Cross-functional coopetition in new product development: Can constraints drive integration?

A case of the design–manufacturing interface of electrified cars

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Abstract

Enhancing cross-functional integration in new product development becomes increasingly important for industrial players to keep up with shorter product life cycles in technological innovation dynamics. Abundant research reflects the topic's significance, yet ambiguity in empirical results persists and industrial adoption of existing methods remains incremental. This thesis employs a qualitative approach to build a case study at the design-manufacturing interface of new product development of electrified cars. Cross-functional coopetition, as the joint occurrence of cooperation and competition, is adopted to generate an in-depth understanding of integration dynamics. Socio-organizational and contextual aspects are found to shape integration in a new product development context substantially. A model of interface dynamics is developed which provides for analysis and prediction of these aspects' impact on effective integration. A grounded theory approach to enhance integration is explored that introduces constraints as stimuli to consider manufacturability aspects in the design process. Constraint introduction is found to positively impact both cross-functional integration and creativity, with eight characteristics of constraint quality identified as moderating factors. A theoretical model is contributed which outlines cause-effect relationships of constraints' impact on antecedents of new product development success. It substantiates constraints' role in innovation contexts and encourages application for design-manufacturing integration as well as for other interfaces or purposes.

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List of Abbreviations

BEV	Battery electric vehicle
CAD	Computer-aided design
CEO	Chief executive officer
eHPV	Engineered hours per vehicle
FMEA	Failure mode and effects analysis
GMA	General morphological analysis
HR	Human resources
km/h	Kilometre per hour
KPI	Key performance indicator
MTM	Methods-time measurement
NASA	National Aeronautics and Space Administration
NPD	New product development
OEM	Original equipment manufacturer
PC	Personal computer
PDF	Portable document format
PHEV	Plug-in hybrid electric vehicle
QFD	Quality function deployment
R&D	Research and development
SOP	Start of production
TMU	Time-measurement-unit
TQM	Total quality management
VBA	Visual basic for applications

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1 Introduction and objectives

1.1 Motivation and objectives

"The long-term survival of a business enterprise hinges upon its ability to successfully introduce new products into the marketplace […]. The message to senior management is simple: either innovate or die!" (Cooper, 1996, p. 465). The fundamental importance of innovation for the sustainable success of any business is valid more than ever and uncontested in its significance. For innovation success, the generation of inventive ideas has proven to be less challenging than their consequent realization and industrialization (Neubauer, 2008; Bichlmaier, 2000; Schilling, 2017). Facing shortening product life cycles and higher customization, with its substantial consequences on time-to-market and product complexity, many companies strive towards optimizing the new product development (NPD) process (Schuh *et al.*, 2013b; Lühring, 2006, p. 1). Integrating functional counterparts' requirements and inputs into the design process, widely known as cross-functional integration, is of undisputed importance for this purpose, receiving significant attention in research and practice Lorenz, 2008; Brettel *et al.*, 2011).
Effectively integrating functional interfaces in NPD is becoming both more important and more difficult in today's dynamic business environment. Globalization disperses functions of a single organization on a worldwide array; the widespread offshoring of manufacturing in particular cuts ties between design and manufacturing. Cultural distance and intellectual property considerations foster walling-off tendencies between remote cross-functional partners. Increasing product complexity results in higher specialization, inhibiting cross-functional exchange or rotation. Continuously expanding enforcement of profit-centre structures during the last years likewise contributes to isolationism rather than promoting cross-functional integration. Even the extensive penetration of information technology has shown to create further barriers based on incompatible software systems and data bases instead of enhancing integration by virtually connecting remote cross-functional partners (Boutellier *et al.*, 2008, p. 26; Hirsch-Kreinsen, 2000; Ehrlenspiel and Meerkamm, 2013, p. 149; Ettlie and Stoll, 1990, p. 13). Complicating matters further, the same dynamics render cross-functional integration more important: "[…] factors like rapid technological change, flexible production processes, and global competition are making close collaboration across functions even more crucial for the introduction of profitable and timely new products" (Olson *et al.*, 2001, p. 258). The ever-proceeding expansion of knowledge enforces increasing specialization, making effective methods for cross-functional integration indispensable (Ehrlenspiel and Meerkamm, 2013, p. 149).

A broad body of relevant literature reflects the topic's importance. Empirical efforts examining cross-functional integration's impact on NPD success and theoretical contributions providing methods how to enhance cross-functional integration are manifold. However, empirical results remain ambiguous and partially contradicting (Troy *et al.*, 2008; Brettel *et al.*, 2011), and existing methods lack sufficient industrial application due to their high theoretical burden as well as insufficient recognition of organizational and social factors (Lindemann *et al.*, 2001; Ehrlenspiel and Meerkamm, 2013, p. 156; Cratzius, 2003, p. 96; Lühring, 2006, p. 13). The challenge of cross-functional integration in a NPD context seems well acknowledged by academics and practitioners, yet remains unsolved for satisfactory industrial application and sufficient explanatory theoretical depth.

Among the different functional pairings in consideration for a scientific reflection, the interface between the design department and the manufacturing department is of particular interest for innovative projects, as barely plannable design activities collide with highly structured production processes (Neubauer, 2008). Besides, this interface has been neglected in existing empirical studies of cross-functional integration with few exceptions (Brettel *et al.*, 2011; Dekkers *et al.*, 2013; Nafisi *et al.*, 2016).

The motivation for a scientific study on the topic is spurred by innovative NPD projects in practice, for which insufficient cross-functional integration crystallizes as a particularly pressing matter. To provide an example, the empirical case which is analysed in the course of the study at hand is concerned with the development of an innovative electrified powertrain for automotive application, supporting a shift towards environmentally friendly mobility. Sufficient integration of different functional requirements into the design phase is decisive hereof; from marketing for example, to enforce a high electric range, and from manufacturing to enforce low production costs for wide affordability. The resulting challenge represents a question of cross-functional integration, emerging from this and similar endeavours of innovative NPD alike.
Due to its complex products, multi-layered NPD processes and its significant role of driving industrial innovation, the automotive industry appears to be a fruitful empirical environment for scientific engagement regarding cross-functional integration in NPD (Womack *et al.*, 2006, p. 11; Fujimoto, 2000).

With the problem of cross-functional integration in NPD being widely acknowledged, increasingly under pressure and yet insufficiently solved, the objective of the study at hand is to forge new paths to address the topic. Recent theoretical approaches will be integrated to this aim. First, coopetition, defined as the simultaneous existence of cooperation and competition (Tidström, 2014) and a highly acclaimed novel theory, is believed to provide an in-depth perspective of underlying mechanisms of cross-functional integration in NPD. Second, the theory on constraints in innovation, finding insightful application in NPD contexts recently, is developed towards an alternative method to enhance cross-functional integration in NPD.

1.2 Structure of the thesis

The structure of the thesis follows the aims outlined in the previous chapter, likewise taking into account the deployed case study methodology. Illustration 1 depicts the sequence of and the linkages between different chapters.

After the introduction in *chapter 1*, subsequent sections outline theoretical fundamentals and the current state of empirical research on the theoretical approaches this thesis builds on: Research on cross-functional NPD (*chapter 2*), coopetition research (*chapter 3*) and research on constraints in NPD (*chapter 4*). Building on identified academic gaps in the underlying theory, *chapter 5* presents the research need including a detailed discussion of the topic, as well as the presentation of the research model and research questions guiding the empirical study. In *chapter 6*, the design of the empirical study is delineated. This includes discussing the research methodology and deriving the case study design. A detailed description of data collection, data analysis and the fulfilment of quality criteria for qualitative research follows suit. *Chapter 7* constitutes the core of the empirical study, with the central case study being portrayed in respect to all research questions. After a description of the empirical setting, cross-functional integration at the empirical object of analysis is examined by adopting a perspective of cross-functional coopetition. The summary of results, and the theoretical contribution following from it, is provided hereinafter (*chapters 7.2-7.3*). *Chapters 7.4-7.9* illuminate different aspects of a theoretical approach on the enhancement of cross-functional integration building on the introduction of manufacturability constraints. Accordingly, the theoretical model to be derived from the results is presented subsequently. *Chapter 8* concludes on findings and contributions to literature. Likewise, limitations of the study are discussed, avenues for further research are presented and implications for practitioners are provided.

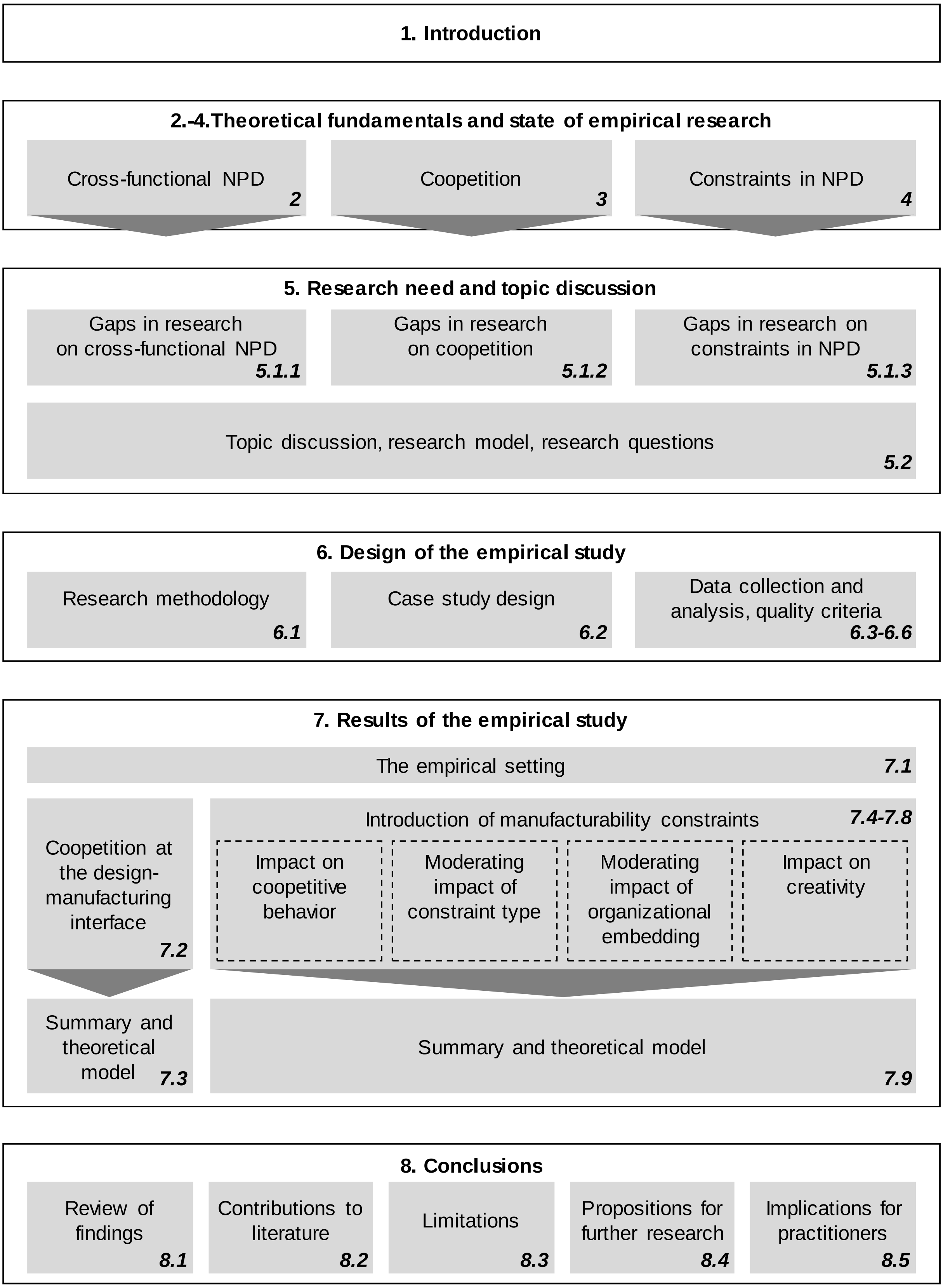

Illustration 1: Structure of the thesis

2 Theories on cross-functional new product development

2.1 Theory overview

In the following, theoretical principles that are essential for the understanding of cross-functional integration in NPD are summarized. This includes normative models of the NPD process itself, followed by the fundamentals of interface management. The latter is a required theoretical basis for fundamentals of cross-functional integration in NPD for later chapters throughout this thesis.

2.1.1 Normative models of new product development processes

It lies in the systematic nature of innovation, that it always takes place in a rather complex process involving several stakeholders from R&D, marketing and production (Fagerberg *et al.*, 2005; Olson *et al.*, 2001). NPD activities are characterized by unstable dynamics with regard to customer needs and technological possibilities, creativity requirements, communication intensity, planning intensity and interdisciplinary cross-linkages with activities on the individual, functional and inter-functional levels (Negele, 1998; Paashuis, 1998). All of those emphasize the need for organizational coordination to maximize NPD success; NPD processes have therefore ever since been the subject of extensive research (Sosa and Mihm, 2008). Cooper (1996, p. 466) summarizes that it is the “new product process - its nature and quality - that has the strongest impact on the business's new product performance”.
In the following, the evolution of such coordinated, normative models of NPD processes is presented.

A first structured approach to NPD, called phased project planning, was introduced by the National Aeronautics and Space Administration (NASA) in the 1960s to manage NASA’s large-scale development projects. It differentiated four phases (preliminary analysis, definition, design, development/operations) with intermittent checkpoint reviews after each phase to ensure that mistakes are not carried forward into downstream phases. Phased project planning was soon adjusted to suit smaller and less complex industrial NPD projects (von Stamm, 2008, p. 49; Lorenz, 2008; NASA, 1968).
In the early 1980’s, Booz, Allen & Hamilton analysed existent NPD procedure models in the United States, coming up with a generic description of NPD processes that is, in variations, still valid for most companies up to this day (Booz, Allen & Hamilton, 1982).

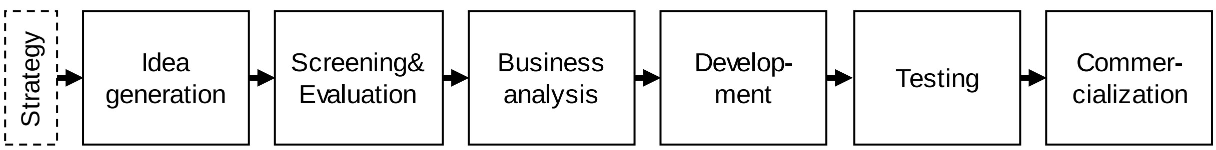

Illustration 2: NPD stages identified by Booz, Allen & Hamilton based on Fraker (1984, p. 38)

After a phase-based view of NPD had emerged, integration or separation of different conceptions of stages evolved from the late 1980s onwards, with serial models evolving towards more connected models with links and feedback and finally concurrent models (Teece, 1989; Trott, 2003; Johannessen, 2009; Jürgens, 2000). Cooper (1990) describes the evolution along three generations, with the first one following a simple supplier-to-customer relation with information flows pounding back and forth between the stages.

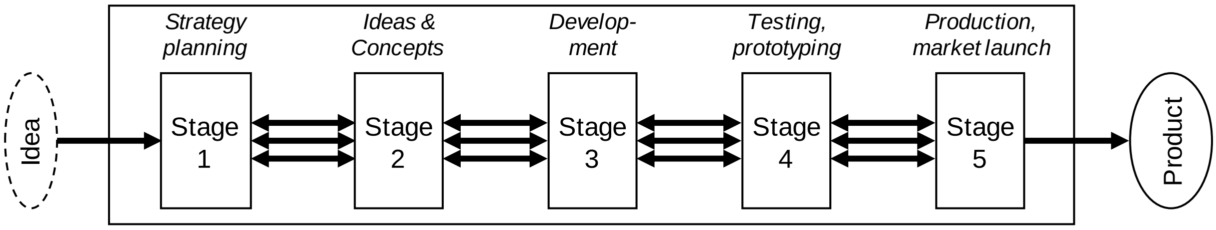

Illustration 3: First generation of NPD process models based on Albers and Meboldt (2007, p. 3)

Entailing a rise of global competitive dynamics in the early 1990s, pressure for reduced cycle time and costs as well as for enhanced product quality led to the development of a more efficient and effective second generation of NPD processes, the stage-gate system. The central idea, from which it takes the name, are gates to separate individual development stages, inspired by production processes where value is created between gates that ensure quality and eliminate variance. The adoption of this production view to NPD are gates, that safeguard a certain quality standard and stages, that imply a higher product value for every stage downstream the NPD process (Cooper, 1990; Cooper and Kleinschmidt, 1991).

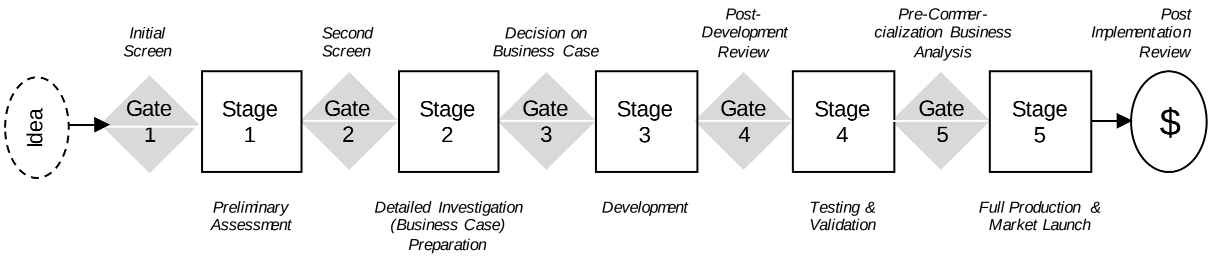

Illustration 4: Second generation of NPD process models: The stage-gate process based on Cooper (1990, p. 46)

While the stage-gated system experienced rapid adoption in the industry, criticism emerged towards the time-intensive passage of gates, slowing down NPD speed by setting back entire products at gates for merely one incomplete activity. Therefore, a third generation of NPD processes was developed to bring more flexibility and improved project prioritization to previously rigid stages, therefore named fuzzy stage-gate system (Cooper, 1994). It supports a more fluent process, where stages may overlap and gates allow for conditional criteria to pass, as opposed to absolute measures that required fulfilment previously. While these improvements yielded higher efficiency, complexity and coordination requirements were on the rise for stages whose limits are fuzzy and contingent on conditional criteria (Albers and Meboldt, 2007).

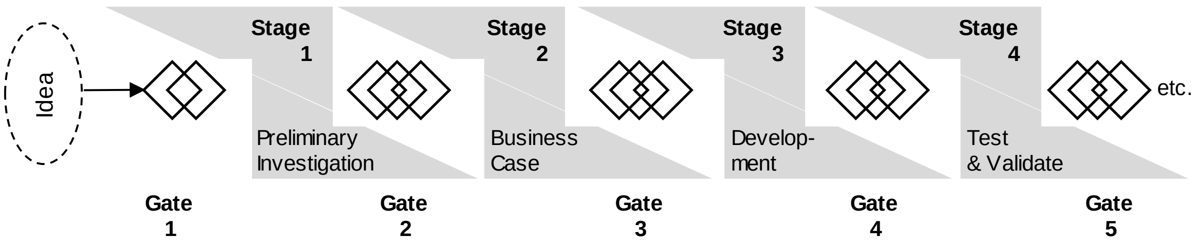

Illustration 5: Third generation of NPD process models: Fuzzy stage-gate system based on Cooper (1994, p. 5)

Until this day, the stage-gate system is widely utilized in practice and the most renown among existent NPD models, with a recent study identifying 88% of North American companies employing it in their NPD activities (Kahn, 2013, p. 28). Other structured models of NPD processes include the loose-tight concept (Albers and Eggers, 1991), in which innovation projects are managed in an increasingly tight manner towards the end of the process, or Lynn *et al.*'s (1996) probe-and-learn process which is specialized on scientific and technologically intensive NPD efforts (Gassmann and von Zedtwitz, 2003).

In summary, normative models of NPD processes have evolved to become more flexible and comprehensive over time, entailing a higher burden for implementation. With rising product requirements, the need for reduced development cycle time and increasing interdisciplinary focus, complexity is becoming a major challenge in NPD management since the late 20th century. While the refinement of structured NPD approaches has been crucial to improve development activities, the interaction between different functional stakeholders of any stage-gate system remains difficult (Cooper, 1996; ElMaraghy *et al.*, 2012; Simms and Trott, 2014).

2.1.2 Management of organizational interfaces

Whereas interface integration in a NPD context is at the core of this thesis, interfaces generally exist in a broad range of organizational situations. A fundamental characterization of interfaces, explanations on their emergence and instruments to manage them will be broadly outlined in the following. Barriers and supportive aspects to interface integration in the specific context of NPD will be discussed in a subsequent section.

Interface management constitutes a central problem in management and organizational research that goes back to the times of Adam Smith: Referring to Smith's conception of production based on the division of labour, List (1841, p. 224) notes that "the separation of business operations, without the unification of productive

forces towards a collective purpose, can hardly foster such a production" (translated from the German original).
The fundamental root cause leading to the emergence of interfaces and all concomitant coordination difficulties is the steady increase of industrial specialization from the beginning of the industrialization age onwards. Given the simultaneous explosion of knowledge, with its velocity increasing up to this day, specialization is simply a necessary condition to support the expansion of knowledge (Ehrlenspiel and Meerkamm, 2013, p. 3). The result is the organizational paradigm of specialization and coordination mutually presupposing each other, with the emergence of interfaces being an unavoidable consequence thereof. Hence, managing interfaces emerges as an important management activity, as its failure to do so risks to eliminate the benefits from specialization (Brockhoff, 1989, p. 1; Cratzius, 2003, p. 17).

Interface management denotes "the systematic management of collaboration between different functional areas, above all function areas of marketing, production as well research and development" (Brockhoff and Hauschildt, 1993, quoted by Cratzius, 2003, p. 28, translated from the German original). According to Albach (1994, p. 198), the overall aim of interface management is closely related to NPD: the exchange of knowledge between functional departments in the innovation process.
Following Brockhoff (1994, p. 10), interface management designates both an intra-organizational and an inter-organizational perspective. Inter-organizational interfaces, occurring between individual organizations as opposed to intra-organizational interfaces between functional departments of one organization, are omitted from the scope of this thesis. For the questions examined in the empirical part of the study at hand, their inclusion is assumed to yield few insights, as the integration mechanics differ widely. Thus, differentiating causes and effects for inter- and intra-organizational interfaces would go beyond the scope of this thesis.

2.1.2.1 Characterization of organizational interfaces

While the expression "interface" originates from a technical context, designating transmission zones between software or hardware parts where energy or information is transferred, it is widely used in a broader social and organizational context to account for linkage points between organizational units or groups that work relatively autonomously in the greater context of an interlinked process or task (Specht, 2000; Lühring, 2006, p. 43; Brockhoff and Hauschildt, 1993, p. 3).

According to Brockhoff and Hauschildt (1993, p. 4-6), organizational interfaces are specific types of a social relation characterized by six aspects: autonomy of organizational units, equal hierarchical position, and common superiors, enforced relations, interactional relations and lastly, the existence of conflicts. The last aspect is inherently related to barriers to integration, which are generic causes to interface conflicts that hinder integration. Barriers to integration are manifold, including cultural divergence, information asymmetries, different strategic perspectives and physical barriers. They constitute an entire body of research itself, see Ginn and Rubenstein (1986), Gupta *et al.* (1986), Dougherty (1992), Brockhoff (1989, p. 43-84), Kahn and Mentzer (1994).

2.1.2.2 Emergence of organizational interfaces

Following Brockhoff (1994, p. 32), organizational interfaces emerge when a task or process requires more than one functional stakeholder and when classical approaches to organizational coordination do not apply: Hierarchical directives are not relevant, as there is no direct common superior. Market mechanisms, e.g. coordination via transfer prices or outsourcing to an external supplier, do not apply as economic reasons apparently led to an internal solution for the interface to materialize in the first place. Illustration 6 depicts internal and external causes for the emergence of interfaces, with external causes being imposed on an organization, e.g. through regulatory requirements, and internal causes created by the organization itself (Brockhoff, 1994, p. 18).

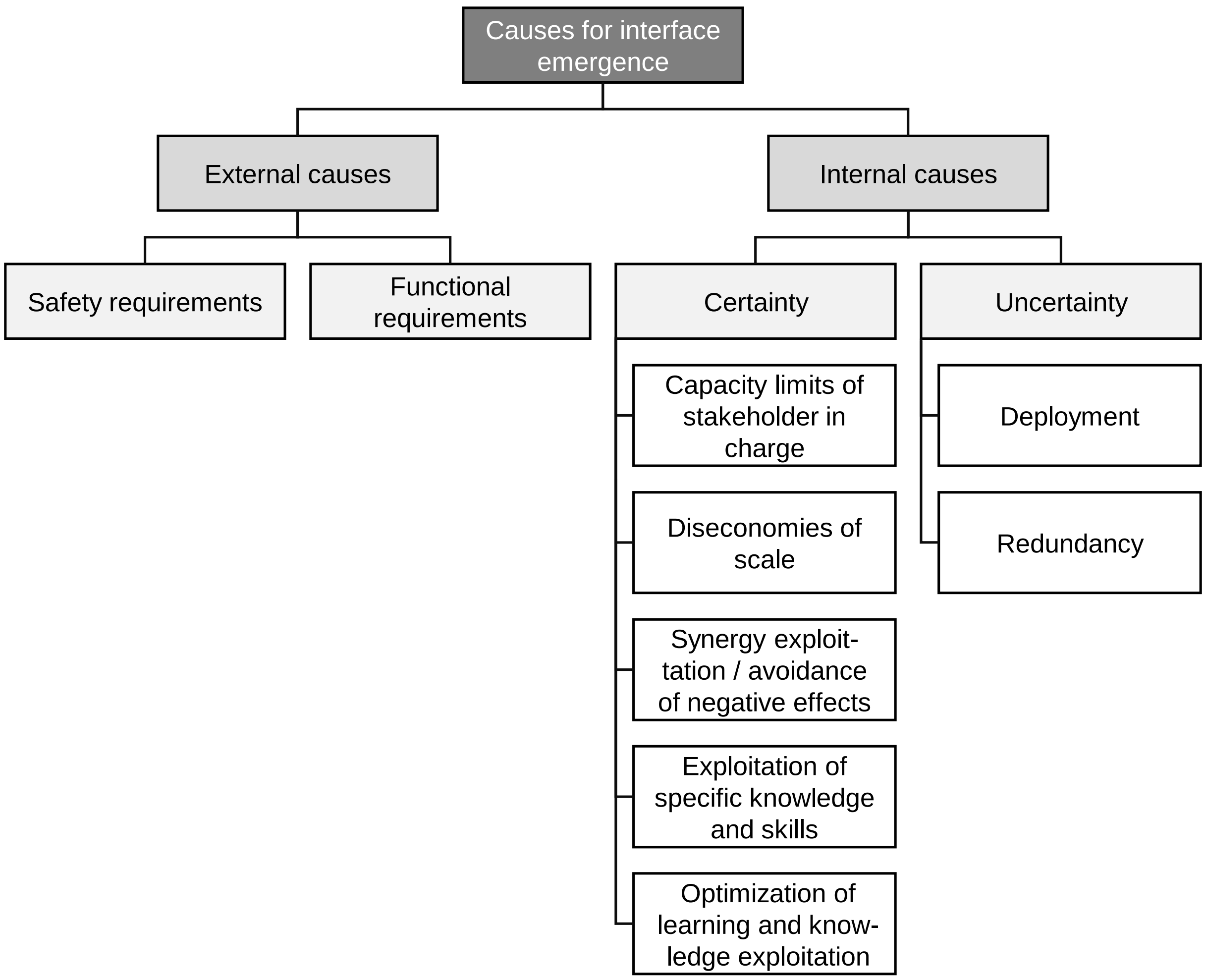

Illustration 6: Causes for the emergence of organizational interfaces based on Brockhoff (1994, p. 18)

2.1.2.3 Instruments of interface management

An extensive body of literature covers coordination mechanisms to improve interface cooperation, presenting instruments that draw on a broad range of organizational and management levers. With literature featuring instruments as diverse as corporate culture mechanisms, process organization and personal incentivization schemes, a summary of prevalent literature will be given in the following.

Brockhoff and Hauschildt (1993, p. 7) take the hierarchical organization as reference point to their categorization of instruments to overcome interface difficulties. They distinguish between mechanisms that are hierarchy-neutral, hierarchy-complementary and hierarchy-substituting. Accordingly, hierarchy-neutral instruments can be applied to any hierarchy level and affect individual behaviour either implicitly or explicitly. Explicit mechanisms encompass incentive systems, recruiting schemes, education on the job as well as job rotation, while implicit mechanisms imply visions, goals and corporate culture. Hierarchy-complementary instruments focus on affecting group behaviour in a personal manner, with liaison people, central staffs, commissions or project management named as examples. The last group, hierarchy-substituting elements, make hierarchical structures and directives partially obsolete by affecting groups' behaviour in an impersonal way. Markets and transfer price systems, programs and planning as well as spatial room arrangements, i.e. sitting together in one room, are mentioned as examples under this notion.

Brockhoff (1995, p. 205) distinguishes between interface management as a main function and complementary instruments, with the latter differentiating between instruments that address the vertical organization (structure) and instruments that affect the horizontal organization (process). Details are provided in illustration 7.

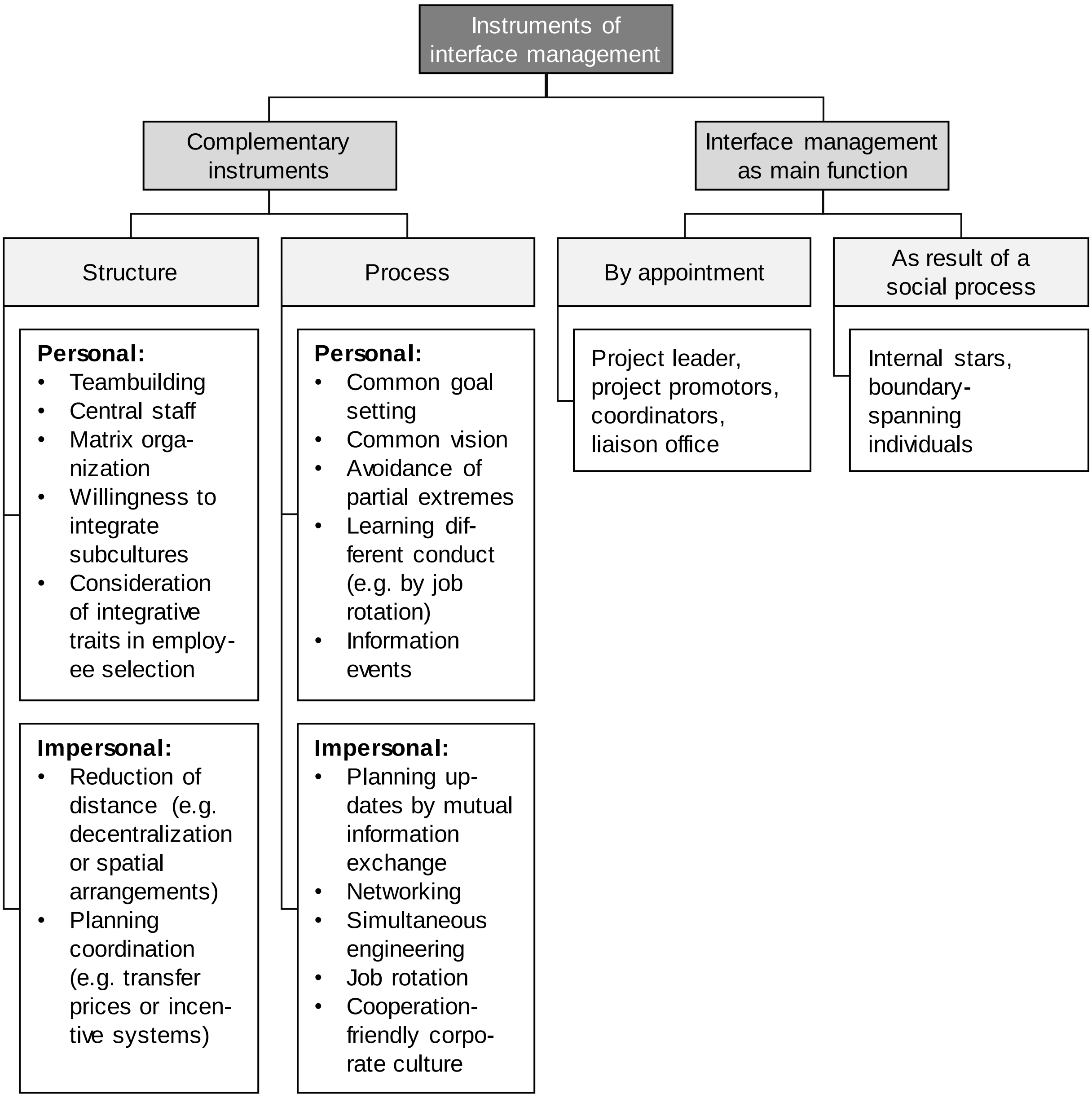

Illustration 7: Instruments of interface management based on Brockhoff, 1995, p. 205)

Griffin and Hauser (1996) describe social aspects of interface integration in NPD projects, such as communications patterns between different interfaces (see also Griffin and Hauser, 1992). They emphasize personal instruments, suggesting several mechanisms without joining them into a comprehensive instrument catalogue or overarching framework. Informal social systems, personnel movement, relocation and physical facilities find mentioning as levers to bring cross-functional stakeholders closer to each other, both physically and mindset-wise. Furthermore, they suggest incentive and reward systems to encourage members from different functional backgrounds to work with each other. In terms of organizational structure, different approaches, such as matrix organizations, project teams or coordinating groups are stated. Lastly, they suggest formal integrative management mechanisms to support integration in a manner similar to the normative models described above, e.g. formalized review procedures in Cooper's (1990) stage-gate process.

