilCo

FoilCo develops and produces plastic foils for surface applications and decorative finishes with a variety of functions, tailored to the application and the setting of each customer's finished products. FoilCo was founded in 1893 but changed its production in 1945 and started producing plastic foils. Today, its products are sold worldwide. Due to its maturity in the technology and production process, FoilCo has become more CoD and customizes products for specific customers. This is also seen in the organization chart, where PD has been moved from the old development department to be part of market and sales. This was done *'in order for us [the product developers] to better be able to focus on customer requests'* (R13). FoilCo's two main NPD processes are FDTD and FDPD/CoDPD.

The FDTD process is viewed as an informal and organic approach to developing or incorporating new technology, mainly due to the rareness of such projects and the maturity in products and processes. However, an ongoing FDTD project is intended to develop a new production method. Despite the project's theoretical foundation, the application is uncertain. The project thus started with Science Research (see Figure 1) and intends to end, if not cancelled, when a new production method is developed, and the principles and the applications are tested. An FDTD project often has a deadline (but not always), and the lead time mainly depends on the project's complexity, varying from 6 months to 5 years.

The FDPD/CoDPD process is used for developing new standard products for the coming year, as well as for making both bespoke and incremental changes to existing products. According to R13, the process is *'currently being revised, where we have tried to better describe the different inputs to the product development [process]'.* These inputs or drivers of the process may vary; *'for instance, you have inquiries from customers… and I estimate that 85% of all our product development [projects] are customer driven […]; then we have legal and governmental requirements that can result in product development, especially on the material side'* (R13). Other examples are new demand from the market and novel or phased-out materials by a supplier. Since FoilCo's products are sold in major regions of the world and used on board ships, for instance, these should comply with different classifying societies' codes (e.g. Bureau Veritas, Lloyd's Register, Nippon Kaiji Kyokai and the United States Coast Guard). The products should also be free from chemicals and other materials forbidden by the Registration Evaluation and Authorisation of Chemical Substances and the Restriction of Hazardous Substances, for example. If a material *'is in danger of becoming restricted, then we start to look for alternatives at an early stage and phase out the material and replace it with a new [one]… . So, we always try to be one step ahead, partly not to fall under time pressure, but also in order to keep our market position so that competitors do not end up ahead of us'* (R13).

The process can, therefore, start with engineering activities carried out in Engineer, testing the material to determine if it complies with the codes and the standards set by the different governments, unions and test institutes or utilizing existing codes and standards. However, the goal is always to end up with a finished product. The FDPD/CoDPD process is also used for customizations and can vary from bespoke, new one-off products where tools have to be acquired, to incremental changes in existing standard products, where customers may want new imprints, colours or finishes. Either way, in all the projects, FoilCo always attempts to leverage its knowledge and experience gained from similar projects. By doing so, it acquires a better understanding of the colours and the coatings used, along with knowledge of their standards and compliance with the regulations and the standards set by governmental laws and research institutes. If a customization can be achieved with the colours and the tools used for other existing customers, the process starts by utilizing existing components for a particular solution (i.e. Finalized Design). The development lead times for FD and CoD projects, therefore, vary and can take 1–26 weeks and 1–20 weeks, respectively, plus 8–12 weeks if new tools have to be acquired, totalling 1–38 weeks and 1–32 weeks, respectively.

4.6. ChimneyCo

ChimneyCo develops and produces prefabricated and modular building products, including brick-clad chimneys, arches, as well as cut-and-bond brick specials. Its main customers are national house builders and developers, as well as, merchants that sell in a retail capacity to major developers. Founded in 1997, ChimneyCo has experienced impressive growth in recent years. Traditionally, it has had a CoD focus. Due to a combination of market maturity and advances in technology, it has decided to embark on larger and more ambitious but speculative (i.e. FD) marketplace innovations. Its three processes are therefore FDPD and major and minor CoDPD.

The FDPD process is used for developing new product lines or product families and can include some TD. For instance, several investments in glass-reinforced plastic technologies have been made to produce chimneys through an injection-moulding technique. This process has involved initial testing of materials, principles and applications, as well as developing injection moulds. This step has further led to a revision of existing production processes (e.g. making caps on traditional brick-clad chimneys via glass-reinforced plastic processes). At the testing phase, these products may need to be accredited or approved by the British Board of Aggregates or the Construction Glassfibre Manufacturers Association. Individual customers are not directly involved in these stages, but they are consulted in the development of standard options. In this case, four standard sizes and designs have been developed. Given the time spent on gathering expertise, developing moulds and testing their conformance with standards, this process can take 6–24 months. ChimneyCo experienced significant challenges in implementing the FDPD process, leading to a scaling back of glass-reinforced plastic products after they had been launched. An internal 'lessons learnt' review found that the analysis of competitors and market needs prior to the launch had not been robust enough, and there was a lack of customer involvement in the customer development process.