Specht (2000) follows a logic of standard elements of organizational theory in putting forward his systemization of interface management instruments: He distinguishes mechanisms of the process organization, the organizational structure, culture- and individual-affecting instruments as well as information and communication instruments. With regard to the process organization, he names promotors, review, mapping and integrative planning systems and refers to existent methods, e.g. simultaneous engineering. Within the organizational structure, Specht differentiates between instruments of the primary organization, such as flat hierarchies or coordinating offices, and instruments of the secondary organization, such as project groups, management committees or linking pins. Similar to Brockhoff and Hauschildt's explicit hierarchy-neutral instruments, Specht's culture- and individual-oriented instruments encompass education on the job, job rotation, incentive systems as well as corporate identity and leadership role model measures. Lastly, Specht's information and communication instruments bring together physical and virtual ways of working and communicating with each other, ranging from video conferencing over shared databases and group rooms up to virtual reality and mock-up applications.

2.1.3 Cross-functional integration in NPD

2.1.3.1 Definitions of cross-functional integration in NPD

No generally accepted definition of cross-functional integration has yet materialized in the existent literature (Olson *et al.*, 2001; Brettel *et al.*, 2011; Reiferscheid). Indeed, cross-functional integration is a concept with many different facets and interpretations: "[…] a great deal of variance exists in extant literature regarding how integration is defined and implemented and how relevant studies are conducted" (Troy *et al.*, 2008, p. 132). Moreover, no prevalent generic term has emerged yet, with cross-functional integration, interfunctional cooperation or interdepartmental collaboration exemplifying just a few verbal manifestations. Throughout this thesis, the term cross-functional integration is used.

Definitions of cross-functional integration in NPD

Source	Definition
Kahn, 1996, p. 139	"It is proposed that interdepartmental integration be defined as a multidimensional process that subsumes interaction and collaboration"
Song and Parry, 1997, p. 4	"Cross-functional integration refers to the level of unity of effort across functional areas in developing and launching a new product"

Song et al., 1997, p. 37	“Cooperation is broadly defined as coordination of behaviour […], numerous terms and phrases that have been used analogously, such as interfunctional integration, collaboration and teamwork. Basically, cross-functional cooperation refers to interdependency and information sharing between the various organizational units”
Olson et al., 2001, p. 260	“Our operational definition of cooperation includes both the frequency of interaction and the amount of information and resources shared between a pair of functions involved in an NPD project: marketing – R&D, marketing – operations, and R&D – operations”
Luca and Atuahene-Gima, 2007, p. 95	“Cross-functional collaboration refers to the degree of cooperation and the extent of representation by marketing, research and development (R&D), and other functional units in the product innovation process”
Brettel et al., 2011, p. 253	“The present study mainly relies on integration as the multidimensional construct including (a) the frequency of formal and informal communication, (b) the frequency and the amount of information and resources exchanged between the functions, and (c) the existence of collective goals”
Engelen et al., 2012, p. 53	“CFI [cross-functional integration, author’s note] as a multidimensional process of interaction and collaboration between functions, where interaction refers to the structured nature of cross-functional activities, such as the use and exchange of communication among functions, and collaboration is the unstructured, affective nature of cross-departmental relationships”

Table 1: Definitions of cross-functional integration in NPD

Table 1 lists definitions that are used by predominant authors in the field of cross-functional integration. The central aspect common to all definitions is the exchange of resources, above all information, between different functional units in the NPD process. However, two aspects are seen as controversial: the degree to which stakeholders interact to exchange resources, and the functional units that are included in this definition. Therefore, two aspects are discussed in the following: At first, it will be discussed which functional units are involved in cross-functional integration. Second, I will investigate whether cross-functional integration concentrates on mere interaction or includes cooperation or collaboration.

2.1.3.2 Functional units involved in cross-functional NPD

With regard to functional units involved in NPD activities, the following is widely accepted in pertinent literature: R&D, marketing and production are perceived as the most important functional actors in NPD (Brockhoff and Hauschildt, 1993, p. 2; Olson *et al.*, 2001, p. 259; Neubauer, 2008, p. 24; Brettel *et al.*, 2011, p. 252). Nevertheless, a multitude of empirical studies on cross-functional integration focusses only on R&D and marketing as central actors, neglecting the role of production.

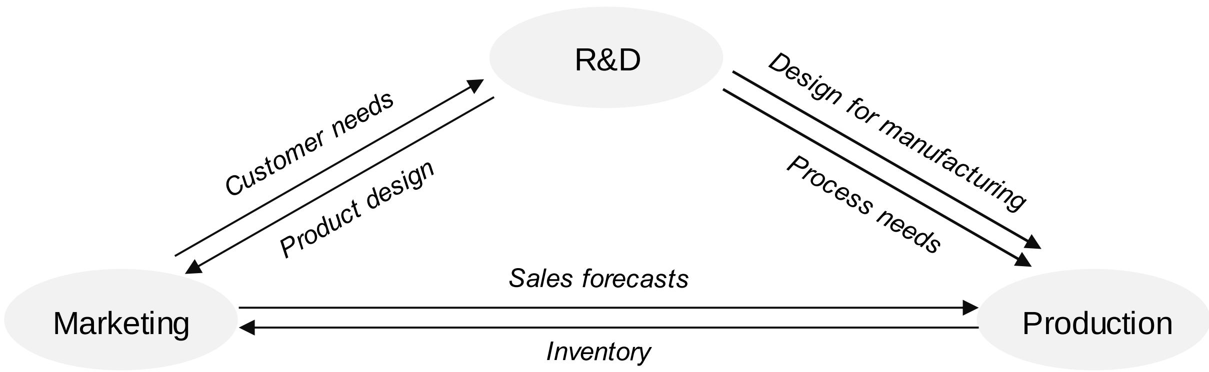

Illustration 8: Generic information streams between functional units in NPD adapted from Song et al. (1997, p. 37)

Illustration 8 depicts generic information streams between the three central functional units and resulting respective interdependencies. Marketing has to identify and translate customer needs into a well-conceived product positioning, with R&D depending on them to prioritize product features. R&D needs to deliver functioning designs that are producible within costs that are non-prohibitive to customer pricing, hence they are exposed to several interdependencies with production regarding manufacturability, required manufacturing capabilities and design validation with prototypes. Production depends on marketing's forecasts, and marketing in turn on production to have reliable information on inventory, lead time and cost projections (Brettel *et al.*, 2011; Wheelwright and Clark, 1992, p. 227 ff.).

2.1.3.3 Manifestations of integration between functions

Existent research presents several conceptions of integration; interaction, cooperation and collaboration are mentioned most frequently and shall therefore be described in the following.

According to Kahn (1996) and Moenaert *et al.* (1994), *interaction* refers to the frequency of formal communication and is structural in nature. It includes coordinated interdepartmental activities, both impersonal and personal, such as routine meetings or the sequential exchange of standardized documents (Neubauer, 2008; Kahn, 2001). *Collaboration*, on the other hand, tends to be unstructured and intangible, hence representing a more informal aspect of integration. Kahn (1996, p. 139) describes it "as an affective, volitional, mutual/shared process where two or more departments work together, have mutual understanding, have a common vision, share resources, and achieve collective goals". It touches upon qualitative, attitudinal aspects of integration as opposed to the mere frequency of interaction (Gerpott, 2005).

Furthermore, *cooperation* constitutes yet another conception for cross-functional integration that looks into the content of interdepartmentally shared information and relations; going beyond the mere outward nature of integration. Following Song *et al.*

(1997, p. 37), cooperation refers to “interdependency and information sharing between the various organizational units”.

Different models of cross-functional integration manifestations build loosely on those conceptions; two prominent ones by Kahn (1996) and Olson *et al.* (2001) are outlined in the following.

Kahn (1996) postulates a two-pillar model building on the interplay of *interaction* and *collaboration* as defined above. In a series of empirical studies (Kahn, 1996; Fisher *et al.*, 1997; Maltz and Kohli, 1996; Kahn, 2001; Kahn and Mentzer, 1998), the impact of both interaction and collaboration on NPD success was examined. It is found that interaction alone is not sufficient to yield improvements in NPD success. Collaboration is shown to be the more effective integration manifestation for NPD success, with interaction taking a rather presupposive role as a precondition for collaboration to develop.

Olson *et al.* (2001) builds on Song *et al.'s* (1997) conception of *cooperation* and develops a model that measures the frequency of communication, the amount of shared information and levels of transferred work. The authors deliberately focus on those more behavioural dimensions of integration, which are easier to measure for researchers and easier to influence as managers. Attitudinal dimensions, as they are included in Kahn’s definition of collaboration, are therefore neglected.

2.1.3.4 Importance of cross-functional integration in NPD

As discussed above, NPD success is an undeniable requirement for organizations of all sorts and sizes. In particular for manufacturing companies, often with large asset bases forcing their management to generate a steady stream of business to cover fixed costs, predictable NPD success and rigid planning is essential for survival (Gao and Bernard, 2017).

Cross-functional integration is undisputedly one of the factors that bring NPD projects to success: “The need for a close collaboration, especially in the early phase of the developments, is undisputed in academia and practice” (Lorenz, 2008, p. 11). In its complexity and uncertainty, the NPD process implies various interdependencies between different functions, making NPD fundamentally a multidisciplinary process and hence cross-functional integration a necessary antecedent of NPD success (Olson *et al.*, 2001; Lorenz, 2008; Lee and Markham, 2016). Despite its recognized impact on NPD (see for example Ehrlenspiel 2017, p. 233 ff., Brown and Eisenhardt 1995, Boutellier *et al.* 2008, p. 156 ff., Albach 1994, p.198 or Wheelwright and Clark 1992, p. 227), the implementation of cross-functional cooperation is a success factor for NPD that remains challenging for most organizations. Therefore, it remains one of the top list items of agendas in academia and practice alike (Gupta and Wilemon, 1996; Neubauer, 2008).

Lindemann *et al.* (2001) emphasize the holistic importance of integrated NPD. They state that integration in NPD impacts all aspects of the so-called magic triangle (cost-time-quality) in a universal way. Likewise they are noting flexibility and robustness of processes as beneficiaries of integrated product development.

One of the most detrimental effects of lacking integration is that the entire design process is disassembled into sub-problems of different functions to be solved subsequently. This results in sub-optimization, potentially sharply disadvantageous of the global optimization that the new product would require from a life-cycle perspective (Minnaar and Reinecke, 2012).

Often cited, the important role of NPD for the entire life cycle shows another essential need for cross-functional integration. The lion's share of costs that occur over the entire product life cycle is determined in early phases of NPD. Hence, product designers, as the predominant stakeholders typically involved in early phase NPD, decide over costs that downstream functional areas are bound to bear, such as manufacturing, sales or aftersales, see illustration 9 for details (Negele, 1998; Lindemann *et al.*, 2001; Ehrlenspiel and Meerkamm, 2013, p. 668). This implies a natural requirement for downstream functions to become involved. Resulting cost saving estimations are impressive:

Womack *et al.* (2006, p. 111) cite a two-third reduction of engineering efforts and a one-third reduction of development time. However, particularly in early phases, costs that occur later are hard to assess, which constitutes a central paradox in NPD cross-functional integration: Consequences on downstream stakeholders are the easiest to impact when they are the hardest to assess (Hacker, 2002).

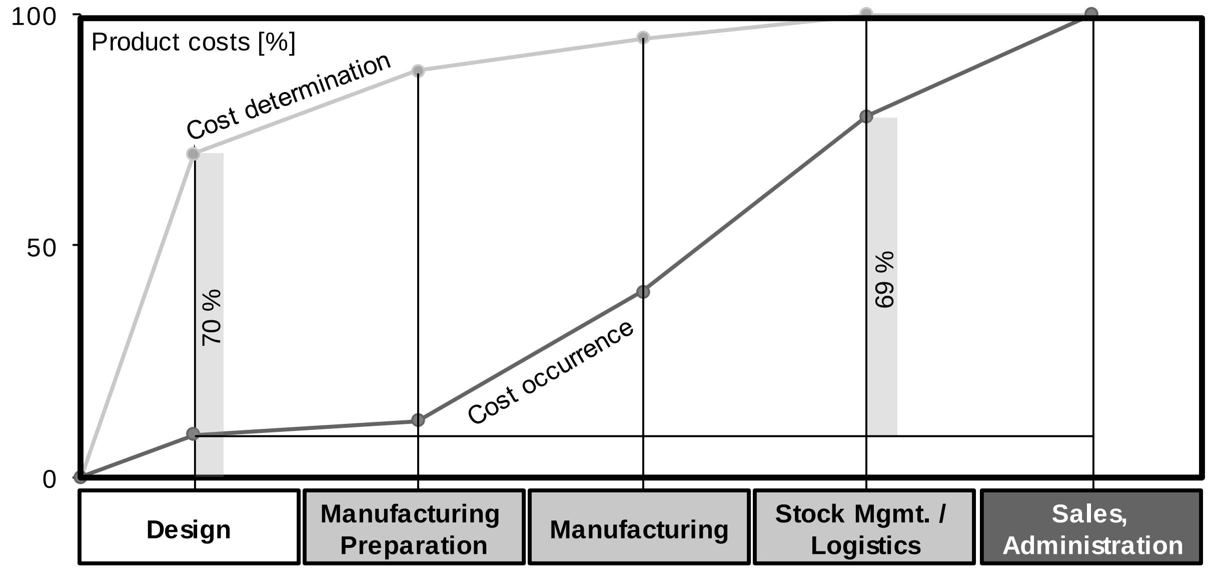

Illustration 9: Time gap between cost determination and cost occurrence in NPD based on VDI (1987, p. 3)

Besides these arguments, today’s business environment requires cross-functional integration on an augmented scale. Innovation pressure is on an all-time rise, with higher frequency of new products and the need for shorter development times putting additional complexity to new product development, entailing higher pressure on cross-functional integration alike: “The more innovative the NPD projects are, the greater is the need to integrate marketing and R&D functions within the company" (Fain *et al.*, 2011, p. 599). Olson *et al.* (2001, p. 258) enumerate macro trends such as rapid technological change, flexibility requirements of production systems and global competition that make “close collaboration across functions even more crucial for the introduction of profitable and timely new products".
One of the underlying causes for this increased integration pressure is uncertainty, which is an inherent part of every innovation project. Breakthrough innovations call for large investments and carry tremendous risks. In this regard, cross-functional integration helps to compensate for instabilities of innovative products, as it increases planning accuracy and reduces manufacturing costs by integrating production. It also moderates market- and demand-related risks by integration marketing. Thus, cross-functional integration helps mitigating the risks connected to innovation (Land *et al.*, 2012; Song *et al.*, 1998).

In summary, cross-functional integration becomes more important today to achieve higher innovation frequency, radically innovative products and reduced development time than it has already been, although very much the same reasons make cross-functional integration more difficult to achieve as they all likewise increase complexity. A later section will touch upon these barriers to integration in NPD in large-scale industrial environments in more detail.

2.1.3.5 Detrimental effects of cross-functional integration in NPD

While the majority of the literature focusses on positive effects of cross-functional integration, and indeed empirical studies propose that it is overall supporting NPD performance, it may likewise bear costs.

High levels of integration entail high communication and alignment efforts, with reduced efficiency and lower decision speed as results. Reaching consensus across functions is typically more difficult than it is within a functional unit. This further increases alignment efforts and possibly requires specifically educated managers able to cope with the complex coordination of cross-functional processes (Brettel *et al.*, 2011, 2011; Neubauer, 2008; Song *et al.*, 1998). Shim *et al.* (2016) argue that enhanced integration can possibly result in important information being disregarded or technological completeness being triggered, bearing costly delays of the development period. Moreover, integration violates basic management principles that state that authority should be linked to responsibility and every employee should be subordinated to a single manager. Those violations carry the risk of organizational conflict, resulting in personal distress that decreases overall productivity (Song *et al.*, 1998).

2.1.3.6 Barriers to integration specific to NPD contexts

As specified above, interface management is a pressing business issue in manifold contexts. However, environments of large-scale industrial NPD expose certain barriers to integration that make cross-functional integration even more difficult.

Following Lühring (2006, p. 66), higher levels of market uncertainty and technical uncertainty increase coordination requirements between functional areas. Hence NPD projects, which by their very own nature bear market-related and technical risks, demand generally higher coordination levels. Reasons thereof can be found in planning uncertainty which rises with longer development duration and lack of experience with product or process technologies that make it difficult to predict consequences on cross-functional counterparts (Thom, 1980, p. 27; Lühring, 2006, p. 65).

In addition, involved functional units as derived above (marketing, R&D and production) exhibit function-specific traits and cultures that pose significant barriers to integration. In his conceptual model of innovation processes, Seidel (1996, p. 28 ff.) distinguishes barriers along four different levels: The factual-intellectual level, the socio-emotional level, the value-based-cultural level and the creative-playful level.

To begin with, the factual-intellectual level includes different objectives that involved functions have regarding their NPD activities. On this level, production often takes a position that opposes the objectives of the other functions. Marketing and R&D typically strive to bring about change through new products and new technologies, while production strives for stability and efficiency (Song *et al.*, 1997). On the same factual-

intellectual level, the involved functions need very different kinds of information. While R&D and marketing embrace uncertainty to establish innovative solutions, production prefers reliable and less volatile information (Lühring, 2006, p. 58; Neubauer, 2008).
On the socio-emotional level, function-specific languages and subcultures, often named "thought worlds" in prevalent literature, take effect as well as very different academic backgrounds (Dougherty, 1992). Production again protrudes, with its members often lacking the academic background that its counterparts from R&D and marketing largely exhibit (Maltz, 1997). Different thought worlds likewise impact the value-based-cultural level, with different planning horizons taking a dominant role. Marketing's preferences lean strongly towards short-term reaction times to enable fluid responsiveness for altered market demands. Both R&D and production, on the other side, prefer long-term planning horizons to support large-scale technological innovation and a stable process build-up, respectively (Lühring, 2006, p. 58; Song *et al.*, 1997).
Barriers to integration on the creative-playful level account for different functional affinities for creative solutions. Again, production takes the maverick position due to a function-inherent opposing attitude towards novel and inventive features, that endanger stability and long-term efficiency gains in the production process (Lühring, 2006, p. 58).

2.1.3.7 Barriers to integration specific to large-scale industrial environments

Large-scale industrial environments pose particular barriers to integration stemming from three root causes: organizational size, complexity of products and suppression of innovative forces.

To begin with, organizational size impedes cross-functional integration by the spatial and personal distance between involved stakeholders. For most cases, distance increases with increasing firm size: The larger a functional department, the more difficult is it to know all employees within the department or from the cross-functional counterpart department in person. In addition, the larger an organization, the more likely is it to have several, spatially distant sites, further impeding personal acquaintanceship with employees at other sites.
Furthermore, higher levels of specialization occur in large organizations, which increases the distance between different functional thought worlds (Womack *et al.*, 2006, p. 63; Damanpour, 1996). Organizational size induces organizational layers and substructures detrimental to integration: While one layer of functional specialization, e.g. division of R&D, marketing and production suffices to small companies, large companies divide their activities between more functional units: Marketing tends to split up along products, R&D along technologies, production along locations or plants. Integrating substructures that organizationally do not fit to each other impedes integration. Formalized career paths and incentivization, as well as specialization and decreasing mobility within the company, all reduce a personal exchange and job

rotation between functions that would have supported integration (Wheelwright and Clark, 1992, p. 256-258; Hirsch-Kreinsen, 2000). Formalized decision structures, such as formal committees, often are rooted in a certain functional unit, with the first cross-functional decision alignment occurring only on high hierarchical levels (Teece, 1999; Damanpour, 1996). Large organizations often operate on a global scale, with cultural distance and intellectual property uncertainties inducing them to wall off, again impeding integration. For production in particular, globalized organizations are prohibitive to integration, as production is often off-shored to remote locations while R&D and marketing often remain centralized (Hirsch-Kreinsen, 2000).

On the other side, large-scale industrial enterprises are often characterized by the complexity of their products, as those require high levels of specialization found in large organizations. While product complexity further induces specialization with all the effects on integration mentioned above, additional aspects come into play. At first, components of complex products exhibit high levels of both functional interdependency and process-related interdependency, so both R&D and production require so much alignment within their own groups of specialists that integration with other functions is at risk to be neglected. For the same reason, modularization in small cross-functional teams is often not feasible. Rising levels of regulations and security requirements for many complex products, such as in the automotive or aviation industry, increase pressure on intra-functional alignment and reduce leeway for design or process adaptations asked for by other functional units (Fujimoto, 2000; Wenzel, 2003). Furthermore, cost pressure often requires complex products to be designed as platform concepts today, further reducing the chance of other functional units' demands to be respected. For example, production may ask for a certain design to be altered to enhance manufacturability, but R&D has its hands tied to remain within the specifications of the modular design. Likewise, production may refuse to produce a certain design as this would require alternations of production lines that are already used for other products on the same platform (Fujimoto, 2000).

In summary, particular barriers to integration make cross-functional cooperation in NPD and large-scale industrial environments even more difficult. It is important to note, that of the involved functional units it is often production that is pushed towards a maverick position through the mentioned barriers, making the integration of production particularly strenuous.

2.2 Existing methods to enhance cross-functional integration in NPD

This thesis strives to shed a comprehensive light on existing methods and their application. Therefore, the literature groundworks must not be limited by disciplinary boundaries of a certain research field, but should cover all areas that might play a role in empirical applications.

As a consequence, the following literature survey includes both methods in engineering theory and management theory, with the latter likewise including aspects of social theory that are applicable to the object of research.

2.2.1 Methods in engineering theory

From an engineering perspective, the integration of different functional stakeholders within NPD is a frequently discussed topic for the same reasons that are valid for management research alike. Hence, a large body of literature on integrated NPD in engineering-related research fields is in place. While management research generally takes a broad methodical perspective applicable to many industries and problems of interface integration, the engineering perspective on integrated NPD often is narrower in scope, considering more specific questions such as assembly-optimized product design. In particular, methods of information-oriented integration, e.g. computer-aided design techniques, are frequently presented as specific methods to enhance cross-function integration within NPD (Anderl *et al.*, 2012, p. 7 ff.).

In the following, five well-established method systems for cross-functional integration from engineering theory will be explained in more detail. Simultaneous engineering, integrated product development, axiomatic design and design for X all are methods that consider the integration of different interfaces, with the design-manufacturing interface being just one of them. On the other hand, design for manufacturing and assembly is focused particularly on the integration of manufacturing into the design process.

Notably, any delineation between methods, approaches or individual techniques remains debatable. Ehrlenspiel and Meerkamm (2013, p. 207) note that the method body on cross-functionally integrated NPD itself is complex, because individual methods and approaches have been developed from different perspectives and requirements and are far from being consistent and unitary. They suggest to summarize individual approaches and techniques as method systems, naming simultaneous engineering or integrated product development as examples of these systems. This delineation is followed hereinafter: simultaneous engineering, integrated product development, axiomatic design, design for X and design for manufacturing and assembly are considered as paramount method systems and presented in the following; individual techniques which are widely used within these method systems are explained furthermore.

2.2.1.1 Simultaneous engineering

Simultaneous engineering is a large research field serving as foundation for many methodical refinements in the field of new product development, such as integrated product development or TQM (total quality management) (Negele, 1998). According to the prevailing opinion, the terms simultaneous engineering and Cconcurrent engineering (CE) are used interchangeably (Bullinger and Warschat, 1996, p. 15; Parsaei and Sullivan, 1993). According to Swink (1998, p. 103), simultaneous engineering is defined as follows: “In the CE [concurrent engineering, author’s note] approach, integrated, multi-functional teams work together, simultaneously attacking multiple aspects of new product development. Control and responsibility are shared among functions and development activities overlap […]. Concurrent engineering can therefore be defined as the simultaneous design and development of all processes and information needed to manufacture a product, to sell it, to distribute it, and to service it”. Minnaar and Reinecke (2012) take an analogy to manufacturing when explaining simultaneous engineering as a just-in-time method, where development information is exchanged immediately and in small batches. Illustration 10 shows the central idea of overlapping functional subprocesses, simultaneously run, with knowledge of downstream functions being available in early development phases and a resulting shorter development time (Stjepandic *et al.*, 2015; Bochtler, 1995; Minnaar and Reinecke, 2012).

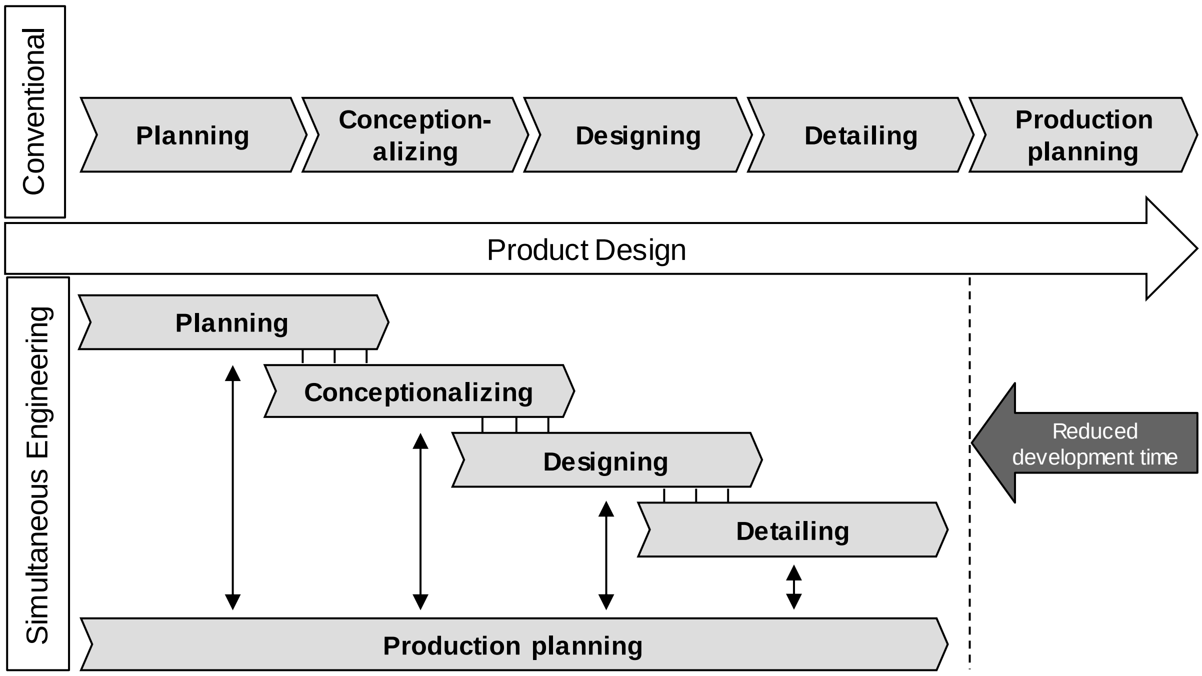

Illustration 10: Reduction of development time through simultaneous engineering based on Bochtler (1995, p. 2)

The vertical integration of tasks which, in conventional models of NPD, are only horizontally integrated, is in the focus of all simultaneous engineering efforts. Krottmaier (2013, p. 13 ff.) describes three methodological approaches for its operational enactment: the integration of process organization through parallelization and merging of competences, the integration of hierarchical organization through establishment of simultaneous engineering teams, and the integration of information through system and data integration. Product and process classifications, process interdependencies and life cycle interactions are resulting requirements for simultaneous engineering, entailing high coordination and communication efforts (Prasad *et al.*, 1993; Bullinger and Warschat, 1996, p. 57 ff.). Resulting high implementation costs and increased coordination complexity are often mentioned as reasons for low industrial application levels of simultaneous engineering (Kessler and Chakrabarti, 1999; Kessler, 2000; Bullinger and Warschat, 1996, p. 41 ff.), although its relevance and success potential has been studied and proven manifold, see Cratzius (2003, p. 96) or Lorenz (2008) for an overview. A strong process overlap can likewise result in risk being carried forward and potentially multiplied, making simultaneous engineering less suitable for radical innovation projects and early project phases (Gerwin and Susman, 1996; Herstatt and Verworn, 2007).

2.2.1.2 Integrated product development

Integrated product development as a methods system is a composure of widely applicable techniques for problem solving, procedural organization and construction. Moreover, it integrates suitable soft- and hardware support tools. It can be seen as an advancement of simultaneous engineering's basic principles, as it evolves simultaneous work efforts of different functions based on mutual consultations to a continuous exchange of information and intermediary work results (Lühring, 2006, p. 80; Lindemann *et al.*, 2001).

Integrated product development was first conceived by Ehrlenspiel (Ehrlenspiel, 2017, 1995) as a process model based on the fundamental topic-related thinking of Andreasen and Hein's "Integrated product development" (1987). Lindemann and Kleedörfer (1997) built their own system based on Ehrlenspiel's work, finding further development in the Munich procedural model (Lindemann, 2005, p. 40).

Integrated product development's objective is a comprehensive, process-overarching information flow across all stakeholders of NPD, such that product design would take into account customer feedback as well as inputs from production, sales or other downstream functions. Illustration 11 depicts these information streams following Ehrlenspiel and Meerkamm (2013, p. 204).