The major and minor CoDPD are used to customize products for specific customers. The major CoDPD addresses bespoke customer requirements that are often major, complicated prefabrication requests (e.g. large replacement chimneys and brickworks for old elegant buildings). This process typically involves technical and estimating teams liaising with each customer to co-develop drawings and computer-aided design (CAD) models based on existing codes and standards, with a product specialist providing input. Bespoke parts usually have to be purchased, and a bespoke metal frame needs to be designed. Hence, such projects typically take 6–7 weeks. The minor CoDPD is then used for incremental changes to existing standard products. This process concerns the customization of brick-clad chimneys using prefabricated options, such as size (e.g. taller and wider) and details (e.g. caps, pots, corbel, brick finish and decoration). The designs can also be adapted to suit each roof's pitch or angle. Hence, the minor CoDPD always includes the activities under Complete and possibly under Parts, where individual parts are customized. Nevertheless, the overall design rules have already been established. The design and engineering process has been significantly improved by the introduction of a product configurator, which allows new designs to be developed quickly and efficiently, often within 4 weeks.

ChimneyCo wishes to continue with a combination of FD and CoD processes, acknowledging the need for speculative market-driving innovations. Company changes were being undertaken at the time of this writing to support this aim, including the formation of cross-functional teams, formalized NPD stage gates and management systems, the introduction of measures for innovation, and the development of a company vision/strategy for innovation.

5. Analysis

The introduction has stated two research questions concerning (1) similarities and differences among manufacturing companies' NPD processes in terms of drivers, activities, outcomes and lead times, and (2) how organizations can structure a