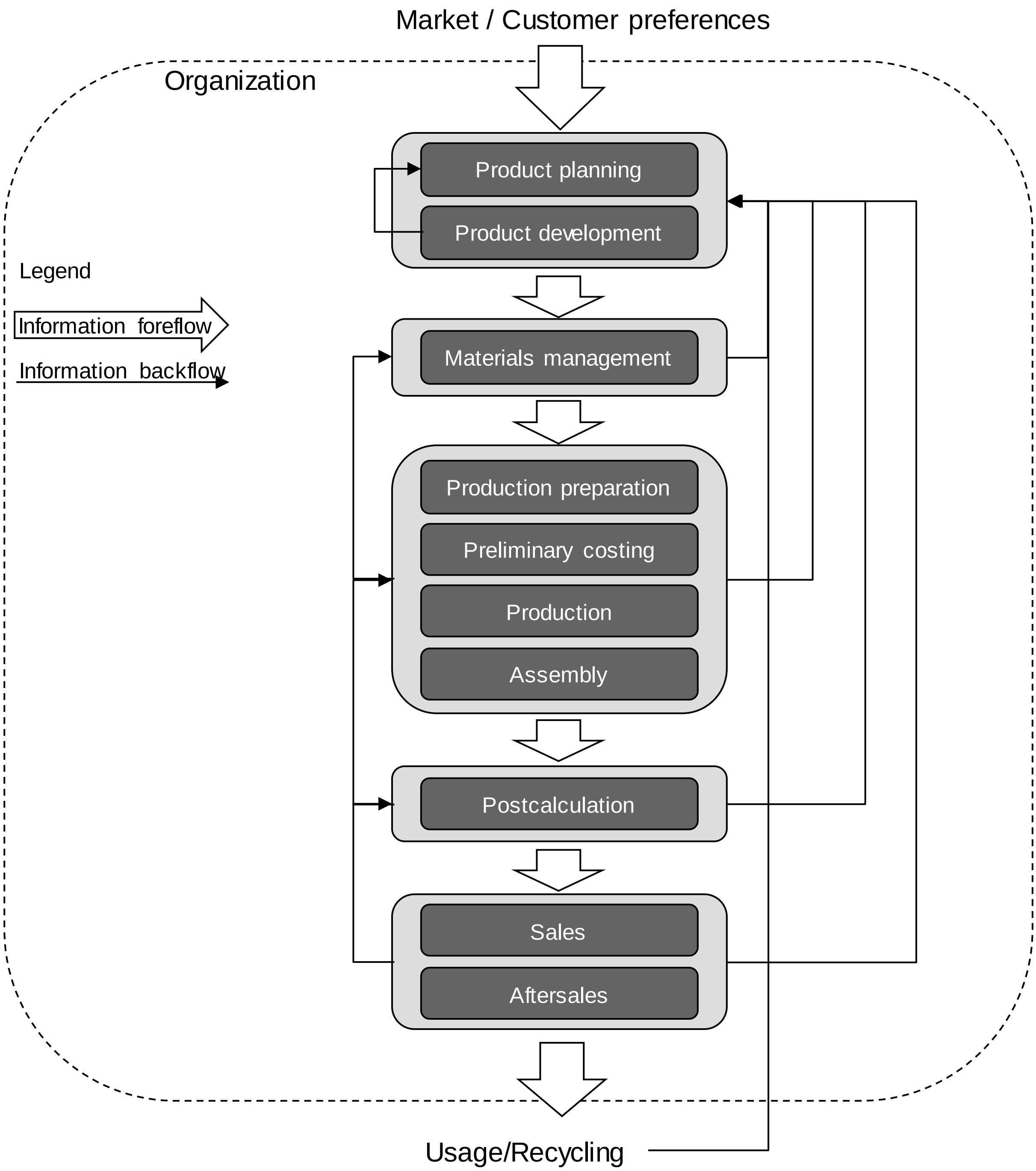

Illustration 11: Information streams in integrated product development based on Ehrlenspiel and Meerkamm (2013, p. 204)

A widely used technique within integrated product development is the TOTE (Test-Operate-Test-Exit) scheme, describing the human problem solving process as an iterative loop system, a procedure cycle, suggesting a structured work procedure for an individual participant, and procedure planning, structuring tasks and work stages for larger projects. Besides further techniques and tools for specific problem tasks, integrated product development emphasizes the need for a comprehensive change of mindset supporting integrated learning and the abandonment of an exclusive focus on the own function (Ehrlenspiel and Meerkamm, 2013, p. 329; Vajna, 2014).

Integrated product development is subject to further methodical development up to this day, with tools and techniques being added to its underlying tool box, see Gausemeier *et al.* (2012) and Bichlmaier (2000) as examples.

2.2.1.3 Axiomatic design

Axiomatic design, developed by Suh (2001) in the late 1970s, relies on the belief in two fundamental principles or axioms, which have been identified to characterize good designs after extensive examinations. The first one, called “independence axiom”, entails the independence of functional requirements. The second one, called “information axiom”, accounts for simplicity in the design, stating that the best design of all those fulfilling the first axiom is the one with the lowest information content (Gausemeier *et al.*, 2012; Suh, 2001).
Following the general perception of an axiom, all features of a good design can be derived from the independence and information axiom (Suh, 2001).

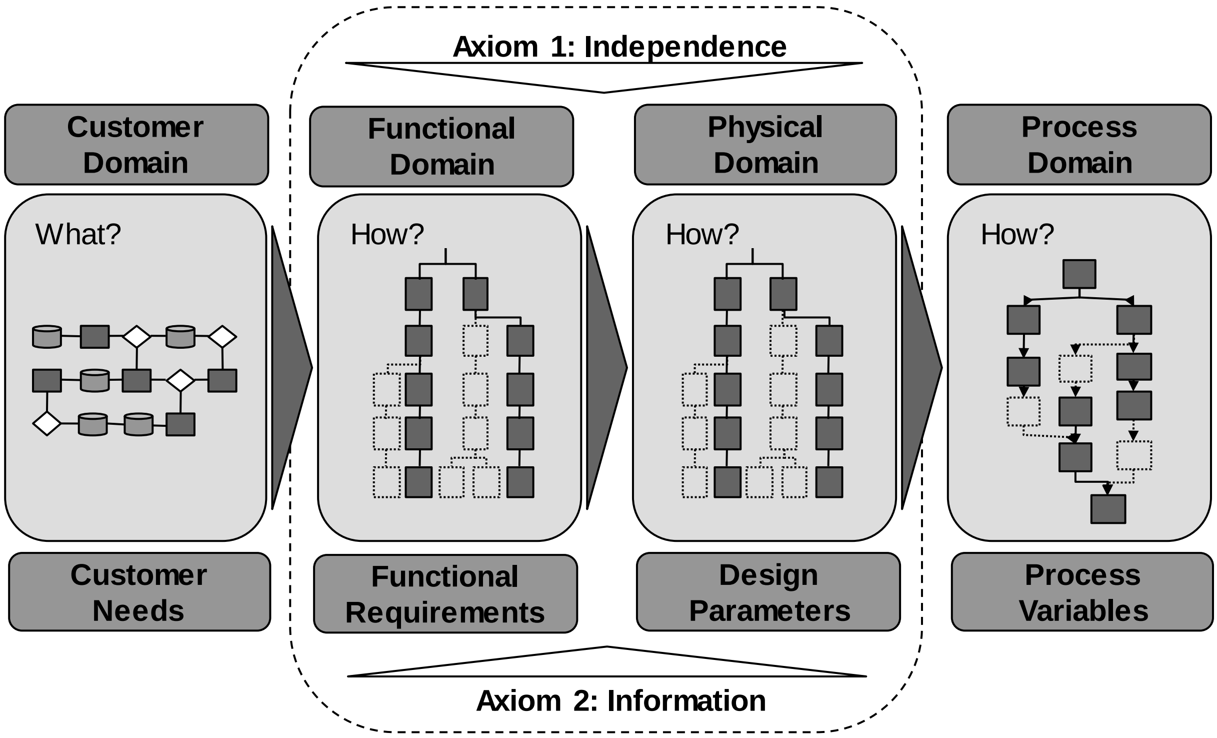

Illustration 12: The procedure model of axiomatic design based on Gausemeier et al. (2012, p. 36)

The design process is divided into four domains, see illustration 12 for a visual explanation. To begin with, customer needs are translated into functional requirements from an engineering point of view. The actual engineering design process concerns the translation of those functional requirements into design parameters, eventually leading to suitable process variables. The actual translation between the domains follows an iterative process of decomposing and allocating requirements, called the “zigzagging process”. It occurs between all four domains, mapping a set of variables of one domain to the set of variables to another domain, e.g. mapping customer needs, expressed by a list of attributes, into functional requirements. Notably, the outcome of such a mapping procedure is not necessarily unique. There could be several design solutions that fulfil the functional requirements. In this case, the design axioms guide the choice which of the designs is to be chosen (Suh, 2001).

While the mapping approach itself is applicable to all domains, the translation between the functional and the physical domain is the central task in the axiomatic design process (Gausemeier *et al.*, 2012). Relations between functional requirements (functional domain) and design parameters (physical domain) are modelled in the design matrix, which can be mathematically modelled (Suh, 2001). Following the independence axiom, axiomatic design strives to find independent relations, denoted as “decoupled design”.

2.2.1.4 Design for X

Conventional design practice places the achievement of product-related functional objectives as first priority of their design efforts, with other design objectives being neglected at first. As shown by Dylla (1991) in examining design engineers’ patterns of thinking, a multivariate optimization that takes other requirements simultaneously into consideration is rare in common engineering design thinking. Design for X summarizes approaches to give priority to those other requirements beyond mere functionality within the design process. A multitude of possible requirements are mentioned in prevalent literature, most of them coming from aspects downstream the design process, such as production or usability concerns (Feldhusen and Grote, 2013, p. 366 ff.; Ehrlenspiel and Meerkamm, 2013, p. 354; Bichlmaier, 2000). For a comprehensive overview of design guidelines to follow when engaging in design for X, see Feldhusen and Grote (2013, p. 366 ff.).

Procedure models for design for X are closely related to approaches of integrated product development, as trade-offs between the main requirement and other requirements emerge with high likelihood and are best solved in a cross-functional team (Ehrlenspiel and Meerkamm, 2013, p. 354 f.). A large number of tools to support design for X feature a rating or score that quantifies acceptable levels of requirement fulfilment (Ettlie and Stoll, 1990, p. 108 f.).

2.2.1.5 Design for manufacturing/ Design for assembly

Design for manufacturing is a method system that subsumes various approaches to design a product in a way that is optimized for manufacturing. It may be categorized as one of the approaches among design for X; due to its prominence in design theory and the focus on the design-manufacturing interface in this thesis, however, it is described in detail hereinafter.

For Ettlie and Stoll (1990, p. 79), it is a philosophy that “may be defined very broadly as the full range of policies, techniques, practices, and attitudes that cause a product to be designed for the optimum manufacturing cost, the optimum achievement of manufactured quality, and the optimum achievement of life-cycle support (serviceability, reliability, maintainability).” Following this perception, several approaches are included in the following, all of them optimizing for a specific aspect within a broader understanding of manufacturing, be it assembly, standardization, direct or indirect costs of manufacturing, e.g. design for assembly, design for producibility, design for life cycle or the house of producibility (Bichlmaier, 2000; Ettlie and Stoll, 1990, p. 111).

The underlying principle of design for manufacturing is to apply production-induced guidelines to the design phase, either unidirectionally or as a parallel alignment of process and product design. Conceptual antecedents date back to the beginnings of mass production, with Henry Ford’s statement “buyers could have any colour as long as it is black” (Duncan, 2008, p. 11) being an early example for manufacturing’s increased self-confidence in the realm of product design, which later supported the development of design for manufacturing.
For operationalization, Ettlie and Stoll (1990, p. 82) point towards an iterative design process, where production both contributes specifications before the start of the actual design process and decides for acceptability of the current design.

Other approaches, such as Boothroyd’s design for assembly (Boothroyd, 1983), feature a quantitative evaluation scheme that seeks to minimize production costs by a rigid indicator-based assessment of different design stages, introduced as requirements into the design process. Boothroyd’s approach is largely based on industrial engineering methods and has been continuously developed since its first conception at the end of the 1980s. It has become one of the most widely used methods within the broader groups of design for manufacturing (Boothroyd *et al.*, 2011; Kuo *et al.*, 2001, 2001; Bichlmaier, 2000; Ettlie and Stoll, 1990, p. 108).
The quantitative backbone of this method is the calculation of so-called design efficiency as the central assessment criterion, at its core a relation between the theoretically optimal assembly time and the design-specific assembly time.
The practical implementation of Boothroyd’s approach is guided by a software tool along two stages. In the first stage, specifications of the part to be analysed are provided that support a more detailed analysis of the design efficiency, e.g. weight, handling requirements or design symmetry. During the second stage, the resulting assembly time and design efficiency serve as basis for design optimization suggestions, which may be used to improve the overall design in an iterative manner (Boothroyd *et al.*, 2011; Huang, 1996).

2.2.2 Methods in management theory

Existing methods how to achieve integration in NPD from a management perspective build on a broad range of managerial and organizational concepts. In the following, a comprehensive collection of different integration mechanisms will be presented.

Subsequently, three integrated models for the employment of cross-functional integration in a NPD context will be discussed.
They all build on managerial and organizational theory, with overlaps into social theory, and hence can be easily differentiated from pertinent engineering research. However, as with methods in engineering theory, the delineation between a real method and mere techniques and approaches is blurry.

2.2.2.1 Integration mechanisms

In the course of several decades, a large range of methodologically diverse studies has identified many different mechanisms that spur integration in cross-functional cooperation within organizations and teams. While not representing a coherent framework or comprehensive method, the mechanisms each represent a building block of what might work to achieve cross-functional integration.
As groundworks for his qualitative research endeavour to discover integration mechanisms, Nihtilä (1999) summarizes all prior research, structuring integration mechanisms in a coherent way. Illustration 13 builds on Nihtilä's work and complements it by adding results of related research efforts.
Certainly, many of the identified mechanisms borrow from the general instruments of interface management. However, they are grounded in a context of NPD and emerge from a real empirical setting, as the employed methodology shows. Much of the compiled research efforts were performed as empirical case studies in an industrial context (Ettlie and Stoll, 1990, p. 56-57; Gupta and Wilemon, 1990; Trygg, 1991; Adler, 1995; Nihtilä, 1999; Paashuis, 1998), while others are based on quantitative survey data (Kraut and Streeter, 1995; Van De Ven *et al.*, 1976; Song *et al.*, 1997), and some feature a theoretical conception (Hirunyawipada *et al.*, 2010; Thompson, 1967; Dean and Susman, 1989).

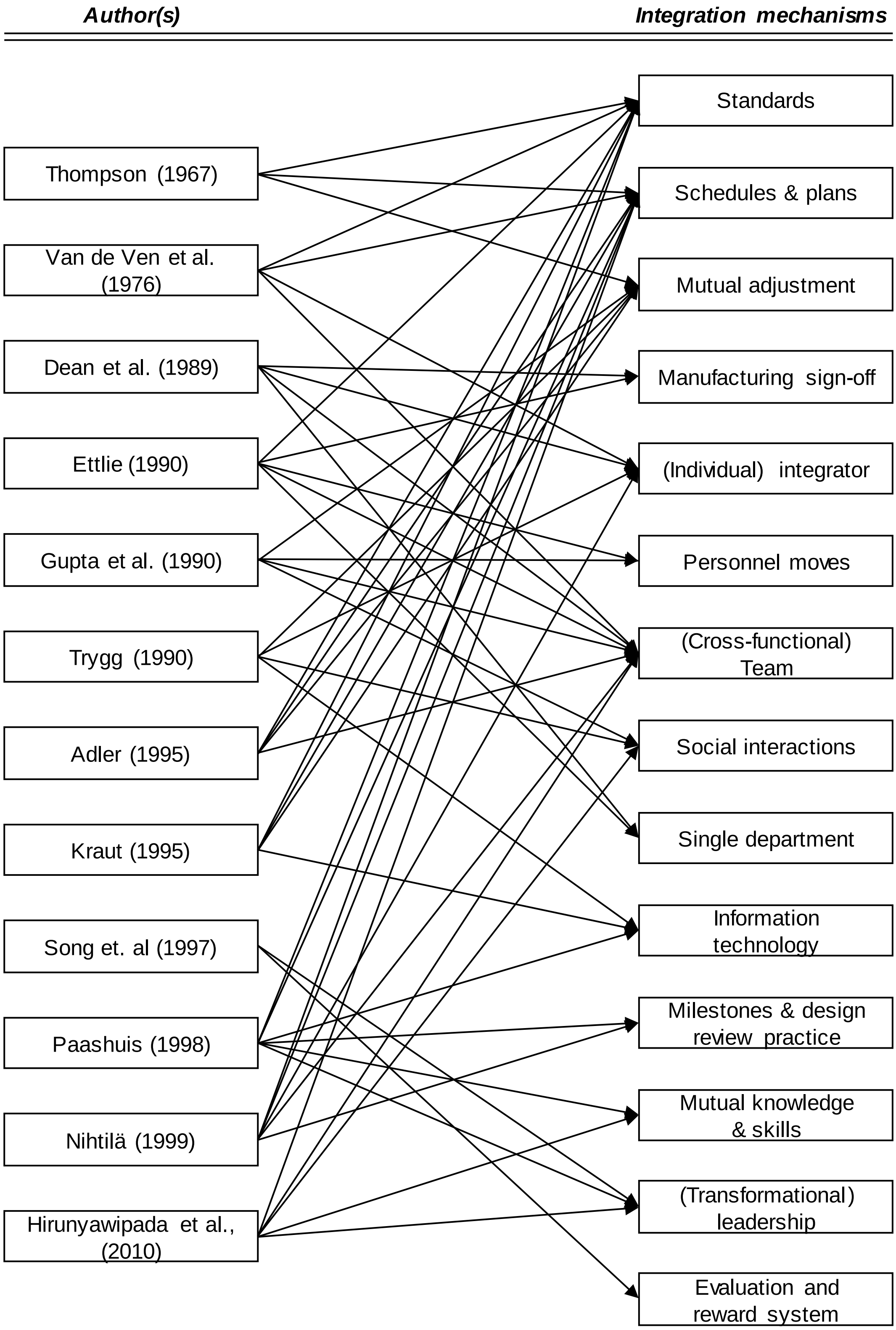

Illustration 13: Integration mechanisms (own illustration building on Nihtilä, 1999, p. 59)

Illustration 13 presents overlaps and differences in integration mechanisms suggested by the respective authors. Therefore, mechanisms where many nodes end are comparatively often mentioned, while others have only one or two authors promoting them. While most of the integration mechanisms are self-explanatory, some interesting connections and interdependencies shall be touched upon in the following. *Standards* as well as *schedules & plans*, including design rules (Trygg, 1991), timeline planning and formalized coordination, constitute the backbone to support the emergence of cross-functional integration. *Mutual adjustments*, meaning responsiveness to other functions' demands or wishes, e.g. design changes induced by manufacturing, are closely related to *manufacturing sign-off*. The latter simply represents a formalized point in time where manufacturing can ask for an adjustment without having to wait for R&D to come up with a consultation in a more mutual or spontaneous way. *Integrators*, *personnel moves*, *teams* and *social interactions* all focus on social mechanisms to generate cohesion between functional units. *Integrators*, i.e. particularly capable individuals with experience and credibility in all involved functions, appear to be particularly important in early integration phases to break the ice between the involved functions (Nihtilä, 1999). *Personnel moves*, e.g. through job rotation programs, may help to create integrators in the first place. *Mutual knowledge & skills* are identified to be important mechanisms as they help to spur discussion at eye level between cross-functional counterparts and enable empathy for mutual requirements (Paashuis, 1998; Hirunyawipada *et al.*, 2010). Albach (1994, p. 136) and Womack *et al.* (2006, p. 129) hint into the same direction, when they describe the advantages of many Japanese organizations over European and American ones: Because Japanese development engineers need to spend up to two years on the shopfloor, they do not only retain personal connections but likewise internalize the shopfloor's requirements in their later design.

2.2.2.2 Integrated models of NPD

In the following, three integrated models of NPD will be presented. In contrast to the rather singular and unconnected integration mechanisms, they constitute coherent models to support cross-functional integration in a NPD context. Still, they borrow elements from management and organizational theory and partially even build up on each other, which is the case for Schmidt-Tiedemann's (1988) triple helix model and Albach's (1992, p. 15 ff.) rugby-team model.

The rugby-team model

Theoretically anchored in innovation interface management theory, Albach (1992, p.16) summarizes sequential models of NPD in an illustrative sports metaphor, the relay-race model of new product development (see illustration 14). Alluding to the baton of a relay-race, Albach describes how information is passed downstream to the next function. While these sequential models are cost efficient, their linear character limits efficiency and effectiveness.

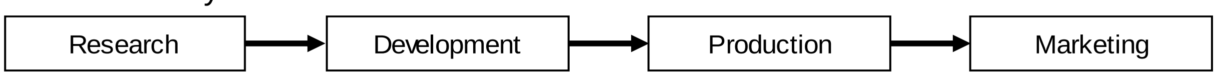

Illustration 14: The relay-race model according to Albach (1992, p. 16)

Albach (1992, p. 15 ff.) introduces another model that is planar in nature and builds on central coordination, the committee model (illustration 15). Due to its many linkages and high coordination requirements, the committee model is likely not an empirically favoured model.

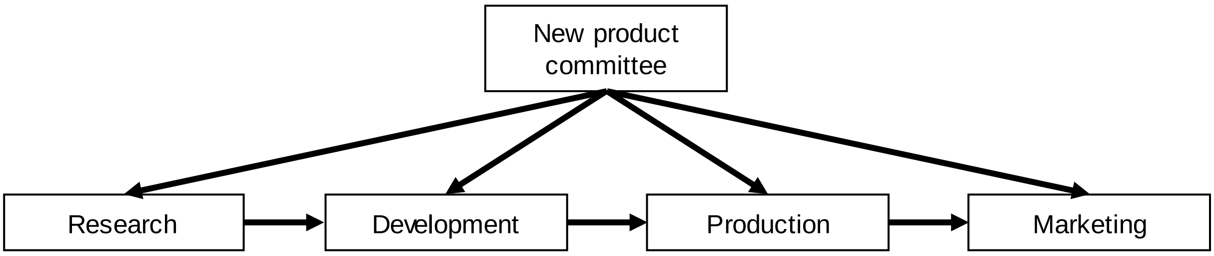

Illustration 15: The committee model according to Albach (1992, p. 16)

As a third generic model, Albach introduces a coupling model containing feedback loops to link functions. It is designated as rugby-team model, because information is not strictly passed forwards but thrown back and forth between players like a ball in a rugby match, with design taking place concurrently. Process speed is increased as well as greater consistency and integrity of the product is ensured; early concerns and requirements from all departments can easily be taken into consideration (von Stamm, 2008, p. 52; Albach, 1992, p. 15 ff.) .

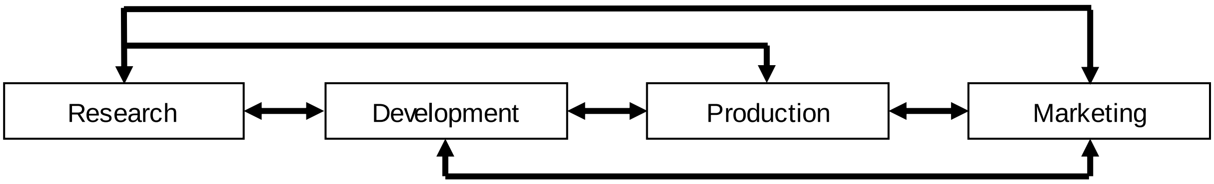

Illustration 16: The rugby-team model according to Albach (1992, p. 16)

All three models solve the integration problem very differently, with required linkages *L* being dependent on the number of functional units *n* involved:

Relay-race model: $L = n - 1$
Committee model: $L = 2n - 1$
Rugby-team model: $L = \frac{n}{2}\,(n - 1)$

Although Albach (1992, p. 15 ff.) does not recommend one model in particular, referring to their different advantages that may come into play depending on the respective context, the rugby-team model is considered as the only truly integrated model and as a generic blueprint for integration of new product development that is connected to approaches of concurrent engineering and integrated product development (Lühring, 2006, p. 2).

The triple-helix model

Schmidt-Tiedemann (1988) develops an approach for integration in NPD that blurs functional boundaries to a certain degree. While other models rely on separate functional units that are to be interlinked more or less closely, Schmidt-Tiedemann

(1988) proposes so-called “concomitants”, specialized fields that are in a constant state of mutual exchange and information transfer. He distinguishes three concomitants that vaguely reflect tasks of R&D, marketing and production: the *creative strand* (research, pre-development, process development), the *productive strand* (product and operating resource development, production) and the *distributive strand* (marketing, distribution, logistics). As the naming suggests, the strands are to work more as strands of the same thread than as separate units.
Accordingly, Schmidt-Tiedemann (1988) designates his model “concomitance-model”, using the illustration of a triple-helix to represent the concurrent cooperation of the three involved strands. Secondary literature addressing his model coins the general conception “triple-helix model”, which will be followed in the terminology of the study at hand.

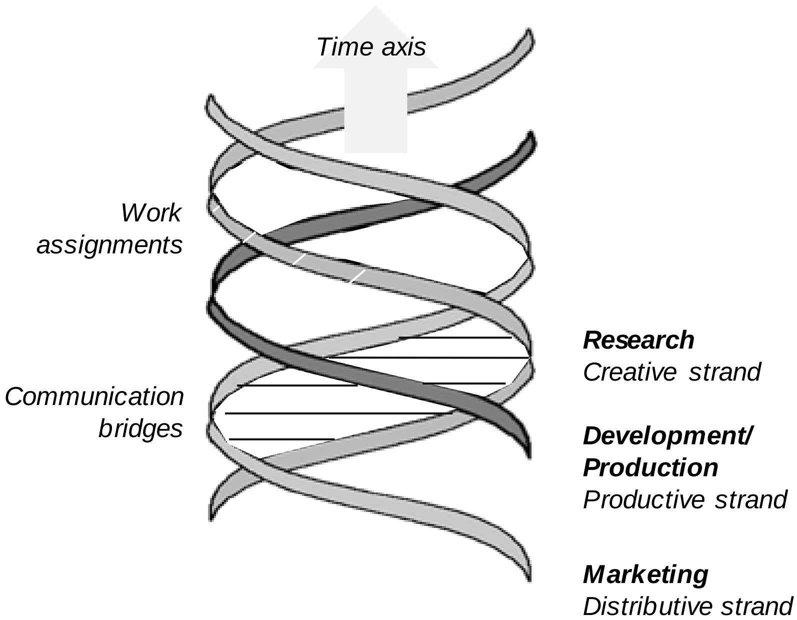

Illustration 17: Schmidt-Tiedemann’s (1988) triple-helix model based on Albach (1994, p. 207)

Just as the nucleobases are central to the DNA double helix, *communication bridges* are essential in the triple-helix model of integrated NPD. They enable the constant interchange of information and influence between the strands and allow for reduced development time and enhanced efficiency. In an organizational setting, communication bridges may be represented by decision committees or working groups (Albach, 1994, p. 206).

Albach (1994, p. 206) concludes that the triple-helix model integrates central features of his relay-race and rugby-team models. Similarities include in particular the communication bridges, which are to resemble the rugby-team model’s communication overlaps between different functional units, which is achieved through manifold feedback loops.

Heavy-weight project management structures

In the 1980s, Japanese cars were introduced to Western markets and were received with astonishment for their high quality at low price levels, which European and American cars could not reproduce. Clark and Fujimoto (1991, p. 71 ff.) embarked on a research project comparing European, American and Japanese car manufacturers to find out how this was possible. According to their results, the Japanese companies were able to develop their products in significantly less time, saving engineering efforts while retaining high quality levels. Clark and Fujimoto (1991, p. 71 ff.) found that to large parts, this was made possible by virtue of a special kind of matrix project organization featuring heavy-weight project managers (Clark and Wheelwright, 1992, p. 274 ff.; Grosse, 2009, p. 71).

Illustration 18 shows the four types of development organizations that Clark and Fujimoto (1991, p. 254) encountered and analysed. In the functional structure (1), development efforts are performed within functions, each coordinated by their functional manager. The light-weight product manager (2) coordinates all functional units with the help of liaison people, though her impact is limited. In (3), a heavy-weight product manager has strong impact over all functions, using it to direct all work and to integrate functional efforts. Structure (4) resembles an autonomous product team, where a heavy-weight product manager coordinates a team whose members are outsourced from their respective functional units and spatially co-located (Fujimoto, 2000; Clark and Wheelwright, 1992, p. 274 ff.).

Clark and Fujimoto (1991, p. 254 ff.) find that development organizations (3) and (4), both featuring a heavy-weight product manager setup, achieved the highest performance in all measured categories of NPD performance (lead time, productivity and product integrity). They explain this discovery with the special role of the heavy-weight product manager, who unifies the roles of a powerful project coordinator and a concept creator (Clark and Wheelwright, 1992, p. 285-287).

Clark and Fujimoto’s (1991, p. 254 ff.) approach hence provides a suggestion for the organizational structure of NPD, which is bound to achieve optimal results through a both effective and efficient way of integrating functional units. In addition, they offer guidelines how a heavy-weight product manager should be selected, advising for certain professional experiences and individual traits that may be referred to in the pertinent literature.

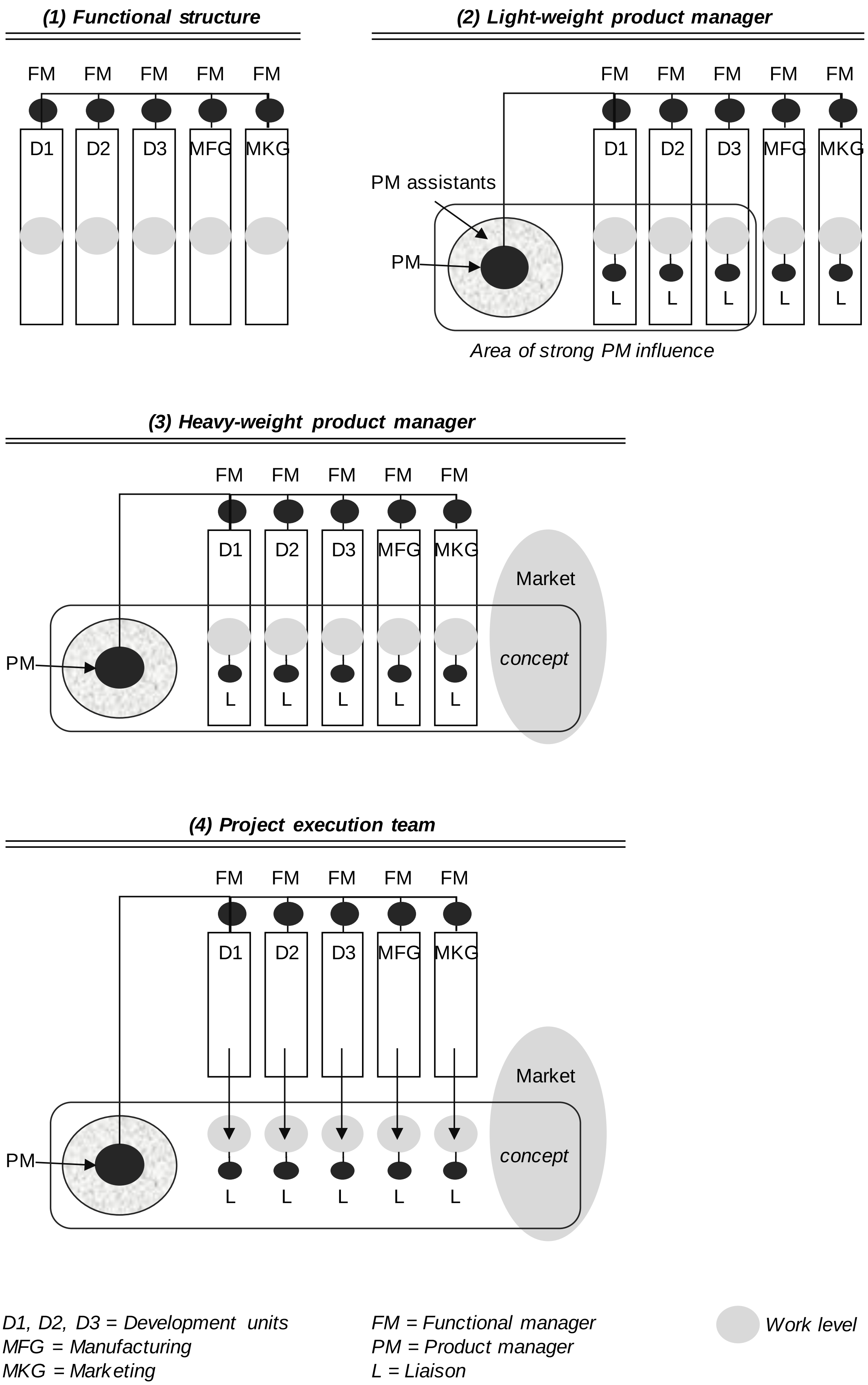

Illustration 18: Development organizations based on Fujimoto (2000, p. 31)

2.3 Overview of empirical research on effects and contingencies of cross-functional integration in NPD

There is an extensive empirical research body that examines cross-functional integration's effects with regard to different contingency factors and constellations. The examined aspects range from different NPD phases and involved functions up to different industrial contexts and mediating or moderating factors. As will be outlined in the following chapter, empirical results show under which circumstances cross-functional integration is fruitful, ineffective or even harmful to NPD success; depending on both examined circumstances and on researcher-dependent factors such as how the examined items are measured and conceptionalized. Consequently, the detailed analysis of existent studies is an important groundwork for this thesis in order to be able to carve out potential result ambiguity and resulting research gaps.

Applicable studies have been systematically analysed with regard to their scope, methodology and sample, involved functional units, NPD success measurements, cross-functional integration measurements, existence of moderators or mediators and finally, results. All details of the structured analysis can be found in Appendix A, a short summary thereof is provided in tables 2, 3 and 4.

Three groups seem to emerge from the entire set of applicable studies, with a first group broadly developing the research field (table 2), a second group deploying comprehensive empirical efforts to explore the effect of moderators and mediators (table 3), and a third group (table 4) specifying singular relationships or moderating/mediating effects. In all analysed studies, the impact of the independent variable cross-functional integration on the dependent variable NPD success was examined. The respective result is summarized by a "(+)", i.e. a positive impact, "(-)", i.e. a negative impact. If a moderating factor was found, it is summarized by "dep. on".

Relationship between cross-functional integration and NPD success

	Methodology/ sample	Functional units	Moderators/ Mediators	Result
Olson et al., 1995	Quantitative survey data/n=45	3	Product innovativeness Formalness of coordination	(+) dep. on product innovativeness, formalness of coordination
Kahn, 1996; Kahn and Mentzer, 1998	Quantitative survey data/n=514	3		(+) dep. on integration manifestation
Song et al., 1997	Quantitative survey data/n=598	3		(+)
Song and Parry, 1997	Quantitative survey data/n=788	3		(+)
Langerak et al., 1997	Quantitative survey data/n=103	3	NPD phase Competitive environment	(+) dep. on competitive environment
Sherman et al., 2000	Quantitative survey data/n=65	3		(+)
Lovelace et al., 2001	Quantitative survey data/n=43	Unspecified		(no impact found)
Frishammar and Ake Horte, 2005	Quantitative survey data/n=206	Unspecified		(+) dep. on integration manifestation

Key: Functional units "3" means R&D, Marketing and Production, "2" means R&D and Production

Table 2: Empirical studies on the impact of cross-functional integration on NPD success (part 1)

The first group (table 2) develops the research field of analysing the impact of cross-functional integration on NPD success in a more general way, measuring the general impact and exploring central contingency factors such as NPD phase, product innovativeness (Olson *et al.*, 1995; Langerak *et al.*, 1997) and external environment (Langerak *et al.*, 1997). Different forms of integration, be it different manifestations such as in Kahn (1996) or different functional pairings (see Sherman *et al.*, 2000) are found to have very different impacts on NPD success. Song *et al.* (1997) examine organizational antecedents in addition to consequences, finding that internal antecedents influence the degree of cross-functional integration while external ones do not. Methodological shortcomings include the rather vague measurement of NPD success by Kahn (1996), only comprising a single item, Sherman *et al.* (2000) excluding incremental innovations from their scope and Frishammar and Ake Horte (2005), who largely reconfirm Kahn's (1996) result, but neglect a specification of involved functional units.

Comprehensive exploration of moderators and mediators

	Methodology/ sample	**Functional units**	**Moderators/ Mediators**	**Result**
Song et al., 1998	Quantitative survey data/n=236	3	NPD phase	(+/-) dep. on NPD phase, functional unit
Kahn, 2001	Quantitative survey data/n=156	3	NPD phase	(+) dep. on functional unit
Olson et al., 2001	Quantitative survey data/n=34	3	NPD phase Product innovativeness	(+/-) dep. on product innovativeness, NPD phase, functional unit
Vandevelde and van Dierdonck, 2003	Quantitative survey data/n=53	2	Product complexity Product innovativeness	(+)
Troy et al., 2008	Meta-analysis of quantitative survey data	Mixed	7 management-controlled 2 researcher-controlled 3 contextual	(+) dep. on many moderators
Brettel et al., 2011	Quantitative survey data/n=118	3	NPD phase Product innovativeness	(+) dep. on NPD success measure, functional unit, NPD phase

Key: Functional units "3" means R&D, Marketing and Production, "2" means R&D and Production

Table 3: Empirical studies on the impact of cross-functional integration on NPD success (part 2)

Building on the majority of studies from the first group affirming a positive impact of cross-functional integration on NPD success (with the exemption of Lovelace *et al.* (2001) under very different conditions), a second group of researchers sets off to yield clarity through comprehensive research covering a large number of different aspects, largely between 1998 and 2011. They focus on differences of the relationship due to its dependence on the NPD phase (Song *et al.*, 1998; Kahn, 2001; Olson *et al.*, 2001; Brettel *et al.*, 2011) and on product specifications such as innovativeness or complexity

(Olson *et al.*, 2001; Vandevelde and van Dierdonck, 2003; Brettel *et al.*, 2011). Most of this group's studies examine specifically the different involved functional units and clearly specify them. However, none of the studies brings ultimate clarity about a positive, ineffective or even detrimental effect of integration on NPD success depending on very specific patterns regarding the NPD phase or the involved functional pairings. Naming just a few examples shows a certain level of ambiguity of the results: Kahn (2001) finds a positive impact for all phases, but also discovers that the interrogated R&D managers do not perceive any positive impact in any phase. Brettel *et al.* (2011) find the integration between marketing and R&D positive for NPD efficiency, but not for NPD effectiveness, both likewise depending on NPD phase and product innovativeness; for other functional pairings they receive again very different results. Olson *et al.* (2001) find higher NPD performance for manufacturing/marketing and R&D/manufacturing integration, but only for late stages and only for innovative products, while manufacturing/marketing integration in early stages is found even negative for innovative products but positive for non-innovative products.

Troy *et al.* (2008, p. 132) "attempt to bring clarity" to ambiguous results by performing a meta-analysis of 25 different quantitative studies with a total of 146 correlations including manifold mediators, moderators and contingency variables. Nevertheless, their study confirms just a general tendency of integration having a positive impact on NPD success, while all the aspects on which this impact is dependent "may be of greater importance" (Troy *et al.*, 2008, p. 132). Their findings summary speaks for itself: "Findings from our study provide evidence that the relationship between cross-functional integration and new product success is indeed complicated" (Troy *et al.*, 2008, p. 140).

Relationship specification

	Methodology/ sample	Functional units	Moderators/ Mediators	Result
Nakata et al., 2006	Quantitative survey data/n=259	3	New product advantage	(+) dep. on new product advantage
Luca and Atuahene-Gima, 2007	Quantitative survey data/n=363	Unspecified	Knowledge integration mechanisms	(+) dep. on knowledge integration mechanisms
Engelen et al., 2012	Quantitative survey data/n=619	Unspecified	National culture, Corporate culture	(+)
Graner and Mißler-Behr, 2014	Quantitative survey data /n=400	Unspecified	NPD method application	(+)
Tsai and Hsu, 2014	Quantitative survey data/n=182	3	Competitive intensity	(+) dep. on competitive intensity
Nafisi et al., 2016	Qualitative case study/n=1	3		Involvement of manufacturing engineers in NPD difficult
Cho et al., 2017	Quantitative survey data/n=189	Unspecified	International orientation	(+)

Key: Functional units "3" means R&D, Marketing and Production, "2" means R&D and Production

Table 4: Empirical studies on the impact of cross-functional integration on NPD success (part 3)

The third group of studies (table 4) includes rather recent studies from 2006 to 2017. They step away from a comprehensive approach and examine individual relationships or aspects that may impact the relationship between cross-functional integration and NPD success. The scholars in this group explore mediating roles of new product advantage (Nakata *et al.*, 2006), defined as "a product's perceived superiority relative to competitive products" (Song and Montoya-Weiss, 2001, p. 65), knowledge integration mechanisms (Luca and Atuahene-Gima, 2007), NPD method application (Graner and Mißler-Behr, 2014) or the moderating effects of national and corporate culture (Engelen *et al.*, 2012), competitive intensity (Tsai and Hsu, 2014) and international orientation (Cho *et al.*, 2017). This third set of studies likewise comprises the only qualitative study in all identified applicable empirical works (Nafisi *et al.*, 2016). Some of the studies present results conflicting with earlier studies. For instance, Engelen *et al.* (2012) cannot confirm Kahn's (1996) insufficient impact of interaction on

NPD success. Others attempt to explain potentially ambiguous earlier results with mediating factors that had been neglected previously. A large part of this third group of scholars does not distinguish between involved functional units, as they often do not even specify which units are covered in their surveys. Cross-functional integration is for the largest part only vaguely measured, often just covering three items on general cooperation in their survey.

As a summary for all analysed studies, the following is valid: There seems to be a positive impact of cross-functional integration on NPD success, however, this is strongly dependent on a large number of aspects that include the environment, involved units, the NPD phase and other mediating or moderating factors. Large efforts have been made by the research community to analyse this relationship in great detail and comprehensiveness. However, results are partially conflicting and often ambiguous in their interpretation. This problem is aggravated by the fact that for many instances, theoretically derived hypotheses have been refuted by empirical results, with theoretical explanations for the results being scarce. There seems to be a lack of understanding for the deeper dynamics of how cross-functional integration impacts NPD performance.

Methodically, the studies lean heavily towards quantitative survey data, with qualitative studies being underrepresented. Furthermore, although many authors confirm the complexity of measuring or even grasping cross-functional integration, the majority of the studies reduces its analysis to just a few survey items. Accordingly, Tsai and Hu's (2014) 12 items are the exception of the typical three to four items. As no countercheck or rebasing has been performed to what survey respondents understand as cross-functional integration, answers from different respondents may vary significantly, and overall results may be difficult to interpret in an objective way. Furthermore, the majority of studies let respondents allow for any NPD project to choose from for answering the survey, which again may distort results by implementing a selection bias. Lastly, although pertinent literature advices that "soft factors" such as organizational or human behaviours impact cross-functional integration to a large extent, only a few empirical studies have included such aspects in their research efforts.

3 Theories on coopetition

As a nascent field of research, coopetition, the simultaneous occurrence of cooperation and competition, has received much attention by academics and practitioners alike. Notably, as a preliminary remark on the expression, competition and cooperation as constituents of cross-functional coopetition have a different connotation than in common usage. Typically, coopetition or competition, respectively, characterize a relationship between separate organizational entities, e.g. individual companies. As will be explained in the following, coopetition may occur at this inter-organizational level, but is not limited to it: Other levels in scope include coopetition between company networks, coopetition between individuals and lastly, coopetition between departments within an organization. The latter, coined intra-organizational coopetition, is in focus for the thesis at hand and thus will be explained in particular detail hereinafter.

In the following, the term and its recent importance will be introduced by building on intuitive examples of coopetition in everyday business. Subsequently, a more detailed look into theoretical fundamentals is offered, before particularities of coopetition in a NPD context will be explained. Finally, a detailed perspective on coopetition is taken on a cross-functional level of analysis, such as coopetition between functional departments. This chapter closes with a detailed overview and critical acknowledgement of relevant research studies on cross-functional coopetition.

3.1 Introduction to coopetition

By definition, coopetition is built on a paradox: the "simultaneous existence of cooperation and competition" (Tidström, 2014, p. 261), with exactly this paradox being its key characteristic and certainly an important reason for the seminal academic interest it has received recently. At the core, coopetition is a "hybrid activity" (Walley, 2007, p. 12) and its paradoxical nature makes tensions unavoidable, which allows for a resourceful area of academic pursuit (Bengtsson and Kock, 2000; Bouncken *et al.*, 2015).

With regard to its practical relevance, countless examples make a point for coopetition and serve as explanation why popular management literature had discovered coopetition long before it aroused academic interest (Bouncken *et al.*, 2015). For example, the automotive manufacturers Toyota and General Motors entered in a coopetitive agreement when they decided to jointly develop fuel cell powered cars while remaining rivals with regard to their cars' sale and on other segments (Chin *et al.*, 2008). Likewise, the electronics company Samsung cooperated with its competitor Panasonic to safeguard the supply of LCD (liquid crystal display panels) for its television sets (Ritala and Hurmelinna-Laukkanen, 2009). While these examples occur on an inter-firm level, practical examples of coopetitive behaviour exist on the intra-firm level alike. Strese *et al.* (2016) point towards two internal consulting departments within Shell which, though competing for business, were required to share knowledge and cooperate. Birkinshaw (2001) mentions the electronics manufacturer Ericsson, that had two independent teams develop high-bandwidth technologies in the 1990s. Though being encouraged to promote their own solution, the teams were obliged to share their knowledge for the company's overall benefit. Tsai (2002) includes multiunit organizations as examples for intra-firm coopetition: to tap economies of scope, departments are obliged to cooperate and exchange knowledge, while they compete on their rate of return. Luo *et al.* (2006) provide examples, where unbalanced intra-firm coopetition leads to business failure. Accordingly, food manufacturer Barilla SpA failed in installing a just-in-time distribution system, as their marketing and sales department obstructed knowledge transfer to the operations department.

Commonly, three pieces of work are attributed to have launched coopetition as an academic topic: With the term coopetition having been raised by the former high-tech company Novell's CEO Nadar, it was introduced into strategy research by Brandenburger and Nalebuff in 1996. Subsequently, Lado *et al.* (1997) contributed the first academic analysis, without mentioning the term coopetition at first, but using game theory and the resource-based view to argue that competition and cooperation are not the two ends of a continuum, as which they had been considered for a long time. The third pioneering milestone was provided by Bengtsson and Kock (1999) in presenting four relational models of companies that are assigned depending on relative industry position and need for external resources. One of them was coined as coopetition, next to coexistence, competition and cooperation (Dagnino and Padula, 2011; Yami *et al.*, 2010b; Devece *et al.*, 2017).
Nonetheless, questions arise if coopetition was "just another fashionable concept" (Yami *et al.*, 2010b, p. 1) or another strategic lens to look at well-known strategic phenomena at most, or if it rather represented a "really true revolution in strategic thinking" (Yami *et al.*, 2010b, p. 1). With its theoretical constructs heavily based on existing concepts, coopetition could as well be just an extension of the competitive paradigm or the cooperative paradigm. However, many researchers stand up for coopetition as a stand-alone, and indeed resourceful academic field. They reason that its complex traits and consequences could not be explained by looking at competition or cooperation alone (Yami *et al.*, 2010b).

With the number of publications pertinent to coopetition being on a constant rise, this view seems to hold true. Today, the research field exhibits methodical broadness on a variety of levels of analysis. The authors of two comprehensive literature reviews (Bengtsson and Kock, 2014; Devece *et al.*, 2017) add a notion that might substantiate the current hype on coopetition. According to them, the increase in today's business dynamics, market uncertainty and complexity make coopetitive strategies attractive for firms. The former reliance on internal resources shifts increasingly towards a networking view, which also makes use of external resources and focusses on a company's ability to integrate those. Eventually, intelligent use of available resources within and outside the own organization might be a successful strategy to cope with greater competitiveness, shorter product life cycles and higher innovation pressure (Gnyawali and Park, 2011).

3.2 Theories on coopetition theory

3.2.1 Theoretical predecessors

"Like any theoretical concept designed to capture a complex reality in the social sciences, coopetition has been interpreted in numerous ways within different theoretical frameworks" (Devece *et al.*, 2017, p. 4). The lowest common denominator herein is always the simultaneous occurrence of competitive and cooperative structures. Quite unsurprisingly, phenomena that meet this approximate specification have existed and indeed been studied before the term coopetition was coined. Incidences, where two competitors have joined forces to withstand innovation pressure or reduce time-to-market, had been analysed from either a competitive or cooperative point of view, see for example Hamel *et al.* (1989). For a long time, these two views were firmly cemented in what is called the cooperative or the competitive paradigm - seldom, the dynamics of interaction of those views were given attention.

The competitive view focusses on a firm's interdependence both in their horizontal and vertical market relationships, suggesting an individual interest search that shuns away from cooperation, based on the belief that competitive success is a zero-sum game where one company's gain is the other's loss. Building on a strong neoclassical position, market relations are seen as discrete events of economic exchange. The competitive paradigm dominated the literature on strategic management almost unrivalled until the 1980s, emphasizing strategic behaviour against rivals to optimize the own relative market position (Bouncken *et al.*, 2015; Dagnino and Padula, 2011).
The cooperative view, on the other hand, focusses on the organization's relational capability as its core competitive advantage. At the turn of the decade towards the 1990s, the cooperative view increasingly drew attention in strategic management, likewise fuelling organization management, with its strong emphasize on relational networks between firms that pursue common interests and create a collaborative advantage (Yami *et al.*, 2010b; Johansson, 2012). Within this paradigm, the market cedes to be an atomistic arrangement of instant exchange, but it can be conceptualized as a system of continuous relations where "the firms progressively strengthen their reciprocal commitments and realize a process of mutual adaptation and joint value creation" (Dagnino and Padula, 2011, p. 8).

As mentioned above, a joint perspective of these two relational views emerged with the seminal works of Brandenburger and Nalebuff (1996), Lado *et al.* (1997) and Bengtsson and Kock (1999). Illustration 19 pictures how Lado *et al.* (1997, p. 21) imagined the joint perspective of a cooperative and competitive rent-seeking behaviour as "syncretic behaviour", coined as coopetition by other scholars in this emergent field.

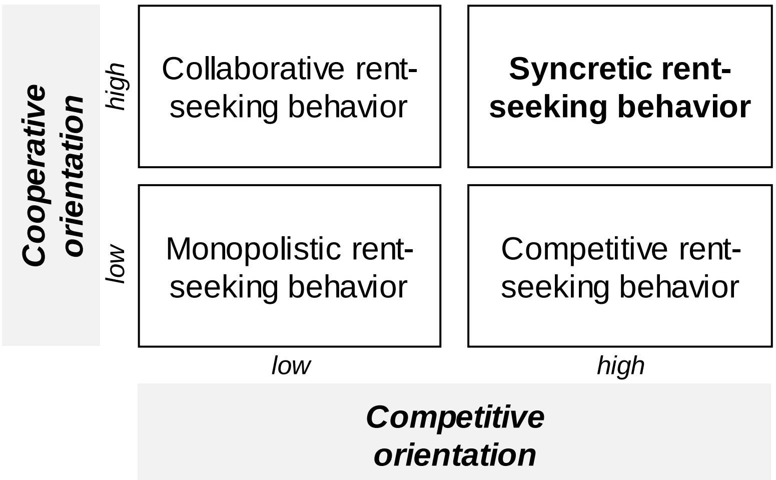

Illustration 19: Syncretic model of rent-seeking strategic behaviour based on Lado et al. (1997, p. 119)

To substantiate coopetition's theoretical foundations, researchers draw on different theoretical viewpoints, with game theory, the resource-based view, social network theory and strategic alliances being the prevalent approaches. They will be introduced with regard to their explanatory power for coopetitive behaviour in the following.

Game theory and the related strategic games emerged as one of the earliest explanations for coopetition, though not remaining the prevalent one (Devece *et al.*, 2017). It recognizes coopetition as a win-win relationship in a mixed strategy game where the players' interests are neither absolutely congruent nor opposed. Game theory provides not only a conceptual framework to explain coopetitive behaviour, but also allows for mathematical modelling to calculate an optimal strategy. However, due to its limited explanatory power for interpersonal relationships, it remains with limited applicability for coopetition (Ghobadi, 2012; Bengtsson and Kock, 2014). For some applications, refer for example to Loebecke *et al.* (1999), Gnyawali *et al.* (2008) or Clarke-Hill *et al.* (2003).

The resource-based view argues that firms, to achieve a better competitive position, should develop and exploit unique and non-transferable resources in collaboration with others or gain access to complementary and otherwise non-accessible resources by joining forces with competitors. Applications of the resource-based view may be found in Quintana-García and Benavides-Velasco (2004), Ritala and Sainio (2013) or Mention (2011).

Social network theory emphasizes the importance of cooperative ties within a network, even if they occur between competitors, to explain coopetitive behaviour: Accordingly, advantages from cooperation outweigh disadvantages that may result from engaging in relation with competing actors. Learning and knowledge sharing as well as the joint development of a collaborative advantage are essential features. To explain cooperation on a cross-functional or intra-firm level of analysis, social network theory is helpful, in particular the strength-of-ties concept and social embeddedness (Strese *et al.*, 2016; Luo *et al.*, 2006; Devece *et al.*, 2017). For applications within coopetition, Luo *et al.* (2006), or Gnyawali and Madhavan (2001) serve as examples.

3.2.2 Definitions of coopetition

As it is the case with the theoretical approaches to explain coopetition, the definitions of coopetition likewise span a broad range of interpretations, with the most frequently noted theme being the simultaneous occurrence of competition and cooperation. In this vein, Tidström (2014, p. 261) summarizes: "Coopetition is defined as the simultaneous existence of cooperation and competition […] and it can be found at intra-organizational […], inter-organizational […] or individual level". Other authors insinuate the merging perspectives of the competitive and the cooperative paradigm, for example Dagnino and Padula (2002, p. 33), who hint at a coopetitive value system that emerges from joining the perspectives: "The coopetitive perspective stems from the acknowledgment that, within inter-firm interdependence, both processes of value creation and value sharing take place, giving rise to a partially convergent interest (and goal) structure where both competitive and cooperative issues are simultaneously present and strictly interconnected. They give rise to a new kind of strategic interdependence among firms that we term coopetitive system of value creation".

In their search for a suitable definition, many researchers admit that there cannot be a consensus on a common definition as long as the phenomena that are described as coopetition are so diverse in their individual dynamics and consequences. Bengtsson and Raza-Ullah (2016) hint at the various levels on which coopetitive behaviour materializes and on which it takes very distinctive but different shapes.
There are a few definitions that handle this difficulty of finding consensus by limiting the applicability of their definition to a particular level of analysis. As an example, Peng *et al.* (2012, p. 532) confine their definition to the inter-firm level as "cooperation with competitors in which they compete in the same market and cooperate in other areas". Bengtsson and Kock (2000) cover a similar scope when describing coopetition as a situation whereby two organizations cooperate in activities such as R&D or procurement while competing in activities such as sales. Other scholars take the opposite approach and enlarge or generalize their definitions to fit a broader scope of applications. For instance, Luo (2005, p. 72) notes: "Coopetition is a mindset, process, or phenomenon of combining cooperation and competition. It means cooperating to create a bigger business pie, while competing to divide it up". In a similar manner, Bengtsson and Kock (2014, p. 180) suggest to widen up earlier definitions of coopetition by stating that "coopetition is a paradoxical relationship between two or more actors, regardless of whether they are in horizontal or vertical relationships, simultaneously involved in cooperative and competitive interactions".

3.2.3 Levels of analysis and conceptualization of coopetitive behaviour

With both definitions and theoretical approaches differing so strongly with regard to the level of analysis, it is imperative to introduce and explain what those levels comprise. Furthermore, the thesis at hand refers to a particular level of analysis in its empirical part, namely the cross-functional or intra-firm level of analysis.

Again, there are different ways of structuring the different levels that find acceptance in prevalent literature. This thesis follows Dagnino and Padula (2002), Strese *et al.* (2016) and Yami *et al.* (2010a) in distinguishing three interdependent levels: The macro level comprises relationships between countries or firm clusters and networks, the meso level covers interactions between individual organizations and the micro level deals with relationships within an organization, be it between departments or subunits (micro level I) or between individuals (micro level II). The latter is also designated intra-organizational coopetition, while macro and meso levels together make up inter-organizational coopetition. In this thesis, the intra-organizational level is likewise denominated cross-functional coopetition, with the terms being used interchangeably.

Levels	**Coopeting actors**	
Macro level	Networks and alliances, clusters of firms, countries	*Inter-organizational*
Meso level	Individual organizations (horizontal), Buyers / suppliers (vertical)	
Micro level I	Departments or subunits within an organization	*Intra-organizational*
Micro level II	Individuals, e.g. in a team setting	

Illustration 20: Levels of analysis in coopetition adapted from Dagnino and Padula (2002, p. 36)

Another frequently quoted level structure is illustrated in Bengtsson and Raza-Ullah (2016), who distinguish between an intra-firm level, different dyadic levels applying to two organizations either in a horizontal or vertical relationship, a triad level between three organizations, different network levels within firm clusters or eco-systems and finally an inter-network level between different networks of firms.

According to a majority of researchers, the best researched level of analysis is the meso level, where cooperation between competing firms is explored. In particular, micro level I is frequently called underresearched.

Besides the different levels of analysis, some scholars suggest different ways of how to conceptionalize the body of research in coopetition. The comprehensive literature review of Bengtsson and Raza-Ullah (2016) suggests the division into two schools: An actor school of thought, defining coopetition in a broad sense as a value net of actors, and an activity school of thought, which concentrates on individual activities or relationships within the broader network context. However, the authors admit that the proposed division works best, if not only, for the inter-organizational level. For the intra-organizational level, a value net, as it has been considered in the actor school of thought is unlikely to emerge within organizations as they are framed by their organization's common guidelines. In addition to that, a singular consideration of specific activities or relationships as required by the activity school of thought is difficult to observe in organizations, as relevant studies mostly discuss multiple involved individuals or subunits and make (bi-)lateral relationship identification difficult (Bengtsson and Raza-Ullah, 2016).

3.2.4 Antecedents, risks and benefits of coopetitive behaviour

As coopetition is a relatively new research area, many fundamental questions around antecedents and consequences of coopetitive behaviour are still being analysed. In the following, current hypothesizing on organizational, external and psychological antecedents, as well as benefits and risks arising from coopetition will be presented.

In their comprehensive DPO (drivers-process-outcomes) model of coopetition, Bengtsson and Raza-Ullah (2016) structure antecedents of coopetition as follows. A first group comprises external drivers that stem from market or industry characteristics, e.g. industrial characteristics, technological demands or influential stakeholders. A second group encompasses relational drivers, which cover partner characteristics and relationship characteristics and are therefore rooted in the relational specificities towards one or more coopetitive actors. A last group includes internal drivers, which emerge within the coopeting network, organization, unit or individual and comprise internal goals and capabilities, prospective strategies and perceived vulnerability.
Strese *et al.* (2016) examine this last group in more detail: in an empirical study, they identify organizational antecedents of coopetition. According to their results, leadership styles that take care of participation or consideration both favour the emergence of coopetition. Regarding the organizational structure, they find that centralization has a negative impact on coopetition while formalization has a positive impact.
Loch *et al.* (2006) take yet another perspective and analyse psychologic algorithms to show that the dynamics of coopetition are deeply entrenched in the human psyche due to evolutionary reasons. Drawing on evolutionary psychology, they find that two basic emotional algorithms decide over a fundamental dilemma of individual actors in human groups: taking care of "me" (competing) or taking care of "we" (cooperating). Finding that the analysis of the algorithms in isolation does not allow to understand its systematic properties, they take a comprehensive perspective: "a holistic account of competitive and cooperative algorithms suggests that the 'dilemma' of competition versus cooperation is not really a dilemma at all […] In general, balancing emotional

algorithms were favoured because competitive or cooperative algorithms working in isolation would have been disadvantageous“ (Loch *et al.*, 2006, p. 229). As a consequence, there is an evolutionarily founded psychological incline to embrace coopetition: “[…] there is perhaps a common tendency to grasp and acknowledge that humans do better where striving and competitiveness are joined by cooperativeness” (Loch *et al.*, 2006, p. 229).

In the following, potential consequences, both positive and negative, are outlined. At first, its potential benefits are drawn on.
In general, research suggests that coopetition leads to better knowledge sharing and quality of shared knowledge, as well as better financial, market and customer performance. In addition, relationship-related outcomes such as organizational learning, relationship maintenance and failure management and commitment are enhanced (Strese *et al.*, 2016; Luo *et al.*, 2006; Ghobadi and D'Ambra, 2012; Tsai, 2002; Bengtsson and Raza-Ullah, 2016). However, the benefits of coopetition differ again with regard to the level of analysis that is taken. On the macro level, coopetition leads to an increase of knowledge and technological capabilities that come from increased communication and knowledge transfer. Economic benefits are attained through less aggressive rent-seeking behaviour that benefits all coopeting partners, e.g. through fund sharing agreements. At the meso level, that is to say between individual organizations, coopetition results in higher R&D investments and workforce training investments with their positive impact on innovation power. Furthermore, faster agreement on standards and reduced time-to-market may result from the cooperation with a competitor. In addition to that, coopetition on the meso level grants access to resources or capabilities that were inaccessible before. This allows to tap economies of scale and scope by combining similar or complementary activities and grants access to new markets. Heavy investments in R&D can be shared, as well as the resulting risks (Gnyawali and Park, 2011). Levy *et al.* (2003) add that in particular for small- and medium sized companies, these aspects make coopetition an attractive strategy, as it enables them to join forces to compete with larger actors. On the micro level, benefits include a better integration between functional areas, leading to efficiency within intra-organizational processes, as well as a generally higher incentive and commitment to work through better internal knowledge creation and better organizational climate (Dagnino and Padula, 2011; Devece *et al.*, 2017; Bengtsson and Kock, 2000; Bouncken *et al.*, 2015).

Potential risks of engaging in coopetition come right as the reciprocal of the outlined benefits. Self-evidently, gaining access to other resources via coopetition means that the coopeting counterpart gains access to own resources equally. Sharing capabilities with a competitor also means forfeiting a competitive advantage over this competitor. In addition to that, managerial complexity and resulting costs are likely to increase when engaging in coopetition (Fernandez *et al.*, 2014; Bengtsson and Kock, 2014). In sum, these risks may result in “continuous risks of unbalanced interactions which in turn might reduce potential gains from coopetition” (Strese *et al.*, 2016, p. 43). Careful management of the resulting tensions to ensure that benefits overweigh risks in coopetition becomes the evident imperative.

Notably, literature on the advantages and disadvantages of coopetition gives priority to advantages from cooperation, while competition is perceived as some kind of necessary evil, which has to be accepted to take advantage of cooperation with competitors. However, a research stream has emerged that adopts a perspective of actively managing both cooperation and competition to draw advantages from both forces. Henceforth, the management of coopetition receives increasing attention from academics and practitioners alike. Often, this builds on a process perspective where cooperation should be intensive in the beginning of a coopetitive engagement, whereas competition should be dominant in later phases. The early phase of cooperative value creation (“making the cake bigger”) should therefore be managed differently than later phases of competitive value capture (“dividing the cake”) (Ritala and Hurmelinna-Laukkanen, 2009; Bouncken *et al.*, 2015). Fernandez *et al.* (2014) outline two general strategies for the management of coopetition. The first, denominated as separation principle, aims at separating cooperation and competition in the best possible way. For inter-firm coopetition, this could be realized by a timely separation as mentioned above, or a personal separation where cooperating individuals differ from the ones that are instructed to deal with the competitive tasks. For intra-firm or individual levels, the separation principle naturally cannot find application. The other principle, the integration principle, strives to reach a maximum of harmony in cooperative relationships. Scholars criticize that integration alone will not solve emerging tensions and it is therefore coined as being insufficient. Fernandez *et al.* (2014, p. 225) argue for a combination of both principles. “[…] an approach combining both the separation and the integration principles would allow more effective management of co-opetitive tensions”.

3.3 Coopetition in a NPD context

“Innovation is one of the most frequently studied dependent outcome variables in coopetition” (Bengtsson and Raza-Ullah, 2016, p. 31). It has to be noted in direct succession, however, that the large majority of research efforts trying to make sense of the relationship of coopetition on innovation or NPD performance take an inter-firm level of analysis. Micro levels I or II are considered in only few exceptions (e.g. Lin, 2007), which will be analysed in more detail later.

Generally, coopetition seems to be positively affecting innovation activities. It helps to overcome knowledge barriers that may refrain firms to engage in innovation. Knowledge sharing under coopetition strongly supports the generation of new knowledge and resulting new products. Furthermore, coopetition decreases risks and investments related to NPD. Therefore, coopetition between firms in NPD may lead to win-win situations with increased sales, market penetration and an improved overall competitive stance (Bouncken *et al.*, 2015; Rodrigues *et al.*, 2011). For small- and medium sized companies in particular, engaging in coopetitive relations allows to overcome investment thresholds and risk-bearing barriers to innovation (Devece *et al.*, 2017). To sum it up, the competitive element within coopetition provides an incentive strong enough to engage in innovation, whereas the cooperative aspect supports innovative activities by facilitating the necessary build-up of knowledge and capabilities (Park *et al.*, 2014).

However, there is a series of studies that present conflicting findings, where coopetition is not as thriving to innovation as other empirical findings might suggest. For instance, Quintana-García and Benavides-Velasco (2004) show that coopetitive relationships of large firms and direct competitors may impede innovation. For a comprehensive list of contradictory findings related to innovation performance, see Bengtsson and Raza-Ullah (2016).