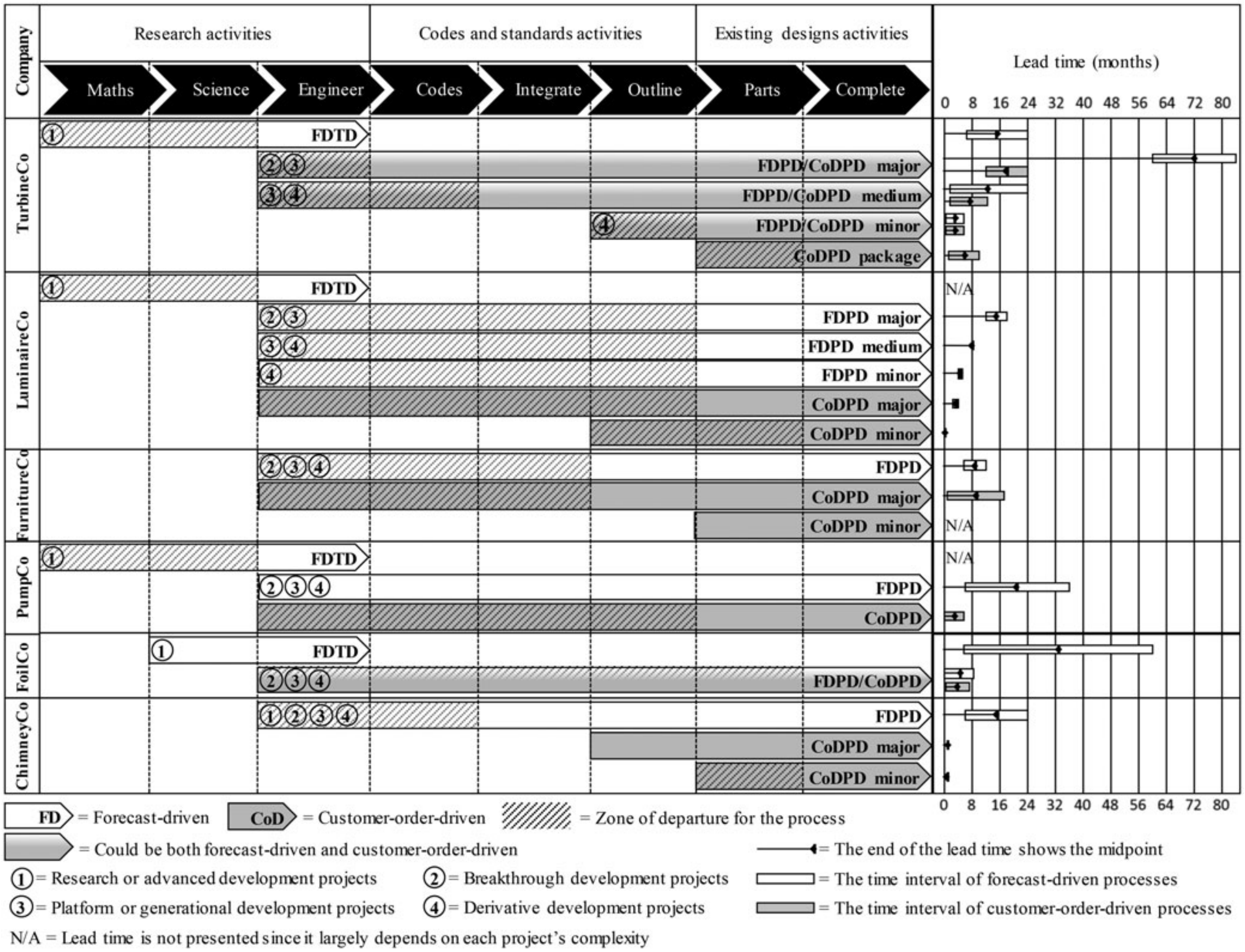

Figure 2. The case companies' NPD processes positioned into the EDP framework. *Note*: See Appendix 1 for the list of acronyms and their meanings.

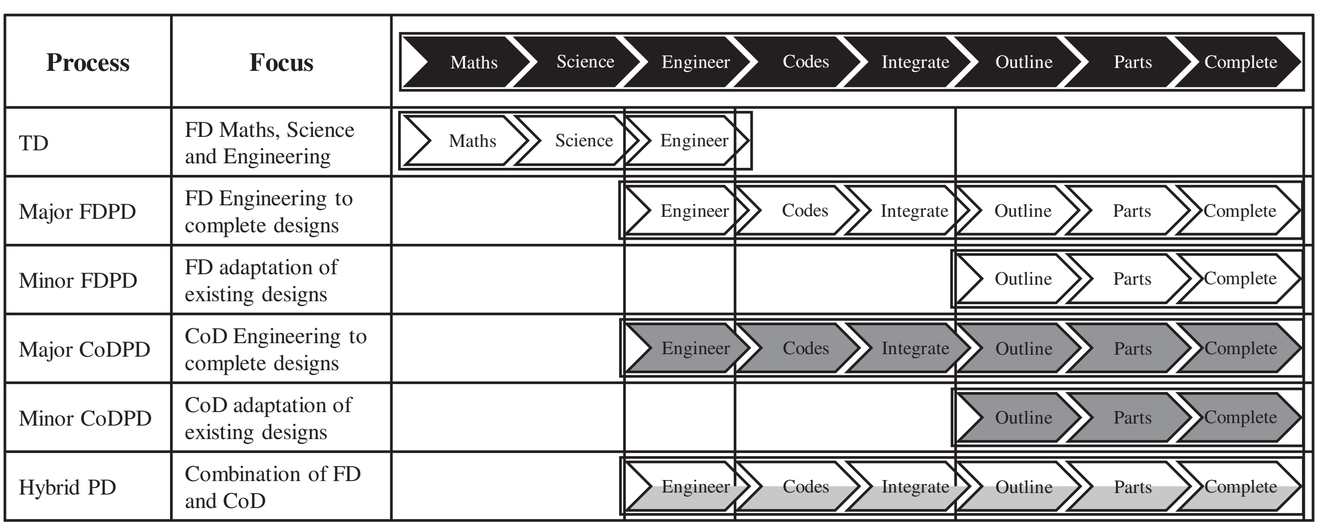

Figure 3. Emergent NPD processes linked to engineering decoupling points. *Note*: See Appendix 1 for the list of acronyms and their meanings.

portfolio of NPD processes using decoupling thinking, incorporating customer-driven NPD projects. To answer these questions, the case companies' NPD processes are mainly analyzed by positioning them by means of Gosling, Hewlett, and Naim's (2017) EDP framework, distinguishing between TD and PD in accordance with Lakemond et al. (2013), classified according to Wheelwright and Clark's (1992a, 1992b) four types of development projects and distinguishing among the different lead times (visualized in Figure 2). The EDP framework describes both the engineering design activities that are performed and whether they are FD or CoD. The eight engineering activities (i.e. Maths to Complete) proposed by Gosling, Hewlett, and Naim (2017), presented as the vertical axis in the EDP framework (Figure 1), are changed to the horizontal axis in Figure 2. This change facilitates the visualization and the comparison of all NPD processes in the case companies (in the same figure). It shows whether the activities and the NPD processes are FD or CoD by using white and grey colours, respectively, in line with the original EDP framework. If the NPD process could depart from different activities for various projects, light upward diagonal lines are used, illustrating a zone of departure.

Applying the EDP framework shows that the case companies' different processes have various contents, in the sense that they do not all start with the first activity and then work their way through all eight activities (i.e. from Maths to Complete). The case companies' FDTD processes may start with the activities under Maths, Science or Engineer. However, these end when the engineering activities are completed, thus not undergoing all the activities in the EDP framework, as first supposed by Gosling, Hewlett, and Naim (2017). Moreover, the companies' FDPD processes start no further than the activities under Engineer and end with the completion of those under Complete. Furthermore, there may be a zone of departure for the process, depending on the type of project and the required activities. The same holds true for CoDPD, which can include different activities, depending on a project's range. However, in most cases, it includes fewer activities than those of FDPD, and the activities are more standardized. The project's range reflects the customer's requests.

In Figure 2, Wheelwright and Clark's (1992a, 1992b) classification of development projects is mapped onto the company processes (see the figure key for details) to highlight the linkages. The projects within FDTD could be described as research or advanced development projects, where new science or know-how is investigated to be available and incorporated into specific development projects. The outcomes of the FDTD process are fundamental technology, new technology solutions and so on, which are later incorporated into the different PD processes, in line with the literature (Lakemond et al. 2013; Nobelius 2002; Säfsten et al. 2014; Wheelwright and Clark 1992a, 1992b). However, ChimneyCo is developing new know-how in its FDPD process rather than in an FDTD process, hence not separating TD and PD, as argued for by Lakemond et al. (2013), Nobelius (2002) and Säfsten et al. (2014). A reason for this might be that ChimneyCo is relatively new and has experienced impressive growth in recent years. They have therefore needed to focus more on an ad hoc approach to NPD but are now working on formulating structured NPD processes.

Concerning breakthrough development projects and platform or generational development, the companies tend to use the same processes for both types. Nonetheless, TurbineCo and LuminaireCo apply a more differentiated strategy, where the latter type of project can be undertaken in two different processes, depending on a task's difficulty and the consequence of not meeting a target or a project's scope. It could indicate larger companies' more differentiated strategy compared with smaller companies. An exception is FurnitureCo, a large organization without such differentiation; since it is rather new (i.e. founded in 1998) and just recently became a large company (in 2013), as defined by the European Commission (2018), these could explain the firm's not yet having established a differentiated strategy, a weakness of which they are aware.

Regarding the fourth type (derivative development projects), the case companies differ in their processes of refining and improving products to better meet market needs. Here as well, TurbineCo and LuminaireCo have applied a differentiation strategy, where this type of project can be undertaken in two different processes, depending on a task's difficulty and the consequences of not meeting a target or a project's scope or exceeding the budget in terms of time and money. To sum up, the companies partly use different processes for Wheelwright and Clark's (1992a, 1992b) four types of development projects but without a one-to-one relation.

The FDTD output typically feeds into the FDPD processes, meaning that the new know-how, technique or process developed in FDTD mostly goes through an FDPD and is thereafter utilized in a CoDPD. Additionally, except ChimneyCo, none of the companies performs pure research within a PD process, whether FD or CoD. Instead, TD is separated from PD, in accordance with the studies of Lakemond et al. (2013), Nobelius (2002) and Säfsten et al. (2014), and is performed based on a forecast. Furthermore, two of the six companies lack an internal TD process but tend to rely more on, or must comply with, technologies developed externally (e.g. research institutes or suppliers). Hence, new technology incorporated into an FDPD process does not have to come from the company's own TD process. Moreover, two of the four companies with internal TD do not consider this a formal process but an organic way of working.

Sometimes, FDPD is initiated due to market changes or new technologies, such as LuminaireCO incorporating the LED technique or FurnitureCo working with suppliers to conduct TD. Similarly, most of the companies do not develop their own internal codes and standards but conform to those set by regulators, institutes and suppliers. Therefore, they conduct tests to ensure their products' compliance with specific standards. It can also be argued that the companies can iterate different engineering design activities, for example, using Codes as starting points but returning to Engineer, to test and to certify each product's conformance. Hence, the practical flows may be less linear than the EDP framework (Gosling, Hewlett, and Naim 2017) suggests, and feedback loops exist.