Other seemingly conflicting empirical results can be found when examining whether coopetition favours incremental or radical innovations to a larger extent. Quintana-García and Benavides-Velasco (2004) show that coopeting firms come up with more radical innovations than traditional strategic alliances between non-competitors. On the other side, Ritala and Sainio (2013) suggest that coopetition is rather negatively related to radical innovations. Other studies provide yet more ambiguous findings, see for example Mention (2011) or Bouncken and Fredrich (2012).

Certainly, engaging in coopetition to increase innovation power entails certain risks. Opportunism and know-how leakages are evident possibilities when cooperating with competitors. Expectation of tensions on the long-term relationship between coopeting actors may obstruct their engagement in radical innovations project in the first place (Le Roy and Czakon, 2016; Bouncken *et al.*, 2015).

3.4 Cross-functional coopetition

3.4.1 Definitions and conceptualizations

As the empirical part of this thesis relates to cross-functional coopetition, i.e. coopetition between departments within a firm, its particularities, which may differ from the overall conception of coopetition, will be outlined in the following. The words cross-functional, inter-unit and intra-organizational are used interchangeably.

With regard to its differentiation against cross-functional integration as it is described in chapter 2, there is a row of aspects which distinguishes the two streams of research. First of all, coopetition evidently includes a competitive, rivalry-focused side, which cross-functional integration only implicitly considers, for example as a barrier to integration, but without considering potential positive effects when looking at it in a holistic sense. As will be explained later in more detail, intra-firm coopetition is based on competition on tangible and intangible resources between departments, e.g. budgets, management attention or the enforcement of functional requirements. Secondly, the cooperative strand within coopetition would still not directly correspond to cross-functional integration, although it is of course related in subject. Coopetition takes a much broader view of collaboration then merely connecting functional partners for the greater good of an entrepreneurial endeavour. Nonetheless, the author is convinced of the explanatory power that coopetition may have for questions of cross-functional integration, which is why the two topics are connected in the empirical part of the thesis at hand.

Intuitive examples have proven the relevance of coopetition, likewise on an intra-firm level, long before the actual term had been coined. For instance, Walley (2007) points towards cross-functional cooperation between production, marketing and finance to manufacture a product, which at the same time compete for access to financial resources in their budgeting process. Literature has recognized this “double-edged sword nature of interdepartmental interaction” (Ghobadi, 2012, p. 34) long before coopetition as a research field came into existence. This translates into the same paradox that shapes other levels of coopetition as well: though they need to cooperate to be successful, business units as well as individuals on the same team are competing for resources, status or knowledge. Hence, the coopetitive paradox is likewise existent on micro levels I and II.

Following the provided characterization, cross-functional coopetition may be considered as generic, as any given organization is likely competing for budgets and sharing knowledge in some form or another. However, relevant research has shown that analysing coopetitive behaviour indeed provides answers to yet unexplained phenomena (e.g. Chin *et al.*, 2008; Luo *et al.*, 2006; Yami *et al.*, 2010b). Accordingly, coopetition’s explanatory power lies in its application to a specific question, and less in a high-level examination of an organizational entity: For the latter, coopetition is presumably present in one way or another. For a more specific question, the mere existence, manifestation or degree of coopetition can differ and can thus be insightful for research. Indeed, research on antecedents of cross-functional coopetition (as an example, see Strese *et al.*, 2016) shows that the emergence of intra-firm coopetition depends on certain organizational and leadership aspects, thus refuting a purely generic existence of coopetition.

Tsai (2002) postulates an according characterization, defining cross-functional coopetition as simultaneous cooperative and competitive behaviours across organizational units. Devece *et al.* (2017) complement this notion by adding coopetitive behaviour across teams and individual units to cover micro level I under the term of cross-functional coopetition. Indeed, the interplay of several levels within cross-functional coopetition is interesting. From a superior level, actors within an organization are obliged to follow goals and structures defined by the organization. On an individual level, however, things can turn out differently. Actors follow their own motivation and rules for interaction may change with regard to different organizational sub-cultures (Allal-Chérif and Bidan, 2017; Poulsen, 2001). This substantiates why a social network perspective and organizational aspects become particularly important explanatory approaches.

Luo (2005) investigates intra-firm coopetition of departments that differ in their level of competition and cooperation (illustration 21). These forms allow to predict a department's behaviour in a coopetitive situation. According to his study, four types of cooperation in inter-unit coopetition materialize: Technological, operational, organizational and financial coopetition, which are determined by three drivers: strategic interdependence, subunit form and technological linkage. Three forms of competition in inter-unit coopetition emerge: Competition for parent resources and support, competition for system position and competition for market expansion, which for their part are driven by local responsiveness, market overlap and capability retrogression.

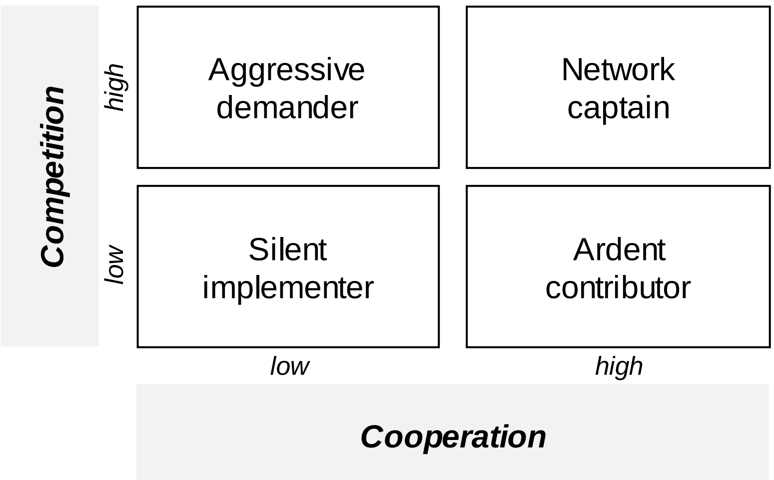

Illustration 21: Typology of inter-unit coopetition based on Luo (2005)

3.4.2 Dimensions of cross-functional coopetition

In their influential study of 2006, Luo *et al.* define three dimensions of cross-functional coopetition which recur in a large number of studies engaging in research on cross-functional coopetition: *cooperative ability*, *cooperative intensity* and *competition*. Hereby, Luo *et al.* split up the cooperation side of coopetition in two strands, ability and intensity, which recalls a similar split up that Kahn (1996) executed on manifestations of cross-functional integration: He distinguished between *integration*, representing the mere frequency of interaction and *collaboration*, which comprises a more intangible side of integration that aims at the ability of understanding and adapting to the cross-functional counterpart. As is to be seen in the following, Luo *et al.* (2006) take a similar perspective. All three dimensions will be explained in more detail in the following.

3.4.2.1 Cross-functional cooperative intensity

Luo *et al.* (2006, p. 72) define cross-functional cooperative intensity as “the extent of the frequency and closeness of the lateral social interactions among functional areas within the firm”. As sources of the construct, they cite Antia and Frazier (2001) and Rindfleisch and Moorman (2001). Frequency of interaction is able to enhance the transfer of complex knowledge as well as improve communication between functions. Cooperative intensity may likewise open the path to mutual recognition of market knowledge to help improve overall company outcomes. Furthermore, Strese *et al.* (2016) complement that cooperative intensity can be influenced relatively well by leadership behaviour and organizational structure, which makes it an important lever to create cross-functional cooperation within an organization. For instance, management could install better facilities for informal cross-functional interaction such as social events, or could similarly demand for formal cross-functional interaction by implementing cross-functional teams.

3.4.2.2 Cross-functional cooperative ability

Cross-functional cooperative ability is defined as “the ability to assimilate and deploy market knowledge in lateral interactions among functional areas” (Luo *et al.*, 2006, p. 72). As theoretical approaches serving as construct sources, Luo *et al.* (2006) refer to Cohen and Levinthal (1989), Szulanski (1996) and Zahra and George (2002).

The strong reference to marketing within this definition is a consequence of Luo *et al.*’s academic bias towards marketing literature. For a more balanced inclusion of all functional areas, denying a particular focus on marketing, this thesis follows Strese *et al.* (2016, p. 44) and define cooperative ability as “[…] the skills of a department needed to recognize, assimilate, transform, and deploy valuable knowledge acquired from other departments and thus represents an absorptive capacity for lateral knowledge transfer”.

Cooperative ability covers a skill set that enables reflecting on the own contribution in a cross-functional setting, recognizing valuable knowledge incumbent to other functional partners, and setting out to assimilate and transform it such that this knowledge can be internalized and deployed effectively.

3.4.2.3 Cross-functional competition

Cross-functional competition is defined as “the degree to which departments compete both for limited tangible and intangible resources and for strategic importance, power, and department charter” (Luo *et al.*, 2006, p. 72). As construct sources, the following authors are cited: Levitt (1969), Houston *et al.* (2001), Maltz and Kohli (1996) and Ruekert and Walker (1987). Reasons to compete on an intra-organizational level despite of a common goal and process structure are manifold. As already mentioned, these range from private gains on an individual level to outperform cross-functional counterparts, over tangible and intangible resources struggles, up to strategic agendas with mismatching sub-goals, for instance cannibalizing on peer units that offer similar products (Luo *et al.*, 2006; Tsai, 2002). Fernandez *et al.* (2014) view the main source for cross-functional competition in the resource allocation process, which in many large-scale industrial organizations is a core process and very central to all activities. The yearly budget allocation has the power to give more or less priority to certain activities, with all related and semi-related activities following suit. Managers hence compete for human, technological, and financial resources with their cross-functional colleagues to ensure survival of their team ambitions and power status – mostly at the expense of others (Fernandez *et al.*, 2014; Strese *et al.*, 2016).

3.4.3 Risks and benefits of cross-functional coopetitive behaviour

Building on a more general view of positive and negative consequences of coopetitive behaviour, the following paragraph will outline particular risks and benefits of cross-functional coopetition.

While the need for cross-functional cooperation is quite solidly researched and remains uncontested at a high level, research on the effects of competition in cross-functional relationships is less prominent and deserves further analysis. A frequently cited benefit is increased efficiency, which results from competition on resources. It facilitates resource allocation to the most advantageous receiver and exerts pressure to economize resources (Tidström, 2008; Lin *et al.*, 2010). From a psychological perspective, a good portion of competition is viewed positively as well, in particular when considering a NPD context. In their work on the psychology of innovations within organizations, Frey *et al.* (2006) explain that, in a state of persistent cohesion with a lack of conflicts, a phenomenon called "group thinking" emerges. Under group thinking, team members prize continuation of the group higher than the success of the company, even deliberately ignoring undeniable facts. For innovations in particular, conflicts and competition "are a necessary condition for success" (Frey *et al.*, 2006, p. 25, translated from the German original). In practical applications, this relationship between conflict and innovation is well known. In their study on innovativeness of cross-functional product development teams, Sethi *et al.* (2001) reaffirm this notion. Likewise, Womack *et al.* (2006, p. 115) criticize Western-culture NPD teams where team members shy away from conflicts in the development process, resulting in conflicts being solved only very late (and correspondingly expensive) in the process.

On the other hand, potential negative consequences of cross-functional competition include complications in the decision-making process with resulting loss of speed and agility (Strese *et al.*, 2016), reduction in the quality of interaction (Clercq *et al.*, 2009) and a decrease of job effectiveness (Lin *et al.*, 2010).

The second group of academic studies is concerned with consequences of the simultaneous occurrence of competition and coopetition on a cross-functional level of

analysis. Frequently cited advantages arising from this constellation are enhanced learning and knowledge sharing, exploiting economies of scope and scale even within organizations and the resulting beneficial results on firm performance, financial efficiency and technological advancement (Tsai, 2002; Luo *et al.*, 2006; Lado *et al.*, 1997; Devece *et al.*, 2017; Bengtsson and Kock, 2014).
For multi-national enterprises in particular, coopetition can be helpful: While cooperation is required to share knowledge and to build up an effective global supply chain, competition is needed to secure mutual respect as well as the resulting resources and top-management support (Bouncken *et al.*, 2015).

Luo *et al.* (2006) examine the interplay of individual dimensions more closely. When cooperative intensity and competition come together, the mere frequency of interaction of competing departments ensures transfer of - otherwise tacit - knowledge. In particular when cross-functional departments engage in coopetition, as opposed to peer units that just do the same in another context, this will create market- and customer-relevant knowledge or increase a company's efficiency. This is resulting from the fact that under this circumstance, knowledge is often complementary and not redundant, as it might be the case with peer units. "This access to nonredundant information fosters better problem solving and decision making […] and is essential for the creation of customer and financial value" (Luo *et al.*, 2006, p. 70). On the other hand, when cooperative ability and competition come together, there are higher incentives to understand and absorb the shared knowledge, with an enhanced ability to reflect on it and deploy it effectively. Again, the incentive is to understand the cross-functional counterparts' strategic agenda, which entails a higher chance of exploiting valuable knowledge. Beneficial consequences include better problem solving to satisfy customer needs and enhanced performance (Luo *et al.*, 2006; Hamel *et al.*, 1989; Tsai, 2002).

Risks of cross-functional coopetition are predominantly rooted in an extreme form of one of the dimensions. As described above, excessive cohesion based on a lack of competition may lead to detrimental effects just as a lack of cooperation may hamper the functioning of the overall organization. In addition to that, risks related to opportunistic behaviour enabled by coopetition apply.

3.4.4 Overview of empirical research on cross-functional coopetition

While research on coopetition is a rapidly growing field of academic interest, empirical efforts on a cross-functional level of analysis remain scarce (Bengtsson and Raza-Ullah, 2016). In the following, relevant studies and their results are presented. In contrast to similar compilations within this thesis, the scope that has been applied here is somewhat broader. No cohesive stream of research that would focus on testing the impact of coopetition on a certain dependent variable, for instance NPD success, has yet emerged. Therefore, a broad range of dependent variables, as well as coopetition as a dependent variable itself or as a mediator is included henceforth. Similarly, the conceptions of how cross-functional coopetition is measured, differ in the studies (Ghobadi, 2012).

Notably, a comprehensive overview of empirical studies on other levels of coopetition is not provided due to this thesis' focus on the micro level I. In particular for the meso level, there is a large body of research with a large variety of methodological applications. For details and a holistic overview of these studies, see the literature overviews of Peng *et al.* (2012), Bengtsson and Kock (2014), Bouncken *et al.* (2015), Bengtsson and Raza-Ullah (2016) and Devece *et al.* (2017).

Regarding the studies' methodological scope, a lack of diversity is striking: All the studies rely on quantitative survey data and feature large conceptual parts; in the case of Luo (2005) even exclusively conceptual. This is surprising, as coopetition research on other levels of analysis relies on a broad methodological backbone, including case studies and qualitative research.
Notwithstanding their cross-functional focus, the majority of studies leave the kind of cross-functional interface they study unspecified. This certainly constitutes a gap in research, as theory suggests that there might be differences in the impact of coopetition depending on whether peer units or cross-functional units are analysed. For the latter, experiences from research on cross-functional integration suggests that again, the result may differ significantly with regard to the exact interface that is being looked at between R&D, production or marketing.
Studies of both micro levels I and II are represented in this overview of studies, although micro level I has a slight dominance.

As already mentioned, conceptions of cross-functional coopetition differ. However, all empirical studies in the overview rely on survey data to portray their concept of cross-functional coopetition, ranging from three to eleven items per dimension. For a construct as complex and still uncharted as cross-functional coopetition is, survey items are likely to provide an insufficient and potentially ambiguous conception, even if rather detailed survey data is employed, such as Strese *et al.* (2016) with their 23 items across three dimensions.

With regard to the studies‘ scope, a substantial inclination towards topics of knowledge sharing is observable, something that Bengtsson and Kock (2014) confirm in their comprehensive literature review. This includes Tsai (2002), Lin (2007), Baruch and Lin (2012) as well as Ghobadi and D'Ambra (2012). Another recurrently represented topic are organizational concerns, for instance in Tsai (2002), Luo (2005) or Strese *et al.* (2016). Although coopetition at a whole features many studies within an innovation or NPD context, on a cross-functional level only Lin (2007) focusses explicitly on a NPD context.

With respect to results, no reliable pattern is recognizable, though there is a slightly positive tendency of coopetition's impact on several performance dimensions. Luo *et al.* (2006) examine cross-functional coopetition's impact on financial and customer performance and find a positive relationship. Lin (2007) presents ambiguous results when analysing cross-functional coopetition's impact on the NPD success. For the cooperative branch, positive results are yielded, whereas the competitive branch remains indistinctly positive or negative. In a similar manner, Lin *et al.* (2010) illustrate a positive relationship between micro level II cooperation and job effectiveness, whereas the same query with regard to micro level II competition remains with unclear results.

In summary, it is difficult to derive clear statements or impact patterns in the field of cross-functional coopetition. Ambiguous results suggest that research still has a poor understanding of the underlying dynamics and mechanisms, and that conceptualizations and research designs are too heterogeneous to produce persisting and reliable results. Table 5 shows the state of research on cross-functional coopetition.

Research on cross-functional coopetition					
	Scope	**Methodology/ sample**	**Level of Analysis**	**Coopetition conception**	**Result**
Tsai, 2002	Impact of centralization, social interaction and competition on Intra-organizational knowledge sharing	Survey data (1 company, n unclear)	Micro level I	• Cooperation: Cross-functional social interaction • Competition: Internal resource competition, external market competition	• Informal relations have a positive impact on knowledge sharing between units that compete for market share but not for units competing for internal resources • Centralization with negative impact on knowledge sharing
Luo, 2005	Coopetition between geographically dispersed subunits	Conceptual	Micro level I	• Cooperation: Technological, operational, organizational, financial • Competition: Parent resources and support, system position, market expansion	• Depending on their levels of cooperation and competition, sub-units belong to 4 types of coopetition • Configuration is contingent on determinant factors, which are neither prefixed nor predetermined
Luo et al., 2006	Impact of coopetition on customer and financial performance	Survey data (n=163)	Micro level I	• Cross-functional intensity: 6 items on frequency and closeness of lateral interactions • Cross-functional ability: 6 items on ability to evaluate, assimilate, exploit market knowledge from other departments • Cross-functional competition:10 items on competition for tangible and intangible resources	• Cross-functional coopetition enhances a firm's customer and financial performance • Market learning is mediating this relationship
Lin, 2007	Impact of coopetition on NPD success (financial performance, development speed) and mediating role of knowledge management	Survey data (n=139)	Micro level I	• Cooperation: 6 items on information sharing, integration in NPD • Competition: 8 items on competition for tangible and intangible resources	• Cross-functional cooperation with positive impact on NPD success • Cross-functional competition with ambiguous impact on NPD success • Knowledge management processes are mediating this relationship

Lin et al., 2010	Impact of coopetition on perceived job effectiveness in virtual teams	Survey data (n=312)	Micro level II	• Cooperation: 3 items on cooperative attitude within team • Competition: 3 items on competitive conflicts within team	• Both cooperation and competition with positive impact on job effectiveness • However, competition with negative impact on knowledge sharing, which is one of the key mediators of job effectiveness
Baruch and Lin, 2012	Impact of coopetition on team performance and knowledge sharing in teams, mediated by team emotional intelligence and competence	Survey data (n=759)	Micro level II	• Cooperation: 5 items on cooperative attitude within team • Competition: 3 items on competitive conflicts within team	• Cooperation with positive impact on team performance • Competition with negative impact on knowledge sharing, but ambiguous impact on team performance
Ghobadi and D'Ambra, 2012	Impact of coopetition on knowledge sharing in cross-functional teams	Survey data (n=115)	Micro level II	• Cooperation: 8 items on 3 dimensions of cooperative task orientation, communication, interpersonal relationship • Competition: 4 items on 2 dimensions of tangible and intangible resource competition	• Cooperation with positive impact on knowledge sharing behaviour • Competition with ambiguous impact on knowledge sharing: competition on tangible resources positive, on intangible resources negative
Strese et al., 2016	Organizational antecedents (leadership, centralization) of cross-functional coopetition	Survey data (n=234)	Micro level I	• Cooperation: 6 items on cooperative ability, 6 items on cooperative intensity • Competition: 11 items on tangible and intangible resource competition	• Leadership antecedents (participation and consideration) both with positive impact on coopetition • Formalization with positive impact, centralization with negative impact on coopetition

Table 5: Overview on research on cross-functional coopetition

4 Theories on constraints in new product development

4.1 Introduction to constraints in NPD

There has been a widespread discussion on the role of constraints of all kinds and sorts as inhibitors or enablers of NPD. A few introductory remarks will facilitate access to this dichotomous topic in the following introduction. Subsequently, a detailed analysis of existent literature is presented as an overview of current applications and explanations of the impact of constraints on innovation and new product development. I will provide a psychological explanation on constraints' particular impact on innovation processes and discuss a defining classification of different constraint types, with a clear differentiation being made with regard to requirements engineering. Finally, relevant empirical and theoretical studies are discussed.
As the nascent field of research on the impact of constraints takes a rather broad perspective, the term *innovation* is more frequently employed than the term *new product development*. In the following, the author will stick with this denomination, but clearly mark or exclude research efforts that deviate considerably from the given definition of new product development.

Constraints seem to shape every task of new product development as an inherent feature: "No matter the domain or the discipline, any creative endeavour will feature constraints" (Onarheim and Biskjær, 2013, p. 2). A chemist is naturally constrained to a fundamental set of 118 elements for the creation of new compounds; a designer at Lego is limited to a finite selection of components that she has to reuse to control the number of unique pieces and to balance required novelties (Sull, 2015).
Popular wisdom has it that constraints can be both forestallers and enablers of such innovation: "Necessity is the mother of invention" points towards an encouraging, at most inspiring role of constraints. "You get what you pay for" indicates the restricting impact that constraints, e.g. in a financial way, might have (Weiss *et al.*, 2011). Looking at definitions, the latter negative role seems to prevail. Rosso (2014, p. 553) delineates constraints to be a "state of being restricted, limited, or confined within prescribed bounds".
Success stories of NPD provide diverse counterexamples to this restricting understanding of constraints: A choreographer from Columbia was constrained to a tape of salsa music in his exercise class, leading him to the invention of Zumba. Start-up companies are usually encouraged to develop a mobile application before other online applications, as restricted space on mobile screens forces developers to focus on the most essential product features (Mayer, 2006; Richardson, 2013). Large parts of the extensive research on bricolage and frugal innovation is attributable to the existence of constraints, that often lead to innovative new products by "making do with what is at hand" (Baker and Nelson, 2005, p. 329), see for example Baker (2007) or Garud and Karnøe (2003). Amazon founder Jeff Bezos stated "I think frugality drives

innovation, just like other constraints do. One of the only ways to get out of a tight box is to invent your way out" (Unruh, 2010, p. 105). A French literary movement called "Oulipo" ("Ouvroir de littérature potentielle") is representative for many artists, who use constraints deliberately to stimulate creativity. They introduce restrictions such as the avoidance of particular letters or the use of certain words to engage in a creative creation process (Arrighi *et al.*, 2015).
There are many examples to prove that, when organizations are simply forced to do more with less, they succeed in competing with better endowed rivals, with innovation often being the decisive factor. The Swiss pharmaceutical giant Roche invested heavily in Genentech, a Silicon-Valley based biotechnology start-up company, as the latter was capable of extracting significantly more return on their (limited) R&D budget than better endowed Roche (Lampel *et al.*, 2014; Honig *et al.*, 2013).

Intuitive explanations for a possibly positive role of constraints in NPD are manifold: Mayer (2006) points towards speed as a possible explanation for a positive role that constraints may take in NPD: They support fast failing and limited investments, such that unsuccessful innovations are not carried forward for an extended period. Korhonen and Välikangas (2014, p. 254) emphasize that constraints may act as "focusing advices", that „attract inventive attention to a specific problem". Gibbert *et al.* (2007, p. 16) confirm this notion by expressing their belief that "the human mind is most productive when restricted. Limited — or better focused — by specific rules and constraints, we are more likely to recognize an unexpected idea." As early as in the course of the 1970s and 1980s, Giddens (1976, p. 169, 1981, p. 56) recognized the positive aspects of constraints in his structuration theory. His theorizing focusses on societally implicated rules and resources, so-called structures. Acknowledging possible positive aspects of those structures, he states that "structures must not be conceptualized as simply putting constraints on human agency, but as enabling" (Giddens, 1976, p. 161). Gibbert *et al.* (2014) point towards an interesting analogy from gaming research: Games are fun because of the very difficulties that they pose to fulfil a certain quest, not because they are easy. They conclude that "the very essence of games is that resources are intentionally and artificially made highly scarce" (Gibbert *et al.*, 2014, p. 199).

In the majority of literary or academic treatises, however, constraints are evaluated as something external and rather negative to the innovation process. "Approaches may lead us to overlook the possibility of viewing constraint handling as something inherent in creative action" (Lombardo and Kvalshaugen, 2014, p. 588). Indeed, creativity and psychology literature concludes on empirical and conceptual evidence which considers constraints to be a very part of the actual process of creative cognition, see for example Ward (2004) or Finke *et al.* (1992).
Despite of significant research efforts that strive to explain the seemingly contradicting role of constraints in NPD, underlying reasons thereof remain unclear (Hatchuel and

Chen, 2017). In the following, an overview of current research streams on the psychological foundations to explain constraints' impact on NPD and creativity is given.

4.2 Psychological background

The effects, which constraints are ascribed to have on cognitive design processes in NPD, can be segmented into two groups. The first group contributes to the notion of constraints that stimulate creativity in cognitive processes. In a second group, arguments are discussed where constraints serve as focusing devices to direct complex cognitive design processes into a purposeful, targeted direction.

In psychology or cognition research, the element of analysis relating to NPD processes typically is the human design process. Therefore, design tasks and the associated cognitive processes on an individual level are in the focus of the following explanations.

4.2.1 Stimulation of creativity

While many techniques point towards unconstrained thinking to unleash creativity, e.g. brainstorming methods, empirical results of psychology and cognition literature "paradoxically suggest that placing constraints on the generative task may increase the amount of creative processing" (Moreau and Dahl, 2005, p. 18).
In examining the cognitive problem solving process, Von der Werth and Weinert (2002) find that human problem solving efforts come about in a so-called "problem space", which includes all theoretically possible solutions. However, all active cognitive activities for a certain problem take place in a frictional part thereof, denominated as "search space". While usual analytical engineering design methods reduce the search space by systematically analysing options and eliminating illicit ones, stimuli may be conceived that extend it. Those stimuli include questions, analogies or incentives to take hitherto unnoticed aspects into consideration. The latter may likewise include different kinds of constraints, e.g. for certain product features, hereby dissolving the apparent paradox of constraints that extend, rather than limit, the search space. Furthermore, Von der Werth and Weinert (2002) find that the mentioned stimuli may likewise encourage designers to consider adjacent topics and potential consequences of their design, again inducing creativity by extending the search space.

Another popular explanation for why constraints may enhance creativity is provided by the path-of-least-resistance strategy brought forward by Ward (2004). This refers to the effort-reducing default approach that is typically employed in solving creative tasks: The first solution that comes to mind is seized and realized. Often, this effort-minimizing approach draws on previously existing or uncreative solutions as this requires less cognitive resources and avoids the uncertainty of novel solutions. The introduction of constraints, however, can force individuals to deviate from the path-of-least-resistance and employ more creative processes (Moreau and Dahl, 2005).

Further explanatory approaches refer to different conceptions of the problem solving process. Schön (1983, p. 76 ff., 1990) conceptionalizes the design process as an iterative procedure of framing and reframing a problem. He disagrees with many design researchers that emphasize the emergence of creativity in the beginning of the design process, see for example Midler (1995) or Karniel and Reich (2011). Schön believes that creativity emerges during the framing-reframing process, and hence is inherently connected to the constraints that serve as some form of frame herein (Arrighi *et al.*, 2015).

Frey *et al.* (2006) suggest a psychologically founded approach, according to which innovations can only occur if the world is perceived as "changeable". Consequently, innovations emerge when previously "unchangeable" worlds are entered and perceptions change towards the world being changeable, indeed. According to Frey *et al.* (2006), the introduction of constraints encourages attacks on unchangeable worlds, turning them into innovation-inspiring changeable worlds.

Hauschildt (1999) complements this notion in stating that conflicts, which arise through the confrontation of problem solving with constraints, inspire creativity as they encourage new ways to overcome those.

4.2.2 Purposeful focusing of design processes

Many approaches within this stream of explanation stem from the recognition that human problem solving is not as structured and analytical as it may seem in a rationality-focused model of human cognition. In this notion, constraints may serve as an orientation aid to purposefully re-target the problem solving task.

VDI 2221 (VDI, 1993) provides a specific guideline for a structured approach to engineering design processes, therefore representing a typical problem solving process in a NPD context. It postulates a procedure which has clearly delimited steps, following a structured iterative solution path, and is widely acknowledged as an industrial standard. However, Hacker (2002, p. 14) finds that the actual design process does not follow this systematic approach, but rather takes "opportunistic" shortcuts based on previous experiences. According to the principles of cognitive economics, this is perfectly reasonable: The designer reduces cognitive efforts by re-using prior knowledge. As this occurs at the expense of a systematic approach, there is a chance of neglecting adjacent aspects and henceforth missing the global optimum solution. In addition to that, Hacker (2002) points towards the limited human working memory, which requires the designer to focus on a partial aspect of the problem instead of having the entire solution space readily available (Hacker, 2002). Constraints may herein serve to put the right features into the designer's focus and to help re-target essential aspects, even if the designer deviates from a linear, perfectly structured design process.

Schütze *et al.* (2002) conceive the problem solving process in design tasks as an iterative procedure with alternating steps of designing and calculating, hence combining a creative, opening element with an analytic, controlling element in each step. Constraints may help to guide the iterative development into the right direction, making sure that creative, opening phases do not go astray from essential product features. Likewise, Hacker (2002, p. 24) calls for "objectification phases", where partial outcomes of the design task can be assessed. Hacker points towards some form of external discussion or measurement, against which the partial outcome can be hold up, be it any form of communication or comparison with an outcome illustration, gauge or formulated vision statement. Constraints may serve as a form of external gauge or measurement in this sense, and hence may help to steer the design process into the right direction.

Fundamental research on design processes has shown that designers tend to follow a model of path dependency in their tasks, for reasons that have been acknowledged in cognitive economics as described earlier. As early as 1966, Allen (p. 83) concludes: "Once a technical approach becomes preferred over any other, it is not easily rejected. Furthermore, the longer it is in a dominant position, the more difficult it becomes to reject". With many design approaches starting right off and only assessing the (partial) design outcomes in retrospective, this can lead to a critical adherence to previous design solutions. The introduction of constraints may help to mitigate this development, as they provide guidance and enforce new design solutions right at the beginning of the problem solving process. Potentially, this encourages to breach the attested design path dependency.

4.3 Classification and differentiation of constraints in NPD

4.3.1 Classifying constraints in NPD

In applicant research, classifications of constraints in a NPD context are manifold, and no generally accepted model has emerged yet. This may be due to the breadth of research fields in which constraints find application, be it the cognition and psychology research, team dynamics or financial econometrics. Researchers are negligent to integrate their constraint applications into previous work, in particular if relevant literature is outside of the own research field (Onarheim and Wiltschnig, 2010). In addition, the semantic expression *constraint* makes it difficult to conjoin efforts across research fields: Different disciplines typically refer to constraints in their own terms, for instance will engineers talk about *requirements* when artists talk about *styles*, *rules* or *guidelines* (Onarheim and Biskjær, 2013).

In order to classify constraints for the applications in NPD that are relevant for the thesis at hand, an effort is made to combine existent typologies into a comprehensive model (see illustration 22).