Although Wheelwright and Clark (1992a, 1992b) discuss refinements and improvements to better meet the needs of specific market segments, their four types of development projects do not consider that a project might be CoD. However, all the case companies use one or more processes to customize products for specific customers and (except

ChimneyCo) have separate processes for CoD projects that are used only for customized products. Additionally, TurbineCo's major, medium and minor FDPD/CoDPD, as well as ChimneyCo's major FDPD/CoDPD, can be used both for developing or reconfiguring products for the market (i.e. FD projects) and for specific customers (i.e. CoD projects). Finally, four of the six companies use different PD processes, depending on the extent of customization requested. FD versus CoD processes can be compared with the reasoning of user as subject versus user as partner (Sanders and Stappers 2008) and customer as an information source versus customer as co-developer (Cui and Wu 2017), although the customers of the studied companies mainly state their requirements for the products and leave the actual design and engineering work to the case companies.

Comparing FDPD and CoDPD processes reveal the latter's tendency for shorter lead times (Figure 2), supporting Stalk and Hout's (1990, 80) findings. Lead times for CoD projects may be much shorter in relation to FD projects because a specific customer is waiting for the project to be finished. Alternatively, the products may be derivatives of existing ones, where existing knowledge is applied to minimize the necessary engineering work, reducing the time-to-customer and possibly increasing the delivery dependability.

The case companies' NPD processes are to a large extent traditional waterfall-type models, with some flexibility included but not to the degree applied in the flexible approaches described by Sommer et al. (2015), for example. The flexibility can instead be found in the way that the companies use several processes. They are thereby able to choose the most suitable process, depending on the aim of the development work, and link the outcomes of the different processes to use lead times effectively. The detailed analysis shown in Figure 2 makes it possible to identify the different NPD processes used by the case companies. A simplified diagram summarizes these processes in Figure 3. It shows that the companies use an FDTD process (FD maths, science or engineering), a major FDPD process and a minor FDPD process. The latter involves minor FD adaptations of existing designs, but the former might involve engineering testing and adaptations for codes and standards. In terms of CoD processes, the case companies use either a major CoD NPD process or a minor CoD process. Finally, TurbineCo and FoilCo show the interesting possibility of a hybrid process, which has the capability to develop FD or CoD products.

6. Discussion

The results show that manufacturing companies use several different NPD processes with different contents, activities and ranges, making it possible to employ different processes for various purposes and contexts. Some examples involve different processes not only for FD and CoD NPD but also for various FD NPDs, depending on the purpose and the initiative. Is the initiative based on a new demand from the market (new to the world, new to the company, additions to existing lines, improvements), new markets, new components from suppliers, new technical opportunities, new laws and regulations (international or national) or the need to reduce costs? With different processes, the most suitable can be used, for example, a less complex process with fewer gates and activities if only one component is exchanged. Moreover, manufacturing companies link the outcomes of different NPD processes; for example, TD results are fed into processes for major adaptations to existing designs, whose results, in turn, are fed into processes for minor adaptations.

Such a differentiated approach to NPD processes offers several advantages. It presents an overview and a better understanding of the activities required in different processes, the resources needed, lead times and so on. The development work in each process can be more focused on the specific activities important for that process, which can result in better use and allocation of resources. It is possible to differentiate among processes where cost efficiency is more important than flexibility and vice versa. Finally, linking the outcomes of different NPD processes facilitates an effective use of the lead time when a customer is waiting.

Based on the presented results, a structured NPD process portfolio is introduced (Figure 4), fulfilling the purpose of the research and summarizing the answers to the research questions. The horizontal axis shows the process driver, that is, if the process is driven by an anticipated market need (FD) or a specific customer order (CoD). The vertical axis indicates the process content, visualized by the filled-in activities in the EDP framework. A TD process includes the activities under Research Subclasses (Figure 1). A major PD process could include some activities under Research Subclasses (i.e. Engineer), Codes and Standards Subclasses, and Existing Designs Subclasses. Finally, a minor PD mainly includes activities under Existing Designs Subclasses. This approach results in six main processes, with the drivers, activities, outcomes and lead times described by the axes and the text in the different cells, answering research question 1 about similarities and differences. Using the CODP in Figure 4 to differentiate between the left-hand FD processes and the right-hand CoD processes, as well as the actual inclusion of the CoD processes, answers research question 2 about using decoupling thinking to structure NPD processes, incorporating customer-driven NPD projects. The portfolio model is populated with empirical observations from the cases, theoretical linkages to both the EDP framework and Wheelwright and Clark's (1992a, 1992b) holistic approach to aggregate project planning, as well as implications for co-creation.

The empirical data in the present research do not include TD based on customer orders and this process is therefore greyed in Figure 4 to emphasize that conducting TD on customer orders might not be so common. Furthermore, the right-hand column (i.e. CoD processes) lists 'co-innovation', 'co-creation' and 'customer as partner/co-developer', indicating a much broader interpretation compared with the descriptions in the literature, as described in the analysis.

The processes' different contents and drivers result in lead-time differences. The CoD processes have shorter lead times since they build on existing products and available solutions, the minor CoD to a greater extent than the major

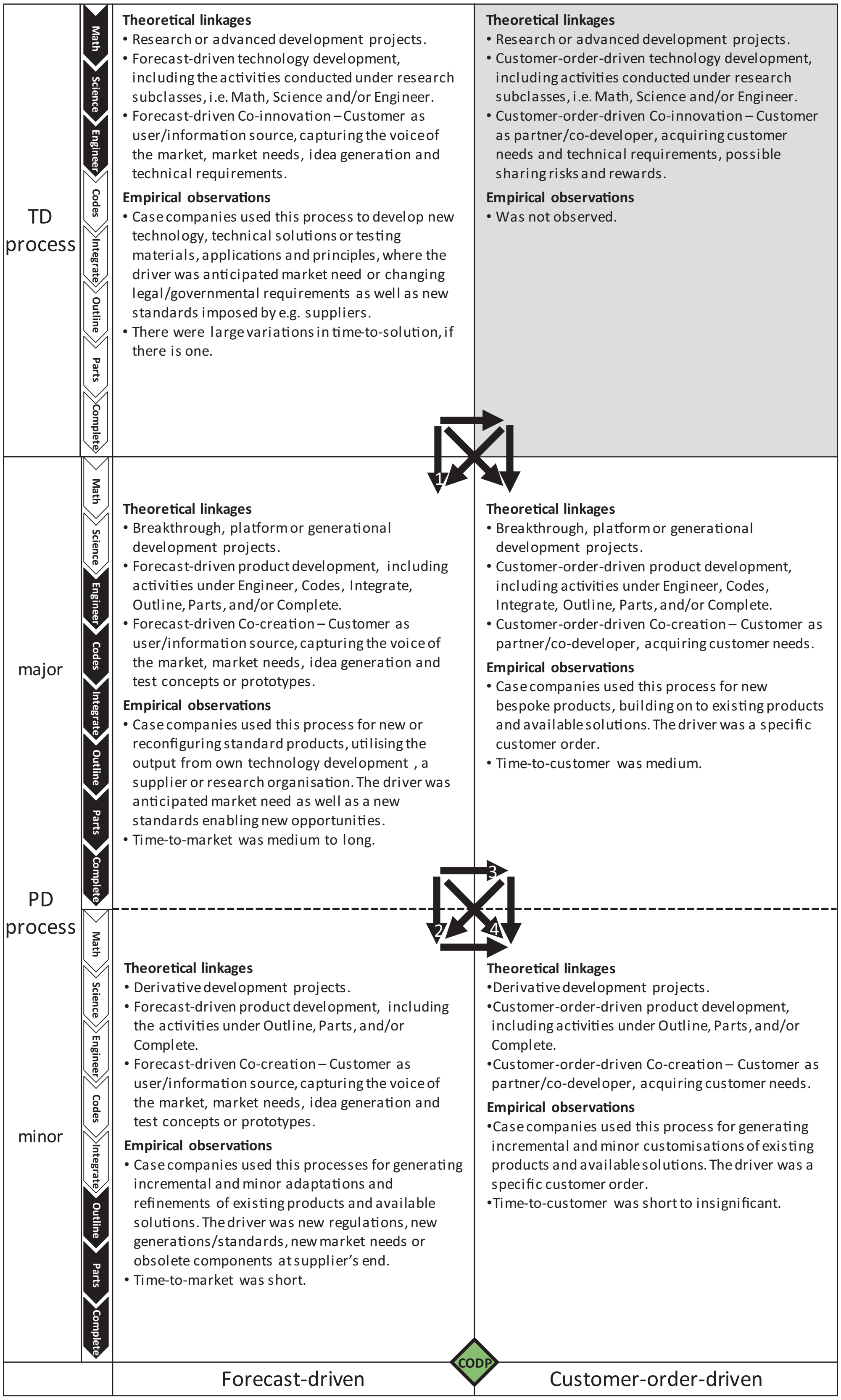

Figure 4. A structured NPD process portfolio. *Note*: See Appendix 1 for the list of acronyms and their meanings.