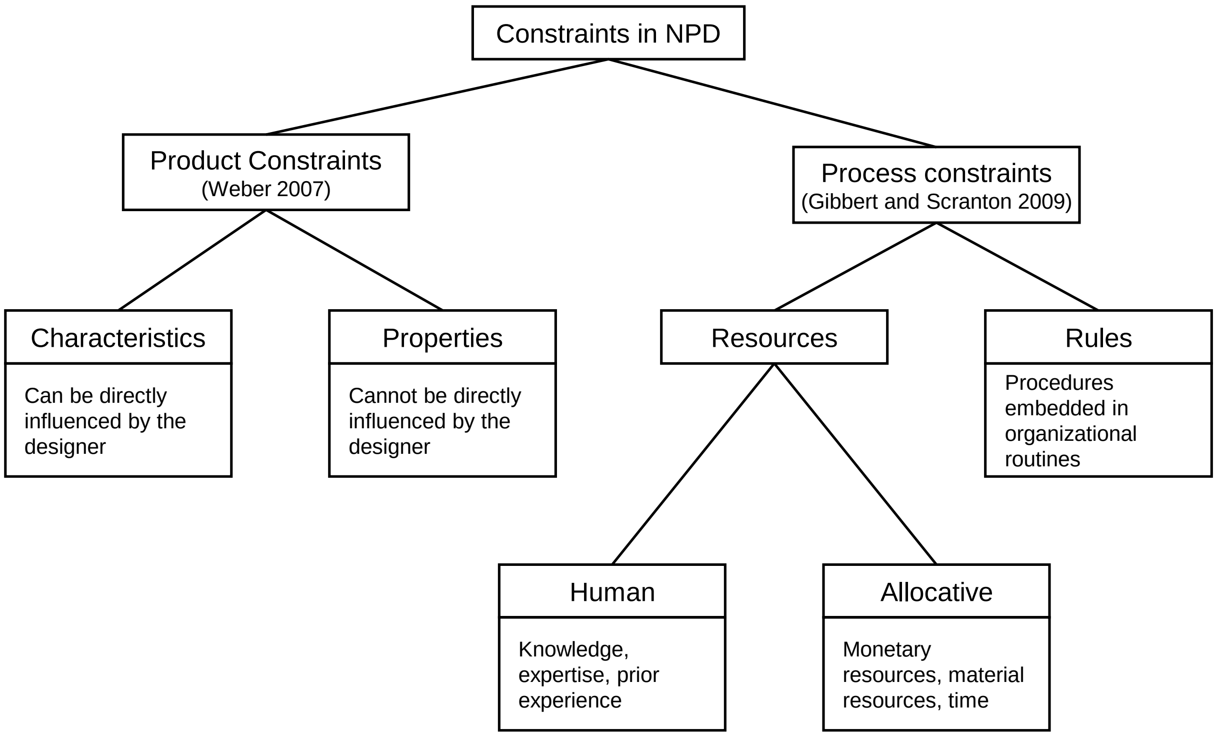

Illustration 22: Classifications of constraints in new product development

At the highest level, *process* and *product constraints* can be distinguished. While *process constraints* influence the way how a task is done, *product constraints* refer to the space of possible solutions and hence influence the outcome of a task (Rosso, 2014). While prevalent literature provides several suggestions how to classify process constraints, it is less elaborate on possible classifications of product constraints. Therefore, this thesis follows scholars of requirements engineering and distinguish between *characteristics* and *properties*, see Weber (2007) or Weber and Deubel (2002). While characteristics refer to product features that can be directly influenced by the designer, e.g. dimensions or materials, properties describe product features that cannot be directly influenced, e.g. manufacturability or environmental friendliness.
Regarding process constraints, the author follows Gibbert and Scranton (2009) and Giddens (1984, p. 15 ff.) in differentiating between *resources* and *rules*. This deviates from other possible classifications such as in Lampel *et al.* (2014), who distinguish structural, resource, and temporal constraints. Resources can be both *human* (e.g. knowledge or simply headcount) and *allocative* (e.g. monetary resources or time). Rules refer to “generalizable procedures applied to the enactment/reproduction of social life” (Giddens, 1984, p. 21), often evident as organizational routines. In contrast to resources, those rules are considered irrespective of their efficiency or contribution (Meyer and Rowan, 1977).

Notably, there are other possibilities to illustrate different kinds or manifestations of constraints other than a structured classification. Onarheim and Wiltschnig (2010) see constraints as polarities on a continuum for different dimensions, for instance internal vs. external, abstract vs. concrete or absolute vs. negotiable. Lampel *et al.* (2014)

complement two other dimensions, namely static vs. dynamic as well as explicit vs. implicit. These constraint dimensions are closely related to ways of embedding constraints in an organization effectively and will therefore be resumed in the empirical part of this document.

4.3.2 Relating constraint research to requirements engineering

The classification of product constraints in accordance to definitions in requirement engineering signals that there is a link between the two research fields. In the following, it will be explained how this study's understanding of constraint research both builds on and is differentiated against requirements engineering.

There is an entire field of research within engineering that is concerned with the definition, formulation and interplay of different product requirements. For a more detailed discussion of this field, the pertinent literature may be consulted, see for example Ehrlenspiel and Meerkamm (2013, p. 391 ff., p. 402). According to Mayer-Bachmann (2008), requirements engineering has a strong focus on technical product features, neglecting non-technical areas such marketing, manufacturing or financial requirements. In Weber's (2007) definition, this is concretized: While characteristics refer to product features that can be directly influenced by the designer, properties describe product features that cannot be directly influenced. Within this definition, requirements engineering focusses on characteristics. Mayer-Bachmann (2008) and Weber and Deubel (2003) criticize that properties and characteristics are insufficiently interlinked, with existent requirement networks built primarily between different characteristics. Recent efforts to connect the characteristics side with the properties side strive to model interrelationships to enhance the predictability of characteristics' impact on product properties, see for instance Weber (2007).

As a conclusion, requirements engineering can be differentiated from constraint research by its narrower focus: With its strong focus on technical product features, requirements engineering excludes the entire branch of process constraints. Even more, it mainly works with product characteristics and neglects the constraining potential of product properties. Quite contrary to this focus, this thesis explicitly uses product properties as constraints, as will be explained in the empirical part of this thesis.

4.4 Overview of empirical research on constraints in NPD

As touched upon earlier, literature on application of constraints in a NPD context involves a broad range of different disciplines and deviating interpretations. The dichotomous nature of constraint application, which sees constraints both as forestallers or enablers of innovation, is a common research puzzle of a majority of studies. Regardless of all recent research efforts, this fundamental contradiction has not yet been solved. In the following, an overview is provided of all current research streams that either support or reject a positive role of constraints in NPD.

The pertinent literature is segmented into two major streams: research on the impact of constraints on innovation performance, closely related to this study's focus on new product development, and research on the impact of constraints on creativity. As both are connected to a NPD context, results and explanations will be detailed for both streams and illuminate remaining gaps to develop the impact of constraints on NPD performance at the end of the chapter.

Cyert and March (1963, p. 258 ff.) were the first ones to pose the question whether constraints inhibit or encourage innovation, limiting their analysis to constrained or slack resources. Up to this day, large parts of relevant research still focus on the constraining role of resources in general or financial resources in particular. While there is a widespread notion that acknowledges a negative impact of resource constraints on innovative activity, there is a series of cases which show that under certain conditions, constraints may encourage rather than forestall innovation (Gibbert *et al.*, 2014; Weiss *et al.*, 2011; Hoegl *et al.*, 2008). Quite naturally, maximizing constraints cannot be the sufficient condition for innovation success; applied to financial constraints, this would mean that the organizations that dispose of the least resources would out innovate all others. There has to be a set of contingency factors or mediating forces to explain under which circumstances constraints have a positive or a negative role for innovation. Even an inverted u-shaped relationship would be conceivable intuitively. Gibbert *et al.* (2014, p. 198) frame a central question accordingly: "if necessity is the mother of innovation, who, then, is innovation's father?" Though several suggestions for contingency factors have been brought into existence (e.g., bounded creativity, an engaging project objective, a skill-leveraging process, team cohesion and team potency, see Hoegl *et al.*, 2008 for details), research has not yet succeeded in bringing about ultimate clarity.

A nascent research stream that focusses on positive aspects of constraints in general and resource scarcity in particular on innovation performance is rooted in the bottom-of-the-pyramid literature. As many of these studies do not specifically examine whether constraints have a positive or negative influence in general, but rather strive to understand what constitutes and enables innovative activity in resource-poor environments, it is not explicitly included in this study's research overview. Nonetheless, a few explanations on its general aspects shall be outlined in the following to illustrate constraint's innovation-inspiring nature. Cunha *et al.* (2014) distinguish three research streams within product innovation in resource-poor environments: *Bricolage*, *improvisation* and *frugal innovation*. *Bricolage* does not embrace scarcity as trigger for innovative activity per se, but focusses on the ability to recognize potentially dormant resources in what is rightly available: "making do by applying combinations of the resources at hand to new problems and opportunities" (Baker 2007, p. 698). It therefore occurs when "bricoleurs" explore existing resources and develop novelty in combining those in a creative or practical manner. For *improvisation*, time constraints are the defining criterion. It occurs when the separation of planning and execution is not feasible. For examples of successful improvisation that led to NPD success, refer to Samra *et al.* (2008) or Day and Shoemaker (2008). Lastly, *frugal innovation* explores ways to respond to needs of non-affluent customers through enhanced efficiency and cost discipline. While many examples of its results have received large attention in media and society, e.g. around the development of the Grameen Bank or the Tata Nano car, the field still lacks theoretical sense-making (Cunha *et al.*, 2014). For research examples on frugal innovation, see Prahalad and Mashelkar (2010) or Anderson and Markides (2007).

Table 6 summarizes essential empirical research efforts and their results examining the impact of constraints on innovation performance, table 7 works accordingly for the impact of constraints on creativity. The underlying literature review spans several disciplines including creativity and cognition research, team performance research, econometrics and innovation management. Research that focuses on mathematical models of constraint networks, e.g. Abdalla (1998), Gayretli and Abdalla (1999), Minnaar and Reinecke (2012) or Fu and Pennington (1993) has been excluded from this overview for its limited applicability to this study's scope.
From a methodological perspective, a broad range of approaches have been found and included in this overview. Tables 6 and 7 list individual studies and specify the level of analysis (i.e. individual, organizational, intra-organizational or industry), the constraint type that is examined, the employed methodology and the result.

Overall, the results are contradictory, exhibiting both positive and negative impacts of constraints for each category. Within the respective categories, different sub-fields of research can be identified which will be highlighted in the following.

Research on impact of constraints on innovation performance

	Level of analysis	Constraint type	Methodology	Result
Katila and Shane, 2005	Organization	Financial	Secondary quantitative data	(+)
Canepa and Stoneman, 2007	Organization	Financial	Survey data	(-)
Mohnen et al., 2008	Organization	Financial	Survey data	(-)
Hoegl et al., 2008	Intra-organizational	Financial	Conceptual paper	(Dep. on contingency factors)
Savignac, 2008	Organization	Financial	Survey data	(-)
Gibbert and Scranton, 2009	Organization	Financial	Case study	(+)
Weiss et al., 2011	Intra-organizational	Financial	Survey data	(0)
Gorodnich-enko and Schnitzer, 2013	Organization	Financial	Survey data	(-)
Almeida et al., 2013	Organization	Financial	Secondary quantitative data	(+)
Honig et al., 2013	Organization	Resource (general)	Case study	(+)
Garriga et al., 2013	Organization	Resource (general)	Survey data	(-)
Troilo et al., 2014	Organization	Slack resources (Lack of financial constraints)	Survey data	(-)
Senyard et al., 2014	Organization	Resource (general)	Longitudinal data (qualitative interviews)	(+)
Rosenzweig and Mazursky, 2014	Industry	Financial	Secondary quantitative data	(+)

Walker et al., 2014	Industry	Product (charac-teristics)	Case study	(+)
Korhonen and Välikangas, 2014	Organization	Resource (general)	Case study	(+)
Efthyvoulou and Vahter, 2016	Organization	Financial	Secondary quantitative data	(-)
García-Quevedo et al., 2017	Organization	Financial	Secondary quantitative data	(-)
Pellegrino and Savona, 2017	Organization	• Financial • Market-related • Demand-related	Panel data	(-)

Key: (+) means positive impact of constraints on innovation performance, (-) means negative impact of constraints on innovation performance, "Dep. on" means depending on

Table 6: Research on impact of constraints on innovation performance

Within research on the impact of constraints on innovation performance (table 6), the dominant research stream involves quantitative surveys, panel or secondary data analysing the impact of financial constraints on an organizational level. In some instances, not financial scarcity, but financial slack is the object of research; this provides the same analysis in just a reciprocal manner and is likewise included in the overview. Frequently, empirical efforts within this research stream deploy econometric methods to examine data for individual countries; often motivated by the question whether the lack of financial resources accompanying a financial crisis has negative impacts on the innovative capacities of an economy. Studies include Canepa and Stoneman (2007), Mohnen *et al.* (2008), Savignac (2008), Gorodnichenko and Schnitzer (2013), Efthyvoulou and Vahter (2016), García-Quevedo *et al.* (2017) and Pellegrino and Savona (2017), all reaffirming a negative impact of financial constraints on organizational innovation performance.
For the few instances (e.g. Almeida *et al.*, 2013), where research finds a positive impact of financial constraints within this stream of research, the underlying reason stems from the improved allocation and selection of financial resources: Financial scarcity enforces the prioritization of successful innovation projects and prevents the financing of unsuccessful ones; however the constraint is not seen as an enabler of innovation in its own sense (Gibbert *et al.*, 2014).

Another research stream within literature examining the impact on innovation performance is concerned with organizational ingenuity and assumes a more positive role of constraints, see for instance Gibbert and Scranton (2009), Korhonen and Välikangas (2014), Walker *et al.* (2014) or Honig *et al.* (2013). The studies feature both resource and product constraints and often cite specific contexts, in which constraints had forced ingenious solutions. To cite the example of Gibbert and Scranton (2009), the development of jet propulsion at the end of world war II provided such a context. Competing teams from USA and Germany strived to dissolve the performance dilemma, that material fatigue occurred the more often the more powerful the engine was due to extensive heat development. While American teams where granted barely unlimited resources and experimented with costly heat resistant alloys, the constrained German teams had to come up with an innovative solution. They focused on developing better cooling for their inefficient alloys, eventually resulting in a successful technology which is still in use today (Gibbert and Scranton, 2009; Hoegl *et al.*, 2008).

Research on impact of constraints on creativity

	Level of analysis	**Constraint type**	**Methodology**	**Result**
Amabile, 1996	Individual	• Product • Process	Various	(-)
Moreau and Dahl, 2005	Individual	• Product (charac-teristics) • Time	Experimental study	(+) for product constraints (-) for time constraints
Baer and Oldham, 2006	Individual	Time	Experimental study	(+)
Dahl and Moreau, 2007	Individual	Product (charac-teristics)	Experimental study	(+)
Stokes, 2008	Individual	Product (charac-teristics)	Painting analysis	(+)
Rosso, 2014	Intra-organizational	Various product & process	Case study	(+) for product constraints (-) for process constraints
Lombardo and Kvalshaugen, 2014	Intra-organizational	Unspecified	Case study	Neither hindrance nor enabler, constraints inextricably intertwined with creativity

Key: (+) means positive impact of constraints on creativity, (-) means negative impact of constraints on creativity

Table 7: Research on impact of constraints on creativity

With regard to research on the impact of constraints on creativity (see table 7), one predominant stream stands out. Often in the form of experimental research designs, an individual’s response to different kinds of constraints is examined. For example, Moreau and Dahl (2005) made study participants build children toys from a large set of different shapes. A first group was allowed to use whatever they liked from the entire set of shapes, resulting with uncreative solutions that were building on familiar conceptions of toys. By contrast, the second group, forced to stick to a subset of certain shapes, developed very creative solutions. Applying time constraints in addition to the input constraints in the same study, however, revealed a negative impact on creativity. In the same manner, different studies with different constraint types in this research stream yield different results. While product constraints tend to have a positive influence on creativity, and process constraints seem to have rather negative effects, overall results are ambiguous and no clear pattern evolves.

Looking at the entire body of the analysed research, a series of observations can be made regarding scope and coverage. To begin with, there is astonishingly little empirical research on an intra-organizational level. The author agrees with Hoegl *et al.* (2008) in marking this as a clear gap, as most innovative endeavours are executed on a team or department level, with the intra-organizational level therefore deserving a stronger academic focus.

With regard to analysed constraints, there is a strong propensity towards financial or, more generally, resource constraints. Product constraints, though seemingly favoured as triggers for creativity, are underrepresented; product properties do not even occur once as the object of research.

Furthermore, comparing the mode of action of studies in tables 6 and 7, an interesting observation can be made. Whereas studies on the impact of constraints on innovation performance see constraints as an externally given factor, researchers on the impact of constraints on creativity actively embrace constraints and use them intentionally as instruments to influence behaviour. Although existent research on the impact of innovation performance has identified a series of effective cause-effect relationships of constraints as well, the potential of constraints for purposefully influencing a certain behaviour for innovation performance has not yet been explored.

Considering overall results, no clear tendency or explanation pattern evolves under which circumstances, with which constraints and with which methodology the impact of constraints is negative or positive. However, there seems to be a tendency towards a unified notion of financial constraints negatively influencing innovation performance. The pieces of evidence for a positive influence that exist for a broad range of contexts do not coagulate in a common research theme or theoretical underpinning.

As mentioned above, existing research efforts analyse constraints’ impact on either innovation performance or creativity, both quite abstract themes within the greater field of innovation research. It would be interesting to analyse constraints’ impact on more concrete measures for innovation performance. For their apparent relevance in innovation research (see chapter 2), NPD success and some of its antecedents, e.g. cross-functional integration, could be interesting measures. As existent constraint research reaches into topics of how it influences team climate and cooperation (see for example Weiss *et al.*, 2011), the leap into researching the impact of constraints on cross-functional integration would be both feasible and interesting.

5 Research need and topic discussion

In the preceding chapters, three streams of literature were presented which can be considered to be substantially independent from each other in existing research. In their different fields of application, however, overlaps exist. Cross-functional integration and cross-functional coopetition both deal with the interplay of intra-firm actors whilst building on different theoretical predecessors and taking a different perspective. Both have been applied to a NPD context which for both is a particularly prominent area of application. The third literature stream, constraints in innovation research, comprises a different object of analysis than the other two streams, but likewise finds application in a NPD context.

Integrating the three literature streams and thus making use of advantages of one stream to solve unexplained areas of another one is at the core of the topic discussion in the subsequent section. A coopetition perspective will be applied to shed light on underlying dynamics of cross-functional integration in NPD; constraints will be applied to improve coopetition at the design-manufacturing interface.

5.1 Shortcomings of existing theoretical and empirical research

5.1.1 Gaps in research on cross functional integration in NPD

5.1.1.1 In-depth dynamics are insufficiently understood

The importance of cross-functional integration for different dimensions of NPD success finds broad affirmation in both theory and empiricism. Another finding is widely accepted and confirmed in different research efforts: “The relationships between various facets of cross-functional integration and performance measures are highly complex” (Brettel *et al.*, 2011, p. 251). Indeed, empirical results are partially conflicting and often ambiguous in their interpretation, even after repeated attempts to bring clarity into this complex matter have been made. The examined relationship seems to depend on a large number of mediating, moderating or context-related factors. Furthermore, preceding theoretical hypotheses are frequently disproved in empirical results and consecutive theoretical explanations remain thin. This inevitably suggests that the deeper dynamics of how cross-functional integration actually takes impact in a NPD context are still insufficiently comprehended.

Several aspects of the existent research body may be held responsible for this deficient understanding despite of considerable research efforts. To begin with, all but one of the relevant studies are quantitative in nature, examining an issue as complex and multi-layered as cross-functional integration based purely on survey data. Although the majority of scholars affirms the complexity and difficulty of fully conceiving the issue, cross-functional integration is reduced to typically three to four survey items. Further aggravated by contextual differences in the understanding of cross-functional integration, this alone might explain ambiguity in existent empirical studies.

In addition to that, scholars such as Gerpott (2005, p. 120) and Dekkers *et al.* (2013) criticize a "partial analytic character" of prevalent studies which can easily be explained by limitations of their quantitative methodology, only taking a limited number of issues into consideration while many others remain neglected: "None of these strands of literature has explored in detail the interaction between product design and engineering management from an integral perspective" (Dekkers *et al.*, 2013, p. 317). Furthermore, survey data is naturally limited to respondents that are easily accessible and willing to answer; potentially more revealing cases that allow to explore in-depth dynamics are mostly only accessible via qualitative case study methodologies.

The disregard of other aspects essential to cross-functional integration sheds more light on why study results may be ambiguous and reveals further shortcomings. First of all, there has been a constructive discussion in research on the manifestations of cross-functional integration. One common denominator hereof is that mere *interaction* between functions does not suffice, some more intangible and deeper-going construct such as *collaboration* (see for example Kahn, 1996) is necessary to generate effective cross-functional integration. When comparing measurements of cross-functional integration in pertinent studies, it is striking that the entire aspect of collaboration is often ignored and interaction is typically reduced to frequency of communication and interaction.

Another aspect that is widely ignored despite of better knowledge in the state of research are contextual organizational and social factors, e.g. different subcultural thought worlds or functional career paths. There is wide acceptance of their uttermost importance for cross-functional integration, e.g. as prominent barriers to integration. Nonetheless, their influence is rarely examined in empirical studies, albeit other contextual factors such as industry or product innovativeness find consideration. Again, this might be attributable to the quantitative methodology, for which it is difficult to capture such influences; in any case it constitutes a significant shortcoming of existing empirical research.

A last shortcoming to explain why in-depth dynamics might not yet be fully understood is existing studies' consideration of involved interfaces. Many of the studies leave involved interfaces in their measurements unspecified and do not distinguish between different interface combinations in their results. This is in so far critical, as a few comprehensive studies that do specify and distinguish interfaces find that dynamics and outcome of cross-functional integration indeed differ depending on the interface combination that is examined, i.e. between R&D and marketing, marketing and production or R&D and production.

Furthermore, a widespread call for inclusion of the often neglected interface to manufacturing remains largely unanswered; the largest part of the research body is still focusing on the interface between R&D and marketing. In addition to that, barriers to integration are prone to make the integration of manufacturing particularly difficult, as those barriers often leave manufacturing in a maverick position. Calls for the inclusion of the manufacturing interface due to its assumed and partially confirmed importance in NPD are repeated throughout the years, see for example Ettlie (1995), Song *et al.* (1997), Olson *et al.* (2001), Neubauer (2008), Brettel *et al.* (2011), Dekkers *et al.* (2013) or Nafisi *et al.* (2016).

In summary, while existing research emphasizes the crucial importance of cross-functional integration for NPD success, it has insufficiently understood its in-depth dynamics. In large parts, this stems from the heavy methodological focus on quantitative survey data, insufficiently capable of capturing important aspects of cross-functional integration, and a common negligence of the production interface.

5.1.1.2 Existing methods are insufficiently accepted

Empirical evidence for a lack of industrial application

There is a large range of empirical studies analysing the industrial application of existing methods to enhance cross-functional integration in NPD. Their respective scopes differ slightly from study to study, with some research efforts concentrating more on the engineering methods such as Concurrent Engineering or Design for X, and others taking a more holistic approach on methods of integrated NPD or integrated design science. Notwithstanding their broadness in scope, they all come to a similar inference, which can be summarized by Lorenz' (2008, p. 11) conclusion of a study investigating integrated product development models in industrial practice: "In spite of the high degree of acceptance the degree of implementation of such methods is still unsatisfactorily low". This is reconfirmed by many authors, finding in their empirical studies that existing methods find only hesitant and incomplete industrial application, although their benefit is scientifically postulated and proven, see for example Cratzius (2003, p. 96), Bullinger *et al.* (1995), Kessler and Chakrabarti (1999), Lindemann *et al.* (2001), Jahn *et al.* (2002), Björk and Ottosson (2007), Steimer *et al.* (2016) or Schuh *et al.* (2013). This lack of acceptance by practitioners even holds true for well-known methods such as Quality Function Deployment (QFD) or Failure Mode and Effects Analysis (FEMA) (Grabowski, 1997; Lindemann *et al.*, 2001). In their recent comprehensive research effort on the application of different methods in product development, spanning likewise medium-sized companies, Gust *et al.* (2017, p. 154) conclude with a discouraging view that "many companies use methods comparatively rarely or completely dispense with their application" and hereby confirm earlier results of Graner (2015), Gausemeier (2000) and Lindemann (2016).

In addition to this general lack of industrial application, the situation at the R&D-production interface seems to be even more pronounced. Several studies prove that the integration at this interface remains even lower than at other interfaces, see for example Jürgens (2000), Cratzius (2003, p. 82), Olson *et al.* (2001) or Nafisi *et al.* (2016). In summary, it must therefore be noted that in spite of promising scientific arguments, the industrial application of methods to enhance cross-functional integration in NPD remains scarce and unsatisfactorily low. Building on this finding, the thesis at hand aims at identifying reasons for this lack of industrial application, as well as proposing an alternative method which finds better acceptance by practitioners.

Insufficient recognition of organizational and social factors

Although theory has widely recognized the critical importance of organizational and social factors for cross-functional integration, existing methods to enhance cross-functional integration continue to neglect them. Even methods that are supposed to enhance cross-functional integration frequently disregard socio-organizational factors. Presumably, this critical observation might be in part owing to the fact that the topic of cross-functional integration is interdisciplinary in nature. Often, it is in the management fields of research, in which social and organizational factors find their strongest consideration. Many of the methods which are technically specific enough to foster cross-functional integration in practice, however, are rooted in the engineering field of research, with the latter often disregarding these "soft" factors. Hence, management research postulates the importance of socio-organizational factors, but its methods to enhance cross-functional integration are too high-level and unspecific to find practical resonance. On the other hand, engineering research formulates methods that are technically specific enough for industrial application, but which neglect important socio-economic factors. Indeed, a series of studies analysing reasons for the low industrial application of existing methods finds that these reasons are less technical, but more social and organizational in nature. As examples thereof, resistance to change, communication, organization or human factors are provided (Abdalla, 1999; Grabowski, 1997; Haque *et al.*, 2003).

Secondly, the disregard of socio-emotional factors in existing methods on cross-functional integration is criticized. In her seminal work of 1992, Dougherty (p. 195) recognizes early that for successful product innovation in large firms "the advocation of rational tools and processes, the infusion of market research information, and the redesign of structures, while important, are not enough". Negele (1998) and Womack *et al.* (2006, p. 112) reconfirm that the non-formalizable part of engineering, namely the creative human and her soft skills, is even more important for integrated NPD than all technical formalizable parts. Similarly, based on an empirical study of NPD projects, Ehrlenspiel and Meerkamm (2013, p. 131) concede in their handbook on integrated product development that “the previous opinion, that problems of practitioners lie mainly within technology, has to be corrected, since the human-organizational area is very decisive” (translated from the German original).

The importance of cultural aspects in cross-functional integration was already emphasized by pioneers of pertinent research fields. Burns and Stalker suggest to adopt a perspective of anthropologists to describe cultural differences between R&D and manufacturing as early as 1961 (p. 12-13). Lawrence and Lorsch (1967, p. 11) emphasize differences in the cognitive and emotional orientation between different functions. Griffin and Hauser (1992, p. 362) state that "one explanation of the difficulties of achieving cross-functional integration is that each function resides in its own "thought world"”. Likewise, the difficulty to capture those receives early attention. Brockhoff (1994, p. 11) views cross-functional interfaces as borders of subcultures, which are so complex and granular that “they are barely accessible for the typical empirical methods” (translated from the German original), with function-specific cultures between different companies even more similar than the subcultures of different functions within one company. Empirical studies confirm this importance of cultural differences as barriers for cross-functional integration – and that existing methods do not sufficiently consider those, see for example Song *et al.* (1997), Vandevelde and van Dierdonck (2003) or Lühring (2006, p. 56 ff.). In particular, differences in language as well as a “we vs. they” mentality stemming from a lower status of production as compared to R&D is observed. Technical specialization, which is constantly increasing, is widely regarded as the root cause why such cultural entrenchments will further deepen in the future.

Lastly, scholars note that the recognized importance of communication is insufficiently represented in existing methods for cross-functional integration. Certainly, many methods emphasize the importance of communication, however many fail to recognize that in a cross-functional context with all of its cultural barriers, this may be easier said than done. Teece (1999) confirms this tacitness of knowledge developed in functional organizations, building on von Hippel’s (1994) influential works on the stickiness of information. The proverbial “druids knowledge” of highly specialized functions or persons in large corporations represents an example thereof.

Over-emphasized complexity for industrial application

Empirical surveys to examine the acceptance of NPD methods in industrial applications of both Lindemann *et al.* (2001) and Grabowski (1997) state high theoretical burden and high implementation effort as important reasons for low implementation. These two critical arguments are reinforced in a broad variety of studies, which are outlined in the following.

To begin with, complexity and theoretical requirements of existing methods may be justified scientifically, however they encounter refusal in practice: “often the methods which can be found in literature are described much too complicate and fussy" (Lindemann *et al.*, 2001, p. 49). Minnaar (2012, p. 7) evaluates Concurrent Engineering, as one of the prominent methods enhancing integration at the design-manufacturing interface, to be "hugely complex", complementing that “large-scale concurrent design […] will call for computer power and capacity not yet available”. High coordination efforts, that result from such complexity, are further cited as important hurdles for industrial application (Kessler, 2000). Lindemann et al. (2001) and Bichlmaier (2000) therefore call for pragmatic and less abstract methods to optimize NPD.

High implementation efforts are repeatedly mentioned as another important hurdle for application, see for example Grabowski (1997), Prasad *et al.* (1993), Lindemann *et al.* (2001), Bullinger *et al.* (1995) or Gust *et al.* (2017). Furthermore, even after a successful implementation, time and resource efforts to provide continuously required input data prove to be high for many of the existing methods, further impeding industrial application. Indeed, the integration of CAD/CAM into NPD projects has shown to rather enhance complexity than reduce it. Additionally, different CAD/CAM systems for different functions, which are in most cases not compatible to each other, constitute further barriers to integration (Claus *et al.*, 2015, p. 131; Teece, 1999; Davenport, 1997, p. 227).

These arguments are likewise alarming for the future: Pressure to reduce both development costs and time will create further rejection of existing methods that are prone for high implementation efforts and high complexity (Gust *et al.*, 2017).

Insufficient recognition of situational and contextual factors

As a last stream of argumentation, existing methods are criticized to obscure or ignore important aspects of the reality in industrial corporate contexts, which might also cause their slow and insufficient adaptation.

To begin with, methods to enhance cross-functional integration are never implemented in a greenfield approach; they always encounter existing practices of organizing NPD, “which may have worked adequately and successfully, can generate a certain "stickiness" to the old mechanism” (Lorenz, 2008, p. 58). In particular, organizational barriers that sustain functional practices, such as functional reward systems or career paths, may undermine new approaches to NPD and therefore hinder industrial application (Vandevelde and van Dierdonck, 2003; Song *et al.*, 1997). Ettlie and Stoll (1990, p. 43) go as far as to claim that the core challenge of the integration at the R&D-manufacturing interface is “improving the coordination between groups that seem to have developed a largely independent, and in some respects, win-lose relationship with each other". For instance, organizational goal-setting often represents such a win-lose relationship: while R&D may have the technological breakthrough of a certain technology as a goal, production strives to minimize production costs, which often means exploiting old technologies to re-use production investments and exploit economies of scale. As other examples, careers are usually made within a functional chimney (Womack *et al.*, 2006, p. 114), and R&D is often organizationally structured by product lines, while production is structured by functions or plant locations (Calabrese, 2000). New methods for cross-functional integration should be aware of such mechanisms and actively address them; otherwise they risk to stumble upon them and be denied industrial adaptation.

In addition to that, corporate reality is often less rational than scholars may assume in plotting down academic methods to enhance cross-functional integration. For instance, corporate dynamics of leadership visibility and rewards may incentivize a culture of “firefighting” more than a stable process that anticipates potential problems with downstream functions, e.g. marketing or production, and integrates them in due time into the NPD process. Weinreich (2005, p. 208) mentions “territory egoisms” (translated from the German original). He describes that past conflicts in cross-functional collaboration may have represented “shocks” in the collective memory of a function that justify a blockade against any cross-functional integration for years ahead – even if this works against own objectives.

Another frequent accusation that is made against existing methods is that they lack situational and contextual adaptability: “[...] it became more and more apparent that the main problem is not that the necessary methods are lacking. The main problem is very often that, during their introduction, methods are not adapted to the given situation […]” (Lindemann *et al.*, 2001, p. 42). Cratzius (2003, p. 83) and Lühring (2006, p. 13) confirm this notion and complement that in particular for NPD, success or failure is significantly determined by contextual factors which often are ignored by existing methods.