CoD. The same holds true for the minor PD compared with the major PD. The arrows in Figure 4 show possible ways of using the outcome of a process in another one. Starting with TD, the next step could be (1) a major FDPD process utilizing the outcome of a TD project to develop new standard products targeting specific markets. The outcome of such a process could then be used for (2) minor adaptations and updates for particular markets (minor FDPD), (3) the development of bespoke products (major CoDPD) or (4) incremental customizations of existing standard products (minor CoDPD). This illustrative pathway is highlighted by the corresponding white numbers in the arrows (Figure 4). It should be noted that the time between ending a process (i.e. closing a project) and utilizing the outcome in another process could vary greatly. For instance, in the case of LuminaireCo, a new standard luminaire could be developed in a major PD and produced for many years before being updated and redesigned due to a generational shift. As such, a product could go through different processes, as well as through the same process several times during its lifetime.

The illustrative pathway also highlights possible interfaces between different processes (Figure 4). First, there is the interface between TD and PD processes. In manufacturing companies, whether undertaking TD in house or relying on suppliers and/or research institutes, a separation between TD and PD processes is likely. This reflects broader discussions about the challenges of commercializing research and development ideas or the 'valley of death', as it is sometimes called (McIntyre 2014). For the companies undertaking TD in house, it is also a question of whether they have dedicated resources for TD or share resources with PD, utilizing different sets of knowledge and experience for different projects. Second, there is the interface between major and minor PD processes. The interviews highlight complex linkages between such processes, particularly where product platforms and modular designs are used as bases for moving between major and minor processes (e.g. Pero et al. 2010). Here, minor adaptations and updates to existing products can be made, such as when a component from a supplier becomes obsolete, requiring new variants to be developed and offered to the market, or when new laws or regulations impact the product design. Finally, there is the interface between FD and CoD processes. Organizations must make very difficult decisions, based on customer preferences and internal capabilities, on whether customer-driven or speculative new products are required (e.g. Schoenwitz et al. 2017). Should the company offer minor adaptations and customizations of existing products or even major customizations, developing bespoke 'one-off' products? Wisely managing the FD-CoD interface is important, and using a tool, such as the EDP framework, can facilitate this by clarifying which activities are FD and CoD, respectively.

7. Conclusion and implications

The purpose of this research is to develop a structured NPD process portfolio to facilitate the organization of NPD processes for both standardized products, focusing on time-to-market, and customized products, focusing on time-to-customer. To address this purpose, a framework developed by Gosling, Hewlett, and Naim (2017) has been applied in a multiple-case study consisting of six detailed cases. Moreover, concepts related to interface challenges in TD (Lakemond et al. 2013; Nobelius 2002; Säfsten et al. 2014), co-creation, co-innovation and knowledge integration (Cui and Wu 2017; O'Hern and Rindfleisch 2010; Sanders and Stappers 2008; Song, Cao, and Zheng 2016), and Wheelwright and Clark's (1992a, 1992b) NPD project classifications have been used.

In fulfilling this purpose, a structured NPD process portfolio has been developed. This approach differentiates between TD and major and minor PD processes, as well as between FD and CoD drivers. The resulting portfolio in the form of a matrix, identifying six NPD processes, provides an overview of potential options for NPD processes and shows different potential pathways through the processes. Companies can use the portfolio to support decisions related to the overall configuration of their NPD portfolios, the roles and the ranges of different NPD processes (along with their linkages), as well as to determine when and how to engage customers. Having established the underlying structures of their NPD processes, companies can then consider how to align their strategies, approaches and resources.

To conclude the research results, the following three propositions have been developed:

P1. An effective NPD approach adopts a holistic view of different process types with different outcomes and their interconnections.

P2. An effective NPD approach structures a configuration of processes that are appropriately aligned with market drivers (e.g. lead times and customization requirements).

P3. Much risk is associated with customer-driven technology development.

This paper's primary theoretical contribution is the enrichment and advancement of the understanding of decoupling thinking (e.g. Dekkers 2006; Rudberg and Wikner 2004; Wikner and Rudberg 2005) in NPD processes of manufacturing companies, for example, by applying the EDP framework (Gosling, Hewlett, and Naim 2017) in a new context. It advances the understanding of the EDP framework in several ways. First, it offers insight into the linearity and the sequencing of the subclasses. Often, there are feedback loops and non-linear phases. Second, it provides a richer understanding of the interconnectedness and the hierarchy of the processes that deliver different types of engineering designs. Some case companies use hybrid processes, as well as show evidence of complex links between standard and customized NPD products. Third, it gives a depth of understanding of the contextual factors and outcomes associated with different project types.

This study combines and acknowledges different literature streams on NPD characteristics, such as drivers, activities, outcomes, interfaces and lead times. In particular, it recognizes the customer as the initiator/driver of NPD activities, in contrast to the customer taking the role of an informant (i.e. representing the market), such as in customer participation, co-creation, co-innovation, knowledge integration and quality function deployment (e.g. Chang and Taylor 2016; Kathiravan et al. 2008; Kärkkäinen, Piippo, and Tuominen 2001; O'Hern and Rindfleisch 2010; Prahalad and Ramaswamy 2000; Song, Cao, and Zheng 2016). As such, the research acknowledges the difference between time-to-market and time-to-customer, as well as the strategic decision if, how and to what extent individual customer orders should drive NPD activities.

It is a theory-building study, proposing testable propositions for further research. The range of frameworks developed offers an organization-level view of the underlying processes and structures that bring different NPD projects into existence, expanding the scope of existing portfolio models, which typically classify different types of NPD projects or focus on a single NPD project process. The presented frameworks show how customers can penetrate the NPD process within the overall portfolio and provide a theoretical structure for organizations and scholars to reflect on customer involvement in NPD.

The research also has practical implications. The structured NPD process portfolio may be used by practitioners and stakeholders in NPD processes to visualize and reflect more deeply on the configuration and the aims of an organization's approach to innovation and customer involvement in new products. As such, the structured NPD process portfolio helps managers reflect on several questions, including the following: How and to what extent should individual customer orders drive NPD activities? What types of activities are involved? What are the implications for the time-to-customer, that is, the delivery lead time? The application is facilitated by the extensive descriptions of the case companies' contexts presented in this paper. Companies can adapt and configure their own portfolios to suit their respective contexts, for example, based on their products (e.g. innovative or functional, complex or simple), customers (e.g. segmented markets or one market, demanding bespoke or market generic products) and organization (e.g. size, resources, type and number of projects per year). A consequence of this research is that ChimneyCo has started such a reflection of its NPD process configuration. Furthermore, FurnitureCo recognizes the need for a more strategic approach to customer interaction, including the management of interaction points with suppliers and different internal teams in the NPD process. This point is revealed in the statement by R10, where the EDP framework *'could be a good way of making people think at the very early stages, where strategically do we want to engage customers?'*, thereby considering not only the time-to-market but also the time-to-customer. The structured NPD process portfolio offers guidance in designing such a strategic approach.

Although the research is based on a multiple-case study design, a limited number of cases have been used. Further studies should, therefore, ascertain whether these results could be generalizable and replicated in other contexts. Further research could also test the three propositions, as well as the proposed structured NPD process portfolio. The portfolio could be used to structure and visualize empirical data from future studies to analyze companies' NPD processes and compare patterns. Especially interesting leads to follow are the factors that drive the process and whether the drivers are internal or external. The study has focused on NPD activities carried out based on the commitment from actual customer orders, where the customer is not involved in the actual design and engineering work, in contrast to customer participation, such as co-creation, co-innovation and knowledge integration. As such, one interesting lead for further research is to apply the EDP framework to co-creation and knowledge integration projects, updating the structured NPD process portfolio to include participatory activities, types and benefits of knowledge exchange and then the role of the customer or even the supplier (e.g. Eslami and Lakemond 2016). Moreover, it would be noteworthy to reconnect this study's results to Rudberg and Wikner's (2004) and Wikner and Rudberg's (2005) two-dimensional framework.

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Appendix 1. Key acronyms used in the text.

CoD	Customer-order-driven
CODP	Customer order decoupling point
CoDPD	Customer-order-driven product development
EDP	Engineering decoupling point
FD	Forecast-driven
FDPD	Forecast-driven product development
FDTD	Forecast-driven technology development
NPD	New product development
PD	Product development
TD	Technology development