Some scholars hold methodological shortcomings and researchers’ distance to practice accountable for practical deficiencies of existing methods: “Unfortunately much research into design is undertaken by researchers who don't have real insights into or knowledge of its practice” (Gill, 2007, p. 291). In a similar manner, Dougherty (1992, p. 195) obtains her influential findings on interpretive barriers between functions by grounding her research in practice, criticizing purely academic endeavours: “An extensive literature tells managers how they ought to develop new products, and how they ought to design their organizations for innovation. This study has examined product innovation in practice in order to understand why these prescriptions are not often achieved”. In their work on aspects of consideration in product development research, Björk and Ottosson (2007, p. 195) make a strong point towards the use of qualitative research, reasoning that “bad usability and/or low acceptability” of existing methods is the cause for insufficient industrial adaptation. They claim: “We have found that, to grasp what really happens on a daily basis in a development project, to get the opportunity to reflect upon it, and to understand the complex nature of a development process, it is necessary to conduct insider action research (IAR), which is a qualitative approach".

In summary, shortcomings of existing methods to enhance cross-functional integration include the negligence of socio-organizational factors, the over-emphasized complexity and theoretical burden for industrial application, as well as the insufficient recognition of situational and contextual factors of practitioners' reality.

5.1.2 Gaps in research on cross-functional coopetition

The newly emerged research topic of coopetition has experienced much popularity for a broad range of phenomena that exhibit both cooperative and competitive features. In particular for today's business environment, which steps back from the previously dominant competitive paradigm and turns towards a more balanced view that integrates cooperation, coopetition finds abundant resonance. Coopetition has proven its ability to shed light and provide theoretical backing on phenomena that seemed ambiguous and were unexplainable in the traditional categories of cooperation and competition. The research field has demonstrated its explanatory power on many levels of analysis ranging from the individual-focused micro level II up to the inter-network macro level.

Unsurprisingly, a research field this young exhibits blank spaces in its academic coverage; evident gaps relevant for the thesis at hand are summarized in the following. Scholars in the field of coopetition agree that the majority of research concentrates on the meso (inter-firm) level, while research on micro levels I and II (intra-firm) is very limited: "Only few studies focus on coopetition on the intra-firm level, i.e., coopetition between departments within a firm" (Strese *et al.*, 2016, p. 42). This notion is confirmed by five recent comprehensive literature reviews of Peng *et al.* (2012), Bengtsson and Kock (2014), Bouncken *et al.* (2015), Bengtsson and Raza-Ullah (2016) and Devece *et al.* (2017), concluding that only approximately 5% of articles examine the inter-firm level of coopetition. Nonetheless, many scholars point towards the importance and attractiveness of this level of analysis, see for instance Yami *et al.* (2010b) or Strese *et al.* (2016).

Furthermore, there remains a lot of ambiguity in existing studies on the impact of coopetition on several performance dimensions. No clear statement of impact patterns can be derived, as conceptions and research designs are still heterogeneous and selective with regard to their context or scope. Environmental and organizational contingencies are still largely unknown: Under which circumstances and in which contexts is coopetition effective? (Bouncken *et al.*, 2015)

In addition to that, the current state of research is characterized by methodological monotony. Relevant empirical studies on cross-functional coopetition build exclusively on quantitative survey data, with a resulting flatness of explanations and theoretical derivations. Ghobadi (2012) even finds statistical bias in prevalent studies within the field of cross-functional coopetition. More precisely, she accuses the empirical efforts of Luo *et al.* (2006) and Lin (2007) to build on biased interpretations in their results. Cross-functional coopetition researchers' incline on survey data is surprising, as other levels of analysis in coopetition research build strongly on evidence from case studies and qualitative research. Explicit calls for in-depth qualitative case study research are frequent, e.g. by Gnyawali and Park (2009) and Bengtsson and Kock (2014). Strese *et al.* (2016) mention the inherent complexity of coopetitive phenomena that forbid reduction to just a single factor; while qualitative research would be capable to cover a large variety of different aspects and factors in an iterative manner. In addition to that, several authors call for an in-depth analysis of the core dynamics of coopetition, on an operational level that looks at coopetitive behaviour going well beyond a mere question of whether there is coopetition and what its impact is (Ghobadi, 2012; Tidström, 2008; Fernandez *et al.*, 2014). Lastly, a process perspective of coopetition is often called for (see for example Yami *et al.*, 2010b), which would require a longitudinal analysis of a single case. Again, this suggests the use of qualitative research in a case study approach.

Cross-functional coopetition has rarely been applied to an NPD context, with the mere exemption of Lin (2007). This is in so far surprising as on other levels of analysis, in particular the meso level, NPD is one of the most prominent fields of applications of coopetition. Here, coopetition is generally judged to have a positive impact on innovation, as it facilitates knowledge sharing and capability build-up, and simultaneously encourages to engage in creational activities by its competitive element. On the meso level, potential contrary effects such as opportunistic behaviour leading to intellectual property leaks can mitigate these positive effects; on the micro level, this might naturally be less harmful. Hence, there is reason to presume that coopetition on a cross-functional level of analysis may positively spur innovation. Several scholars support this call to look into cross-functional coopetition in a NPD context, see for example Bouncken *et al.* (2015), Strese *et al.* (2016) or Meuer (2015), who suggests that studies on the context between cross-functional coopetition and NPD performance are rare although the correlation is existent and possibly has a huge influence at innovative departments within corporations. Lin's (2007) results hint into the same direction.

As another point, it is interesting to note that solid bridges between the two research areas of cross-functional integration and cross-functional coopetition have not yet been established. Research generally takes a different level of perspective in each respective topic and hence treats them as rather separate fields of research. However, the explanatory power which lies in coopetition to elucidate controversial aspects of cross-functional integration has not gone unnoticed; several scholars point towards fruitful results that may be expected from this connection.

Lin (2007) describes how existent studies examine either cooperative or competitive interactions between functions, with the cooperative side being covered by many studies in the realm of cross-functional integration, and the competitive side often focusing on conflicts with a positive or negative relationship on new product performance. Lin (2007, p. 3), closes with a call “to understand how these seemingly conflicting relationships interplay”. Luo *et al.* (2006) set out from a similar perspective, reaffirming that knowledge transfer in a cooperative manner is essential to achieve cross-functional integration, while on the other side it is corporate reality that functions likewise compete for resources and power. Luo *et al.* (2006, p. 67) conclude that these seemingly conflicting aspects are simply features of corporate reality, and research should be encouraged to dissolve or at least describe this issue: "Thus, the question is whether competing departments can effectively cooperate with one another to enhance organizational learning and performance. More generally, how should firms strategically manage cross-functional competition and cooperation to achieve competitive advantage?” Likewise, Luo *et al.* (2006) recognize that in cross-functional coopetition, the whole may be more than the sum of its parts. Cross-functional coopetition may well offer deeper explanations and encourage better performance than cooperation and competition alone would be able to: “[…] cross-functional coopetition recognizes that interdepartmental conflict is not always unfavourable and can even produce specific benefits” (Luo *et al.*, 2006, p. 69). Indeed, Dagnino and Padula (2002) provide a precise example thereof. They refer to Clark and Fujimoto’s (1991, p. 71 ff.) influential research on Japanese car makers, which were able to win over Western carmakers in terms of new product performance by means of better cross-functional integration. Whereas this has been attributed to “traditional” cross-functional integration by researchers in this field, Dagnino and Padula make clear that cross-functional coopetition may have contributed significantly: Japanese carmakers assigned car development projects to cooperating teams, which were often competing on the same project, with several teams simultaneously cooperating-competing for one car project. Dagnino and Padula (2002) conclude that, while a Western perspective may consider this as redundancies, this approach enabled to speed up the process and smooth the transition from a functional department to another, with positive consequences on NPD success.

5.1.3 Gaps in research on constraints in NPD

Constraints of all kinds and sorts seem to shape every task of new product development. This alone constitutes an intuitive interest in their impact as a research field. Scholars from very different disciplines fulfil this endeavour, leading to a heterogeneous and non-uniform patchwork that leaves many gaps and connections as blanks, many of them promising as new fields for research activity. In the following, evident gaps are identified, and specifically interesting spaces for further research are highlighted.

A common, and maybe the most prominent question discussed in this field of research is whether constraints have a positive or negative impact on innovation. Despite of all efforts, this central question is yet left unanswered. The ambiguity of existing results and a resulting call for enhanced in-depth research to understand dynamics and contextual factors that may influence them is uttered by many scholars from various disciplines, see for example Weiss *et al.* (2011), Hoegl *et al.* (2008) or Hatchuel and Chen (2017). Qualitative research, until now somewhat a rarity within constraint research, might help to shed light on missing links and provide a deeper understanding of the topic.

Another evident gap is the scarcity of empirical research on an intra-organizational level of analysis. This is particularly critical, as most innovative endeavours are executed on a team or department level (Hoegl *et al.*, 2008). Therefore, the intra-organizational level deserves a stronger academic focus (Rosso, 2014) which is currently left unanswered.

A further blank space within existent research refers to the type of constraints that is being analysed. Financial, or more general resource constraints or process constraints, make up the largest part of current empirical research. On the other hand, product constraints, and product properties in particular, are underrepresented, even though a few existing data points suggest that those have a positive impact on innovation performance. This strongly suggests to examine both product and process constraints in a comparative research effort.

Lastly, existing research that tries to grasp a deeper understanding of constraints' impact in the absence of large panel data focusses in large parts on particular circumstances, often involving start-up companies or bottom-of-the-pyramid situations. By contrast, comparable studies on incumbent corporate settings are rare.

As explained above, the role of constraints in an innovation context is intuitively interesting through their omnipresent, even proverbial existence in creative tasks. In this respect, it is surprising to note that research has not yet gone beyond a superficial level of analysis in the innovation space: Until now, most research efforts concentrate on the role of constraints on either innovation performance or creativity; both being quite abstract terms that are difficult to seize or measure. The author follows Hoegl *et al.* (2008) in stating that there must be mediating aspects that explain the wide and abstract relationship between constraints and innovation performance in more detail: Perhaps, constraints affect an antecedent rather than innovation performance itself. Such an analysis could likewise have explanatory potential for result ambiguity as explained above, and would likewise help to make the relationship between constraints and innovation performance easier to capture and understand in-depth. To the author's best knowledge, up to now Weiss *et al.* (2011) made the only research effort in this direction when examining constraints' impact on team climate and cooperation. Continuing on this path by analysing other potential antecedents of innovation performance as dependent variables on constraints' impact, seems both feasible and interesting.

Regarding the broader scope of research on constraints' impact on innovation performance, it can be observed that they mostly study constraints as a given feature of a certain setting. This involves questions of whether, and to what degree, constraints are existent, as well as analyses on what impact these constraints have.
On the other side, research on constraints' impact on creativity takes another approach: Here, scholars often intentionally employ constraints as instruments to enhance creativity. A large part of results herein confirms constraints' positive impact on creativity; hence scholars have understood how to make use of constraints as deliberate instruments to foster creative problem solving.

Bridging this gap by an intentional employment of constraints to trigger a certain purpose within an innovation context would likely reveal insightful findings. Not only might this constitute a method how behaviour in NPD can be steered into a desired direction, but it might also be a method of uttermost simplicity (Bix, 2017).

5.2 Topic discussion

In the following, the identified gaps in research are taken as a starting point and integrated into a study design that guides the empirical part of the thesis at hand. Illustration 23 offers a (significantly reduced) summary of the argumentation in this chapter.

To begin with, the widely accepted opinion of researchers from different disciplines is reaffirmed: Cross-functional integration is an important antecedent of NPD success. This is broadly reaffirmed for different measures of NPD performance and different conceptions of cross-functional integration.

Building on identified shortcomings calling for a better and deeper understanding of cross-functional integration in a NPD context, a qualitative case study design is suggested, which is able to capture cross-functional integration in its entire complexity and includes an explicit consideration of contextual, social and organizational factors. Furthermore it is suggested to focus on the often ignored interface between R&D and production, as this has the potential to reveal new insights which might help complement missing links in this field of research.

Moreover, to encounter deficient industrial application of existing methods and identified reasons thereof, a new approach is to be developed in the course of this thesis, striving for simplicity in industrial application and allowing for consideration of socio-organizational and contextual adaptations, otherwise it would fail to create an added value for both academia and practice.

The application of coopetition on an intra-organizational level in an NPD context seems promising, albeit barely researched hitherto. Likewise, the connection between the two fields of cross-functional coopetition and cross-functional integration has not been thoroughly explored. These research gaps suggest to benefit from coopetition's explanatory power to examine remaining gaps of cross-functional integration in NPD. Existing empirical applications show that coopetition is more than the sum of its parts, cooperation and competition, which might allow for insightful results in deploying it to a setting of cross-functional integration.

So far, different research streams within the research field on constraints in innovation make up a patchwork of promising results and interesting academic gaps, with a comparative application of different constraint types in an intra-organizational context being one of those gaps. In the emergent, yet non-unified field of research on constraints' impact on innovation performance, a logical next step would be to substantiate this wide and abstract relationship, perhaps by examining constraints' impact on one of the antecedents of innovation performance, e.g. cross-functional integration. Most important, empirical studies on constraints' impact on creativity suggest that constraints may be utilized as purposeful instruments to trigger a certain behaviour in an innovative activity. Therefore, an attempt could likely be made to introduce constraints to foster cross-functional integration. Due to its presumable simplicity and adaptability to contextual aspects, this may be the basis for a new approach to enhance cross-functional integration as postulated above.

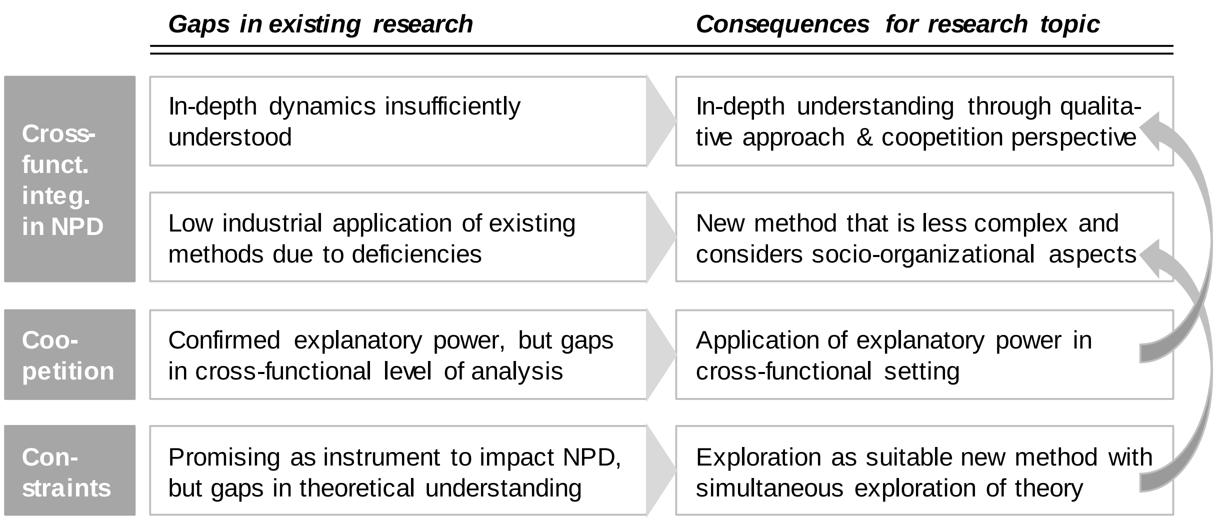

Illustration 23: Summary of research-based topic discussion

In summary, evident shortcomings are integrated to form a research topic as follows: A first part of the research topic aims at elucidating remaining gaps in the in-depth understanding of cross-functional integration in NPD, in particular at the design-manufacturing interface. The explanatory power of cross-functional coopetition is applied to this end; likewise, a qualitative research methodology is proposed. A second part of the research topic follows the call to develop a new, simplified method that is able to consider situational and socio-organizational aspects. For this purpose, the introduction of constraints shall be explored.
In the following, details of the topic and the study design will be outlined.
The research topic can be divided in two parts: The first part engages in an in-depth analysis of cross-functional integration in NPD from a coopetitive perspective. The second part explores a new approach to enhance cross-functional integration in NPD through the introduction of constraints.

For both parts, the explicit inclusion of contextual, social and organization factors is important. This requires a strong empirical grounding as an essential feature of the research approach, because situational aspects of the empirical setting have to be captured in detail. Likewise, the exploratory nature inherent to the development of theory for a new method is calling for qualitative research as well. In the light of those considerations, a qualitative case study approach is a favourable option. Further methodological details are discussed in the methodology chapter of this thesis. Secondly, a large-scale industrial environment is suggested as empirical setting.

For both parts of the research topic, cross-functional integration at the interface between design and manufacturing in a NPD context is the main object of analysis.

For the first part, the in-depth analysis, a cross-functional coopetitive perspective is taken to illuminate the dynamics. For this purpose, the connection between cross-functional integration and cross-functional coopetition is analysed. Cross-functional coopetition is conceptionalized according to Luo *et al.* (2006), which covers dimensions of cooperative intensity, cooperative ability and competition and constitutes a reliable and empirically tested continuation of existing research. Naturally, the original survey items are translated into questions suitable for qualitative research; details are provided in a later part of this document.

In the second part of the empirical study, the introduction of constraints to enhance cross-functional integration in NPD is explored. To be more concrete, its feasibility to serve as a theoretical grounding for a new method shall be analysed. This basic idea needs translation into the empirical setting at the design-manufacturing interface of NPD which can be described as follows: In NPD, production activities occur downstream of R&D activities. Consequently, constraints are formulated from a manufacturing perspective and therefore express concerns of manufacturability. For illustrative purposes, if the interface between R&D and marketing would be in the focus, constraints could express concerns such as customer usability or brand suitability. In this study's case, manufacturability constraints may cover diverse aspects that differ in their respective constraint type. For example, a constraint on a maximum number of fastener elements is a product constraint, whereas a constraint on maximum costs of assembly is a financial constraint.

This generic design of constraints builds on findings from research: First, they have to be easily understandable and reproducible, and second, they have to be introduced in early stages of the NPD process and therefore be integrated in an upstream activity.
To begin with, the simplicity requirement is supported by psychological mechanisms in the design process. Opposed to a rational and systematic conception of the design process which is widely acknowledged as an industrial standard (e.g. by VDI 2221), the actual design process follows opportunistic shortcuts and a path-of-least-resistance strategy to reduce cognitive efforts. In addition to that, the limited human working memory forces designers to focus on a partial aspect of a problem solving task. Constraints, when formulated simple and understandable enough, help to put the right features into the designer's focus and to help re-target essential aspects; they may likewise serve as objectification gauge. Minnaar and Reinecke (2012), Römer and Pache (2002) and Ehrlenspiel and Meerkamm (2013, p. 156) offer further insight, why simplicity of information provision in the engineering design process is essential.
Second, the imperative for early integration of constraints is grounded in the fact that the lion's share of costs occurring over the entire product life cycle is determined in early phases of NPD. Therefore, design, which is typically an early phase NPD activity, determines costs that downstream functional areas such as manufacturing are bound to bear. Furthermore, constraints may help to dissolve the related central paradox in NPD: Consequences on downstream stakeholders are the easiest to impact when they are the hardest to assess. Introducing constraints in a very early phase of NPD discharges the difficult requirement of early assessment by downstream functions, while benefitting from the ease of impact in early phases: Concerns of downstream functions are simply introduced as constraints for the design phase.

Two aspects of constraints are of interest when examining their impact on the cross-functional integration at the design-manufacturing interface: *constraint type* and *organizational embedding*.
Illustrative *constraint types* of manufacturability constraints have been described above. From the research on the impact of constraints on innovation performance, the author has substantial reason to assume that the impact will differ in dependence of the type of constraint that is applied.
The term *organizational embedding* shall include all relevant factors of social and organizational nature that accompany the introduction of constraints. This ranges from an incentivization connected to the fulfilment of the constraint to the level of leadership

which is made responsible for the fulfilment of the constraint, with details being provided at a later part of this thesis. Prevalent theory on cross-functional integration suggests that these socio-organizational factors are of uttermost importance and hence are likely to influence the impact of constraints on cross-functional integration.

Furthermore, it will be interesting to examine the impact of the introduced manufacturability constraints on creativity. Therefore, the question whether manufacturability constraints foster or impede creativity in R&D's design tasks is suggested as part of the research topic, likewise in which constraint type and under which organizational embedding this occurs. While this is not related to cross-functional integration itself, creativity is an unquestioned antecedent of NPD performance just as cross-functional integration is. As the impact of constraints on creativity is unmistakably interesting, it is included into the research topic.

5.3 Research model and research questions

The proposed topic can be illustrated in a research model, which depicts essential relationships that are to be analysed and the respective dependent and independent variables. While this is not as typical for qualitative research efforts as it is for quantitative models, case study methodology experts support such an illustration to foster rigidity in the research approach (George and Bennett, 2005). Nonetheless, the interpretation of a qualitative research model is somewhat different. While relationships and variables that are in the centre of the empirical analysis can be depicted, no measurements for the variables can be provided up-front. Whereas questionnaires for semi-guided interviews, as they will be discussed later in this thesis, contour a variable in a wide circle, concrete measurements emerge iteratively in the research process. Indeed, this is one of the strengths of qualitative research and will be argued in detail in the methodology chapter of this thesis.

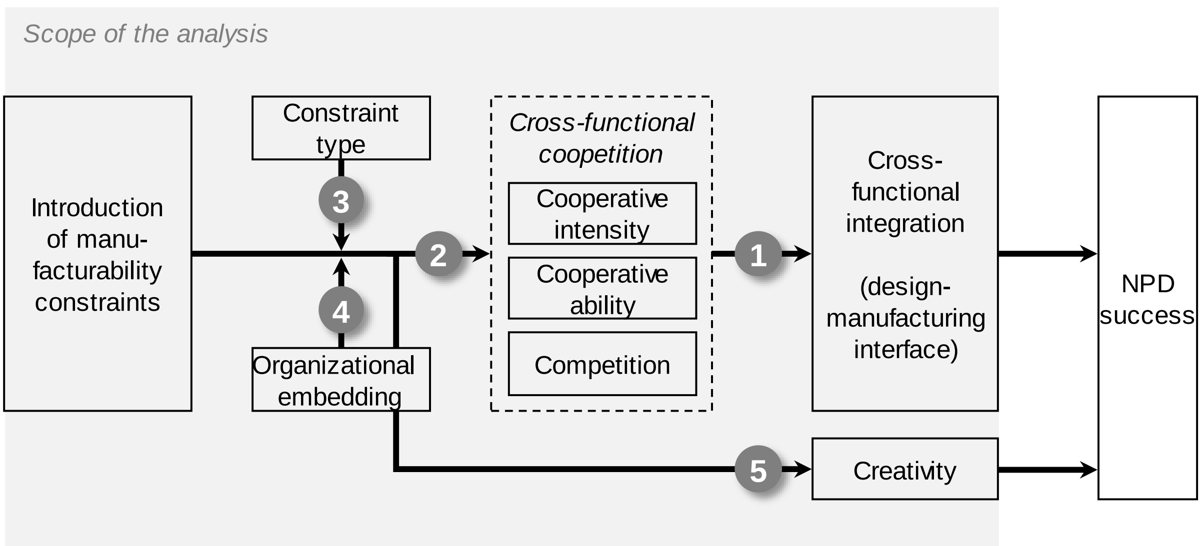

Illustration 24: Research model with research questions 1-5

There are five research questions to guide the empirical study. They are listed below and will be explained in the following. In addition, research questions are marked at corresponding places in the research model, depicted with a number. While research question 1 covers the first part of the research topic, the in-depth analysis as described above, research questions 2-5 all have to do with the second part on the introduction of constraints.

1. *How does cross-functional coopetition impact cross-functional integration at the design-manufacturing interface of NPD?*
2. *How does the introduction of manufacturability constraints impact coopetitive behaviour at the manufacturing-design interface?*
3. *What is the moderating impact of the constraint type on this relationship?*
4. *What is the moderating impact of the organizational embedding on this relationship?*
5. *How does the introduction of manufacturability constraints impact creativity?*

Research question 1 guides the in-depth analysis of cross-functional integration at the design-manufacturing interface of NPD. The relationship to cross-functional coopetition is expected to shed new light on the in-depth dynamics of cross-functional integration. Therefore, cross-functional coopetition at the same interface is analysed likewise, captured along the three dimensions laid out by Luo *et al.* (2006), cooperative intensity, cooperative ability and competition. The author assumes that there are many interlinkages between cross-functional integration and cross-functional coopetition, and likewise a few differences. Both are expected to elucidate the in-depth dynamics at the design-manufacturing interface. “How”, and not “what is the impact” is being asked, because it is the underlying dynamics at the core, expressed by “how”, which lies in this study’s interest.

Research question 2 investigates the introduction of manufacturability constraints: How will the introduction of these constraints impact coopetitive behaviour at the same interface that has been analysed in-depth in research question 1? New scientific territory is explored here, therefore no substantial predictions can be made with regard to the outcome of research question 2. Again, this study strives to understand the underlying mechanics, therefore asking “how”.

Research questions 3 and 4 cover moderating effects, that constraint type and organizational embedding are likely to have on the dynamics examined in research question 2. Its specific dynamics and direction are the subject to be explored. Striving for rigidity in the explorative qualitative research approach means that measurements describing the vague variables constraint type and organizational embedding will only emerge grounded in the empirical setting and hence will be described later in this document.

Research question 5 is not related to the questions around the main subject of analysis, which is cross-functional integration. However, when examining effects and mechanics that emerge from the introduction of constraints within NPD, questions on a potential impact on the creativity of problem solving at this interface arise almost intuitively. Furthermore, just as cross-functional integration is not regarded as an end in itself, but in the broader context of its importance for NPD success, creativity can equally be considered as an aspect certainly important for NPD success.

To summarize it, the thesis at hand aspires to make four major contributions to research by engaging in the outlined empirical effort. They are described in the following.

1. *In-depth understanding of the dynamics of cross-functional integration in NPD*: The employed qualitative research method herein is a major contributor, allowing to capture contextual and socio-organizational factors as well as to seize a holistic understanding of all involved dynamics in the absence of limitations from a finite number of survey items. Besides, taking a coopetitive perspective on the cross-functional integration offers further explanatory power. In addition, the outlined research effort brings light to the underresearched design-manufacturing interface.

2. *Theory on a new method to enhance cross-functional integration*: A new approach based on the introduction of constraints is explored that mitigates identified deficiencies of existing methods: less complex in industrial application and conducive to socio-organizational and contextual adaptations. Likely moderating factors, constraint types and organizational embedding, are simultaneously examined to give substance to theory development. This new approach may as well serve as a theoretical basis to explore other purposes than cross-functional integration at the design-manufacturing interface. Other interfaces, e.g. design-customer or design-environmental stakeholder, could potentially make use of a similar method and introduce their respective constraints to enhance their integration in the NPD process.

3. *Bridging gaps of coopetition research:* The thesis at hand helps to bridge two evident gaps in coopetition research. First, empirical research on the cross-functional level of analysis (micro level I) is scarce; with qualitative research being non-existent and the NPD context only considered in one exemption. Therefore, this thesis constitutes an important contribution on this field. Second, the relationship between cross-functional integration and cross-functional coopetition is for the first time systematically explored in the research project at hand.

4. *Bridging gaps of constraints in innovation research:* For the nascent research fields of constraints in innovation, several contributions can be made. To begin with, a qualitative research effort on the core dynamics is likely to shed new light on the unsolved conflict whether constraints have a positive or negative impact, and under which contextual circumstances this becomes effective. The comparative analysis of the impact of different constraint types will help to explain this conflict and will bridge another gap evident in the existing research. Subsequently, a contribution can be made to the intra-organizational level of analysis, which yet remains barely researched, yet essential for innovation. In addition to that, empirical research on the impact of constraints on innovation in an incumbent company setting, as opposed to the more often analysed start-up or bottom-of-the-pyramid settings, constitutes another contribution. Lastly, the still abstract relationship between constraints and innovation performance is explored to create a more tangible and reliable understanding by analysing two important antecedents of innovation performance: cross-functional integration and creativity.

6 Design of the empirical study

6.1 Research methodology

6.1.1 Choosing the appropriate methodology

Setting out from discussed shortcomings of extant research and the formulated research questions, the choice of qualitative research as a suitable methodology needs to be discussed in further detail. To begin with, characteristics of qualitative research will be discussed that allow to make up for identified shortcomings. Subsequently, features of qualitative research will be outlined that support answering the designated research questions.

„No cleavage has been as persistent or as vociferous as the qualitative versus quantitative debate“ (Gerring, 2012, p. 362). Quantitative research methods that focus on inferences made from large numbers of empirical data dominate text books. On the other hand, qualitative methods, drawing inferences from few data observations by means of causal-process observations, have experienced growing recognition from academic research in recent decades. While qualitative research is often still accused to be only of preliminary nature and less scientifically relevant due to the small sample size, quantitative methodology does not remain undisputable either: “Thankfully, however, the formal logical approach to scientific method has lost a good deal of its former luster” (Weinberg, 2002b, p. 2). Quantitative approaches are held responsible for decoupling research from practice: Utilization research has demonstrated that findings of mainstream research often lack practical application due to required abstraction levels and the resulting distance from the original object of analysis. For the analysis of social, managerial and organizational phenomena, where the object of analysis is human, this constitutes a particularly significant shortcoming (Gerring, 2012, p. 362 ff.).

Social and organizational aspects that have been found essential for the research study at hand, strongly suggest taking a qualitative approach. Undoubtedly, interface integration of large-scale industrial departments in technically sophisticated innovation projects in itself is a complex matter. Additionally, as highlighted in section 5.1, a central shortcoming of existing research is strongly interrelated with contextual factors of the real-life work surrounding. In particular, complex relations between situational characteristics, organizational mechanisms and the social interplay at the interfaces are considered as central aspects for research success. While quantitative research methods have difficulties in dealing with such complexity and resulting ambiguity of data, qualitative research offers explanations of complex phenomena that cannot be reduced to a certain set of variables (Gephart, 2004). Björk and Ottosson (2007, p. 195) explicitly recommend engaging in qualitative research to generate an in-depth understanding of the complexity of NPD processes: “The transfer of research findings over to industry has been shown to be slow and incremental, which could be seen as a result of bad usability and/or low acceptability in research findings from studies on industrial product development processes. According to our research and practice experience, we have found that, to grasp what really happens on a daily basis in a development project, to get the opportunity to reflect upon it, and to understand the complex nature of a development process, it is necessary to conduct insider action research (IAR), which is a qualitative approach.”

The author believes that ambiguous and even partially contradictory results of large-scale quantitative surveys studying cross-functional integration in a NPD context may be explained by the insufficient capability of the chosen methodology to illuminate complexity. Surveys that scale down complex phenomena to indicators may entail too many presuppositions and hence open the door for diverging interpretations by survey respondents, such as in the following example from a survey questionnaire from Brettel *et al.* (2011, p. 266): “In the development phase R&D and manufacturing exchanged large amounts of information”. By generating an in-depth understanding of contextualized subjective perceptions and making use of “richness” of raw qualitative data, qualitative research is better positioned to succeed in explaining complex phenomena (Weick, 2007).

Additionally, the study at hand goes beyond analysing the mere existence and form of cross-functional integration; underlying social mechanisms as well as organizational and situational antecedents shall be explored. Reflectivity regarding unexpected insights from the field, openness to unanticipated events and the ability to adapt diverging subjective perspectives are inherent features of qualitative research methods that are believed to support this research goal. In particular, when it is supported by an interpretative theoretical view, as will be explained in the subsequent chapter, qualitative research is able to explain how social experience is constructed and to identify preunderstandings as well as language constructs. Participants in qualitative research are free to emphasize what is relevant to them and can present it in their own context, rather than being restricted to a presupposed conception framework or study design. All of the mentioned will help to “dig deeper” and find the underlying mechanisms behind the occurrence or non-occurrence of cross-functional integration.

Research questions 1, 2 and 5 as developed in chapter 5.3 strive towards generating an in-depth understanding of integration mechanisms, hence employing “how” questions. Following Flick (2014, p. 153) and Pratt (2009), qualitative research is well suited to answer such questions. Research questions 2, 3 and 4 aim at acting out the new and fairly unformed idea of introducing constraints to enhance integration, and, if possible, develop a theory to substantiate the idea. Accordingly, the central objective of the thesis at hand is theory development. Yin (2013, p. 9 ff.) suggests explorative qualitative research for such studies that lack pre-existing prepositions, yet state a clear purpose. Most applications of qualitative research abstain from tacit and implicit assumptions, thus making theory less a starting point to be tested but an end to be developed, hence encouraging exploratory research. This entails that any generalization, which can be made from the empirical data, is theoretical in nature, and not statistical. A statistical generalization, typical for large-scale quantitative research methodologies, aims at generalizing empirical results to the entire population by ensuring the empirical data’s representativeness. Naturally, a case study with its low *n*, cannot strive for statistical representativeness, instead it aims at theoretical generalizability. This means that the dynamics that emerge from the empirical data can be generalized in theory, therefore substantiating the central claim for theory development.

To attain necessary analytical and explanatory depth, the researcher needs to have profound access to the examined phenomenon going well beyond a superficial insight from an outside perspective. Following Paashuis (1998, p. 78), complex subjects whose boundaries to the context are not clearly evident and for which the context might play a constitutive role, should encourage an “empirical inquiry that investigates a contemporary phenomenon within its real-life context". Likewise, Gerpott (2005, p. 120) criticizes existing empirical research in integrated new product development to be of “partial analytic nature”, only analysing a narrow set of influence factors and lacking an in-depth holistic understanding that would require exclusive access to real-life mechanics of new product development, which only a qualitative case study is able to offer.

In conclusion, the above listed requirements strongly suggest a qualitative case study design featuring participative observation. Therefore, this research design is chosen as the research methodology to guide the empirical study in this thesis.

6.1.2 Underlying epistemological program

According to Silverman (2010, p.332), any methodological choice is inextricably linked to epistemological and ontological issues. The epistemological program provides the theoretical fundament for any research concept and guides decisions regarding the research design, validity criteria and research goal (Flick 2015, p.80). While the present subchapter is not aimed at delivering a complete account of various epistemological notions, it strives to explain underlying epistemological assumptions that guide the chosen qualitative research approach of the thesis at hand. Following Corbin and Strauss (1990, p. 13), it is particularly important for qualitative researchers to understand the very basics of what they are doing, as qualitative approaches tend to lack the rigid “boilerplate” (Pratt, 2009, p. 856) structure that other methodologies can offer.

Most researchers would probably agree with (Weinberg, 2002b, p. 3) that science’s ultimate goal should be “to grasp the true nature of our surroundings and ourselves.” Positivism and constructivism are two opposing epistemological programs that provide guidelines how this can be achieved.
Positivism goes back to August Comte (Comte and Dupouey, 1989 (1830-1842)), who encouraged scientists to use inductive inference to detect generalizable patterns from empirical observations. After becoming one of science philosophy central’s question, it excited a discussion whether empirical observations, as predictable as they may occur, can possibly be developed to become universal law. Karl Popper’s falsificationism (Popper, 1971) utters substantial doubts regarding any universal truth derived from empirical facts and limits generalizations to mere scientifically probable statements, but nevertheless abides to a scientific principle of inferring generalizable outcomes from empirical observations. For the majority of researchers to follow, this view remains the general guidepost (Flick, 2005, 2015; Weinberg, 2002b, p. 5).
Constructivism, by contrast, is an opposing epistemological view subsuming several ideas that question science’s ability to find a true, generalizable nature, even questioning the existence of such a truth altogether. The most pronounced forms of social constructivism suggest focusing research primarily on the process of concept development at both sides, participant and scientist. They regard language to be a constitutive, rather than a representative, aspect of reality (Kuhn, 1970; Flick, 2015, p. 246).

With their opposing epistemological principles, both sides seem irreconcilable and leave it to the respective researcher’s judgement, which one is to guide his or her research. However, Flick (2015, p. 190) suggests that both programs may work well side by side for different empirical purposes.

The author of the thesis at hand takes a moderate constructivist perspective adhering to Wilson's interpretative paradigm, that postulates to reflect participants' background assumptions and gives room to their respective subjective perspectives (Flick, 2015, p. 90; Wilson, 1970). The adherence to this epistemological program is reflected in the overall design striving for a subjective in-depth understanding, the semi-structured interview procedure, large subjective accounts of participative observation and the research goal of theoretical, rather than statistical generalization.

6.2 Case study design

6.2.1 Design approach: Connecting theory and empirical data

Following the argumentation of chapter 6.1, it can be concluded that a qualitative case study design with participative observation is the appropriate methodology for the empirical questions of the study at hand. Further details of this research design need to be discussed in the following, as existing methodological examples offer several design approaches of how theory and empirical data are connected within the frame of such a research design.

At its core, the scope for this discussion is limited by the two extremes of a purely deductive or purely inductive design: Is theory developed exclusively from the empirical data without any previous theoretical propositions or does theory serve as a starting point for the empirical endeavour? A strict deductive design is frequently followed in quantitative research approaches to test existing theory through empirical data. Clearly, research that aims at theory development, as opposed to theory testing, is recommended taking a rather inductive approach. However, different perspectives exist to which degree an inductive research strategy has to avoid theoretical premises to start off. Within qualitative research, the most uncompromising representatives herein are scholars of grounded theory. Glaser and Strauss (1967) originally developed grounded theory, heavily arguing against what they call armchair theorizing: They reproach traditionally working scholars to develop theory that is detached from its empirical context, and to only rely on empiricism when looking for data to substantiate what is already developed. Quite contrary, the use of grounded theory obliges to build theory exclusively from empirical data. Accordingly, even a prior literature review is suspected to distort a pure perspective (Glaser and Strauss, 1967, p. 13 ff.)). Other scholars within qualitative research criticize this extreme view and argue for a more compromising attitude towards prior theorizing, e.g. Corbin and Strauss (1990, p. 49 ff.) in a later representation of grounded theory. Alvesson and Karreman (2007, p. 1265) deny that a strict separation between theory and empirical data is possible in the first place: "Data are inextricably fused with theory". Yin (2013,

p. 37) sees this debate as a defining criterion, where case study theory differs from related qualitative approaches such as ethnography or grounded theory. While he allows for a broad spectrum of research strategies within case study design, a purely inductive strategy is not recommended. Instead, Yin (2013, p. 29 ff.) explicitly suggests to pre-develop theoretical propositions before going into data collection.

This research study follows Yin (2013, p. 29 ff.) to connect theory and data. While engaging in an inductive research strategy in the empirical work, the author has discussed relevant theory in detail (chapters 2-4) and developed preliminary theoretical constructs (chapter 5). With regard to the inductive research strategy, Gioia *et al.* (2013) is followed. Gioia *et al.* (2013) unify an inductive focus with scientific rigor, while suggesting some prior theory consultation. Details on this research strategy are provided in subsequent chapters on the data analysis.

6.2.2 Case study design

Case studies are defined as “rich, empirical descriptions of particular instances of a phenomenon that are typically based on a variety of data sources” (Eisenhardt and Graebner, 2007, p. 25). As a fundamental difference to scientific experiments, which aim at eliminating all contextual interfering factors, case study evidence explicitly embraces contextual factors and includes them as part of the object of analysis. Case studies represent well-suited research designs for theory development, as theory emerging from them is likely to be highly relevant for practitioners due to their empirical roots: “Indeed, papers that build theory from cases are often regarded as the most interesting research” (Eisenhardt and Graebner, 2007, p. 25). Additionally, they tend to complement quantitative research well, as theory that is inductively developed through case studies can be tested deductively in quantitative studies (Eisenhardt and Graebner, 2007; Eisenhardt, 1989).

Several case study designs may be distinguished, with each applying for a different context. Stake (2010, p. 16) differentiates between intrinsic, instrumental and collective case studies. Under his definition, intrinsic case studies are purely descriptive comprehensive accounts of a certain incident with no ambition to generalize beyond this case. Instrumental case studies, again, deal with one single case, but aim at generating deep insights on a particular issue and develop theory from it. Lastly, collective case studies compare several cases to elucidate a known problem in more detail.

Yin (2013, p. 49 ff.) distinguishes four basic designs, applying less focus on the respective purpose. Generally, he differentiates between single-case designs and multiple-case designs. For both categories, holistic and embedded designs exist, depending on whether one holistic perspective on the unit of analysis is taken or several perspectives are screened. Whereas multiple cases allow to shed more light on a known problem by comparing outcomes and dynamics in different settings, Yin

(2013, p. 51 ff.) emphasizes different legitimate rationales for single designs. This includes a single-case design's unique ability to study a particular setting in-depth and with a longitudinal focus. Therefore, it is particularly well-suited to develop or extend theory from it and to justify exclusive access, which researchers might not be granted if involved in several comparable settings for a shorter period of time. Siggelkow (2007) and Eisenhardt and Graebner (2007) counter potential doubts with regard to a single-case designs' persuasiveness: They point towards the aim of theoretical generalization, and not statistical generalization, and emphasize that indeed, theory building from case studies is quite objective due to its close adherence to the original data.

With regard to the different case study designs, this thesis corresponds to the following: Due to my ambition to shed light on in-depth dynamics and to take a detailed consideration of contextual, organizational and social factors, I engage in a single-case design. In its purpose, it is instrumental in nature, and aims at covering a "typical" setting in a large-scale industrial environment of NPD to be able to develop theory relevant to a broad range of applications. As will be explained in more detail in chapter 7, the case concerns the NPD of electrified powertrains at the premises of a large-scale German automotive manufacturer. I was granted exclusive access to dynamics of all levels and on a longitudinal scale. Besides a single-case design, I engage in an embedded design, as research questions 2-5 cover a comparative analysis of different constraint types.

Regarding the overall structure for the case study report, a linear-analytic structure is chosen with elements of theory-building. This choice is justified on grounds of Yin (2013, p. 187 f.), who suggests this structure as the preferable guideline to support a single-case study's exploratory nature.

As a conclusion, the case in the thesis at hand follows an instrumental single-case embedded design with exclusive access. The next chapter on participant observation illustrates how the exclusive access is best used to generate the aspired in-depth understanding of the case at hand.

6.2.3 Participant observation

In the previous chapter, benefits from the envisaged case study design were outlined, which take advantage from an exclusive research site access to understand underlying dynamics of the considered case. To exploit these benefits, the researcher needs to engage with the case context in an active way, featuring both observant and participative traits. Within this spectrum, different forms of participant observation can be characterized with respective applications for certain purposes and settings. As different roles with varying closeness to the field context require different safeguardings to maintain objectivity, the researcher's role in the field must be reflected upon. In the following, different roles are discussed with respect to their suitability for the case study at hand.

Participant observation can be defined as “a field strategy that simultaneously combines document analysis, interviewing of respondents and informants, direct participation and observation, and introspection” (Denzin, 1989, p. 157-158). Gold’s (1958) typology of participant roles in qualitative research comprises four manifestations: complete participant, participant-as-observer, observer-as-participant, and complete observer. Each of the roles has specific advantages and disadvantages, with a dominant observant role fostering objectivity, while a dominant participative role grants access to otherwise unreachable undistorted data. The latter requires relationship building and is time intensive, as study-unrelated tasks need to be assumed by the researcher (Flick, 2014, p. 296). According to this study’s focus on generating an in-depth understanding including all involved contextual, social and organizational factors, a participant-as-observer role is taken.

While this role enables the exploitation of the mentioned benefits and suits the epistemological standpoint, actions have to be taken to ensure distance and objectivity for empirical sense-making. “Going native” is a term borrowed from ethnography research and designates the extreme form of a researcher immersing into a study context and identifying completely with the object of analysis. Whereas this allows to fathom the object of analysis to a maximum depth, it bears the risk of losing the distance required to reflect upon the empirical data and to derive objective theory from it. Qualitative research methodology offers different measures to counteract these risks, such as taking field notes in frequent intervals and discussing observations with other researchers. Both actions force the researcher to take a reflective meta level and discuss observations from an objective viewpoint. In the empirical study of this thesis, both actions were taken. Field notes were jotted on a daily basis and also used as input material for the data analysis (Flick, 2014, p. 323; Yin, 2013, p. 124). Co-researchers included a team of two graduate students, with whom observations were discussed as soon as possible after the incident to compare different perceptions thereof.

6.3 Data collection

The data collection phase of the study at hand encompasses 1.5 years and includes several sources of data, namely semi-structured interviews, direct observation and participant-observation. According to Yin (2013, p. 121), the use of multiple sources of evidence is neither typical for many research methodologies (see for example quantitative research design solely relying on survey data) nor is it necessary for qualitative research. However, the use of several data sources strengthens the case study’s rigidity, as triangulation between the data sources can be employed to solidify result interpretation. All data sources have been integrated in a case study data base.

When data points from this base are mentioned throughout this thesis, their index in the case study data base is subsequently specified as a reference to the original data. In the following, details on each type of data source that is being used for the thesis at hand are specified.

6.3.1 Semi-structured interviews

Interviews are frequently applied data sources in qualitative research. It is important to note that interviews in qualitative research typically work different to those in survey research, following a more liquid stream of conversation as opposed to a more rigid answer-and-question discourse in survey research. This enables iterative adaptation of the interview to a certain focus that may emerge during the interview, overcoming limitations of survey research, but the procedure imposes high requirements on preparation and execution on the part of the researcher (Yin, 2013, p. 110 ff.; Flick, 2014, p. 217 ff.). To this end, the interview approach should be adapted to suit the underlying epistemological standpoint. For the research project at hand, following a moderate constructivist perspective, the interviewee is expected to have subjective knowledge on the object of analysis. This knowledge is subject to certain implicit assumptions that need to be discovered and interpreted in context. Thus, it is essential to give room to the interviewee's subjective perspective and individual focus in the interview setting. Moreover, situational and social aspects of the interview situation are captured likewise, therefore the interview constitutes a complex social setting that provides data on many levels besides the verbal statements being made (Alvesson, 2003).

A semi-structured interview approach, leaving ample room for subjective perspectives while adhering to the line of inquiry defined by the central research questions, is therefore chosen. For this purpose, a five-page long questionnaire guideline was prepared which contains different questions along the central line of inquire based on the research questions outlined in chapter 5.3. The questionnaire is composed in German language. It translates abstract research topics into language and abstraction levels that can be understood by interviewees, who comprise shopfloor workers and senior management alike. The questionnaire consists mainly of open questions, complemented by a few hypothesis-directed questions, with confrontational questions being used throughout the interview where suitable.

In total, 52 interviews were conducted, each lasting between 45 minutes and two hours. In the course of the research period, the content focus of the interview evolved. While interviews at the beginning of the project feature a dominant focus on research question 1, later interviews predominantly focus on research questions 2, 3, 4 and 5, albeit always also touching upon fundamental aspects of research question 1. Interviews covering research questions 4 in particular encompass a morphological analysis performed by the interviewees on the issue of organizational embedding, with

details being provided in chapter 7.4.2. Interviews focusing on research questions 2, 3 and 5 cover different constraint types, respectively. Depending on the professional background of the interviewee, one constraint type or several constraint types were examined, details of this procedure are provided in chapter 7.4.1.
In qualitative interviewing, the sampling approach is quite different to statistical sampling conducted in quantitative research. While the latter strives for representativeness of the total population, sampling in qualitative data collection is more theoretical in nature. Theoretical sampling, as it is widely acknowledged in pertinent literature, is purposive, critically evaluating parameters to be studied and choosing a sample where these are likely to occur (Silverman, 2010, p.144). Theoretical sampling applies for the choice of both the case and the interviewees within a case and is consistent with the research objective: With theoretical generalization as its aim, qualitative research is supposed to follow theoretical sampling. Moreover, it supports objectivity: Eisenhardt and Graebner (2007) emphasize that a rigid theoretical sampling that covers different perspectives by choosing interviewees on different functional and hierarchical levels refutes potential accusations of retrospective sense-making through the researcher.

For the study at hand, due to excellent access to the research site, I was able to conduct interviews with participants from six different functions: product design, process design, production planning, shopfloor manufacturing, production management, purchasing and strategy (details on tasks and responsibilities of these roles are provided in chapter 7.1). I was cautious to have different perspectives based on periods of employment and hierarchy levels. For the latter, I distinguish between low hierarchy with no leadership function, medium hierarchy with group or project leader positions, and high hierarchy for senior management levels. Theoretical sampling was deliberately extended during the investigation since participants would suggest employees that they thought I should talk to. A comprehensive list of all interview participants is offered in table 8.

Interviews were anonymously recorded and comprehensively transcribed, if individual permission was granted, to ensure accurateness in the representation of participants' statements and narratives. As interviews were held in German language, quotes that are represented as data evidence in the thesis at hand had to be translated. The author strived to stay as close to the original sentence structure as possible, which may account for a rough English language in respective passages.

Qualitative researchers typically also include informal interviews, which occur as spontaneous discussions during the researchers' presence on the field site, as part of their interview data. For the study at hand, comparable instances of insightful unscheduled discussions are not included among the interviews, but noted as participant or direct observation.

Overview of interview data

Department	Quantity	Hierarchy	Period of employment (years)
Product design	3 employees	Low	0 – 3
	3 employees	Low	4 – 10
	1 employee	Low	10+
	1 employee	High	10+
Process design	3 employees	Low	0 – 3
	2 employees	Medium	0 – 3
	2 employees	High	4 – 10
Production planning	1 employee	Low	0 – 3
	5 employees	Low	4 – 10
	3 employees	Medium	4 – 10
	1 employee	Low	10+
Shop floor manufacturing	2 employees	Low	4 – 10
	3 employees	Medium	10+
Production management	2 employees	Low	0 – 3
	5 employees	Low	4 – 10
	2 employees	Medium	4 – 10
	5 employees	Low	4 – 10
	5 employees	Medium	10+
	1 employee	High	10+
Other	1 employee	Low	10+
	1 employee	Medium	10+

Table 8: Overview of interview participants

6.3.2 Direct observation and participant observation

As mentioned before, I had exclusive access to the field site by participating in a doctorate program of the automotive manufacturer in question. This entailed a longitudinal presence on the company's premises, allowing to experience the dynamics at the object of research from within. This particular research access made both participant and direct observation possible on an extensive scale during the data collection phase of 1.5 years, of which 80% was spent on the OEM's premises. In addition to that, two graduate students supported the data collection phase, each spending 6 months on the research site and contributing likewise to both direct and participant observation.

With regard to participant observation, I assumed tasks of industrial engineering for NPD of electrified engines and high-voltage batteries, which allowed for work contacts and relationship building with product and process design, production planning and management as well as shopfloor manufacturing. Insightful observations that were made during meetings, workshops or informal discussions related to this work, were jotted down on field notes as soon as possible after they occurred, with formats varying, including paper sheet scribbles and electronic notes. During the roughly 20% of days that were not spent on the field site, these field notes were transformed to short anonymous reports as preparation for data analysis. In total, 129 such reports were collected over data collection.

Whereas data from participant observation emerged from occurrences related to the participative tasks of the author, data from direct observation was generated when an insightful observation could be made from discussions where the author was not actively involved. This includes a broad range of different situations, ranging from observations of office sites and floor talk up to work clothing. Similarly to participant observations, these direct observations were written down as soon as possible after their occurrence and later transferred to processible reports. In total, reports were generated for 47 instances.

6.4 Data analysis

For qualitative researchers, the analysis and interpretation of data is at the core of the empirical procedure and cannot be separated from the data collection phase. Instead, a recursive approach is followed where theory pieces emerging from the data analysis are reintroduced into data collection to be further developed or discarded. The actual process of qualitative data analysis can be described as an iterative building of categorizations, from which theory eventually emerges (Flick, 2014, p. 373).

The analysis of data from all above mentioned sources followed established techniques and procedures for qualitative research. From a methodological viewpoint, the approach of Gioia *et al.* (2013) is followed for data analysis. From a technical viewpoint, Atlas.ti was employed, a renowned qualitative research software, to document data coding and support data analysis. In the following, both viewpoints will be elaborated in more detail.

As mentioned earlier, Gioia *et al.* (2013) provide a qualitative research strategy that combines an inductive approach, well-suited for exploration and theory development, with scientific rigor. First conceived in Gioia and Chittipeddi (1991), the method was refined through subsequent studies. Albeit building on methodological fundamentals

of Corbin and Strauss (1990) and Glaser and Strauss (1967), both seminal groundworks for grounded theory, Gioia *et al.* (2013) do not outrightly reject a prior consultation of literature. Instead, they recommend to use existent theory to bring to light potential gaps and invalidities. From an epistemological perspective, Gioia *et al.* (2013) see the organizational world as socially constructed and the people that construct it from within as knowledgeable agents, who can explain their actions and motives. Consequently, the role of the researchers is to excavate and describe these constructs by staying close to the informants and follow their terms and perspectives. Their research style of "getting in there and getting your hands dirty" (Gioia *et al.*, 2013, p. 19) suits the research objective of this study very well, as it supports the ambition for a deep understanding of underlying dynamics and a careful consideration of situational aspects.
Gioia *et al.* (2013) explicitly discourage from using their approach as a "cook book" method. Instead, the individual researcher is advised to apply recursivity to adapt and innovate the methodology according to the research context. This includes a flexible interview style with continuous focus readjustments during the data collection phase as well as a release from the typical qualitative data structure box-and-arrow form, as long as this can be justified by the research context.

For data analysis, Gioia *et al.* (2013) follow Corbin and Strauss' (1990, p. 153 ff.) staged coding process which represents an established technique for qualitative inquiry. In a first review of data, topics and motives, called first order concepts or codes, are attached to sentences, statements or words. This first review is called open coding, as the list of applied codes is continuously enlarged by new concepts, sticking relatively closely to the original wording in the data. In a second review of the data and the attached first order concepts (axial coding), categories and initial cause-effect relationships are formed, called second-order themes. A third review (selective coding) raises the abstraction level from a descriptive to an interpretative level. Herein, aggregate dimensions are formed from different categories that epitomize central lines of interpretation and serve as basis for the development of a theory model (Gioia *et al.*, 2013; Dacin *et al.*, 2010).

For the empirical study at hand, the comprehensive set of data from interviews, participant observation and direct observation is available in written form through the transcription of interviews and preparation of field notes as described above. These written accounts were loaded into Atlas.ti for the analysis. As a first step, groups were built to assign data points based on source, constraint type, research questions and involved interfaces. Data, be it interview transcriptions or field note reports, underwent continuous open coding, simultaneously with ongoing data collection. The evolving code system was reworked and sorted on a regular basis to avoid duplications and to adjust for new lines of inquiry in the data collection. This was supported by regular discussions of the code system in the research team. To this end, parts of the data were cross-coded individually by different researchers to ensure best possible objectivity of the coding process.

In the first step of the analysis, collected data was coded on the basis of first order concepts, which included, for instance, prejudices of one functional area on another one, conflict topics between certain interfaces or success factors for cross-functional integration. In addition to these content-related concepts, support codes were attached to mark a certain interface, a research question that is discussed in the coded passage or a constraint type or constraint scenario, to name a few examples. In total, 524 first order concepts were applied to 2244 coded passages in the entire data set. Compared to other qualitative research efforts, this forms an extensive data set.

In a second step of the analysis, I looked for codes across the data that could be grouped into higher-level nodes. As an example, first order concepts like “Bridging functions don’t live challenging role”, “Downstream functions react with cynicism” and “Only targets force downstream functions to the table” were aggregated in the second-order theme of “Downstream functions avoid conflicts”. The third step of my analysis focused on organizing second-order themes into distinct clusters that represent aggregate dimensions underpinning theory building. As alluded to above, this was a recursive rather than a linear process. In memos, I noted potential interpretation patterns that would be a basis for an aggregated dimension, with subsequently changing or eliminating such a pattern when I asked informants during ongoing data collection about it and they would refute my interpretation. In addition to that, I learned that informants at the research site tend to have a specific linguistic use of certain expressions, with meanings that are different from or have different connotations than in normal usage. It took some time to fully understand this codified language, and in a recursive way I had to rework a number of codified passages.

6.5 Quality criteria

Quantitative research methodologies have agreed-upon and easily measurable criteria to determine their quality and reliability, for instance the calculated significance level. For qualitative researchers it is more difficult to prove the significance or quality of an empirical study: It is in the nature of things that qualitative data does not easily allow for quantitative measures. Even more so, the interpretation of data requires to take subjective perspectives to be able to reflect upon the individual participants’ perspective and to account for social aspects; proving the objectivity of results is accordingly challenging. Moreover, due to recursivity requirements inherent in qualitative methodology, there is no “boilerplate” for how qualitative research is done correctly to generate reliable results.

Nevertheless, research agrees that it is essential to find and apply criteria for qualitative rigor. Gibbert *et al.* (2008) complement that indeed, methodological rigor might be even more important for qualitative research, as it is often used to develop theory which is subsequently affirmed quantitatively.

While researchers agree on the need for such criteria, they often disagree about which criteria are the right ones. Naturally, different epistemological backgrounds would suggest different criteria, criteria that follow an empiricist tradition are therefore highly debated (see for example Tracy, 2010). Even so, criteria sets building on traditionally empiricist indicators find broad acceptance in qualitative research. Yin (2013, p. 45 ff.) adapts construct validity, internal validity, external validity and reliability to fit qualitative research. As another example, Flick (2014; p. 479 ff.) proposes selective plausibilization, reliability, procedural reliability and validity. For their wide acceptance, this thesis follows Yin's (2013, p. 45 ff.) criteria and discusses them subsequently.

To begin with, construct validity considers the correctness of operational measures for the studied concepts. It tests if the study indeed investigates what it claims to investigate. Naturally, this is particularly challenging for qualitative research, as one of the explicit advantages is openness towards a broad range of measures and aspects of the concept being studied (Gibbert *et al.*, 2008). According to Yin (2013, p. 46), construct validity is mostly determined during data collection and can be ensured by corresponding to design principles as follows: Using multiple sources of evidence and establishing a clear chain of evidence from research questions over questionnaires and citations up to result interpretations.
The empirical study at hand strives for construct validity by using three different data sources that feature a broad range of functional and hierarchical perspectives of involved participants. Furthermore, transparency in the chain of evidence is fostered by providing relevant citations for each result interpretation and connecting them to initial research questions and lines of inquiry from the interviews.

Internal validity tests the logical validity of the relationship between results and variables, inquiring the plausibility of the argument and eliminating spurious explanations. Internal validity is of highest concern during data analysis, as cause-effect relationships are built and substantiated during this phase. To account for matters of internal validity, several research tactics may be applied. Rigorous pattern matching and explanation building make emerging relationships visible and comprehensible. Logic models are a suitable graphic representation to enhance this visibility. In addition to that, proactively addressing rival explanations helps solidifying internal validity. The research study at hand strives for a comprehensible derivation of interpretation and theory, which helps to achieve internal validity. For example, dynamics of cross-functional integration that are integrated in a theory model are deduced from the emerging data structure which can be traced back to the citation level. Logic models are employed when cause-effect relationships are derived. Finally, the limitations chapter at the end of this thesis offers a range of alternative explanations to the observations that have been made in the course of the case study.

External validity takes account for the generalizability of results and has to be ensured in the initial research design. As explained above, for qualitative case studies this does not refer to statistical generalizability in an empiricist sense. Instead, it focusses on whether expected results are interesting and insightful enough to provide a basis for analytic generalization, hence as a basis for the development of theory. While research questions that point towards purely descriptive results are less suitable for analytic generalization, how- and why-questions on a certain occurrence or relationship are well-suited to this end. According to Yin (2013, p. 48), a rigorous review of existent literature to find gaps or invalidities is a suitable research tactic to ensure external validity.

In the empirical study at hand, the author followed the latter by providing a detailed discussion of related theory and pertinent shortcomings. Second, this study's research objective, represented in the research questions, is focused on revealing dynamics and building theory for a new method.

Lastly, reliability analyses whether subsequent researchers would achieve the same result when repeating the study. Therefore, it is concerned with issues of operational transparency and replicability, minimizing errors and biases in the empirical study. For Yin (2013, p. 48), reliability is, at its core, an issue of documentation during data collection: If the circumstances of data collection, the data itself and the inferences that are drawn from it are seamlessly documented, reliability is well ensured.

Therefore, the case study at hand strives to demonstrate reliability by a rigorous documentation of its data, with interviews being transcribed and field notes being jotted down right after the occurrence of insightful situations. An extensive amount of original data is presented interwoven with interpretations in the case study.

6.6 Suitability of the empirical setting for case study research

The empirical field site for the study at hand is a large-scale industrial automotive manufacturer, which is designated by the pseudonym CarCo henceforth. The choice of not disclosing the identity of the case study subjects, neither the company nor names of individuals, has been weighed out based on guidelines provided by Yin (2013, p. 197): As treated topics include sensitive opinions on the corporate climate as well as individual departments' or managers' behaviour, disclosure may affect future actions of the participants. Therefore, anonymity is necessary for reporting the case study. Second, as the study strives to present evidence on a "typical" case, disclosure of identity is not essential for readers' comprehension of the matter, as the case is chosen to be representative for similar cases. Third, ensuring anonymity towards participants of interviews is likely to increase the revelatory power and validity of the provided data, as participants can openly present their opinion without dreading consequences thereof (Yin, 2013, p. 197).

The CarCo case of new product development of electrified powertrains is suitable for the research project at hand for two major reasons that are elaborated upon as follows: It represents a typical case for large-scale industrial cross-functional NPD, and likewise it includes a series of challenges that are both interesting and typical for this kind of corporate setting.

To begin with, CarCo's corporate setting is representative for other large-scale industrial organizations: The functional orientation in process and hierarchical organization, covering research & development, production, sales, procurement and support functions, is likely to be encountered in a majority of large-scale industrial settings. In addition to that, CarCo utilizes a typical stage-gated NPD process comparable to other corporate settings. Further challenges for cross-functional integration, such as spatial distance between some functions due to the existence of multiple sites, and significant involvement of suppliers due to low value-added depth are common features of most large-scale industrial settings, too. Lastly, CarCo is neither a border case for its innovativeness nor for its lack of innovativeness: While participating in many innovative activities, CarCo is a mature company with stable processes, thus offering a typical large-scale industrial NPD setting.

On the other hand, CarCo faces significant challenges for future success: Whereas many of its innovations of the last decades were more incremental in nature, the development and industrialization of large-volume electrified powertrain car concepts requires a higher ambition level with regard to product disruptiveness. Furthermore, volumes for electrified cars are less easy to predict and more volatile than combustion powertrains, posing additional flexibility requirements to the slow-moving and formalized NPD process. In addition to that, the NPD process is under pressure to be reduced in length due to external market pressure from customers, regulation and newly emerged competitors. With product complexity already being high today, rising customer requirements on saturated markets and shorter product life cycles are likely to make the product even more complex and multi-variant in the near future.
While these challenges might have an interesting impact on cross-functional integration, they are likely to be similar for all large-scale industrial settings. Therefore, CarCo represents a typical company with typical challenges for manufacturing companies at the edge of the digitization age.

As already mentioned above, the exclusive access to the research site further increases attractiveness for case study research with the mentioned research objectives. For innovative products in particular, large-scale mature companies are naturally reluctant to give deep insights into their corporate dynamics. The author's membership in CarCo's doctorate program thus provides an outstanding opportunity for research. Granting anonymity to CarCo and all involved participants is expected to further increase truthfulness and reliability of the empirical data.

7 Results of the empirical study

7.1 The empirical setting

7.1.1 A challenging environment

Headquartered in Germany, CarCo operates on a global scale covering development, production, sales and aftersales of cars to a worldwide customer base. The company is an incumbent representative of its industry, looking back on several decades of operations. Consequently, both the hierarchical and the process organization is characterized by maturity, while undergoing constant incremental change to adapt to market circumstances. CarCo covers large parts of the automotive value chain, engaging in all functional areas from pre-development to aftersales at several sites worldwide. Similar to other large-scale industrial companies, CarCo has a strong functional organization, with board members representing their functional domain and all subordinated hierarchical levels sticking to this strict functional separation. Cross-functional organizations, e.g. to represent a product perspective, exist as an additional organizational layer, but are restricted to dotted-line responsibilities without disciplinary lead.
The product portfolio is dominated by cars in premium market segments and focused on combustion engines. CarCo participated in several technological advancements in the automotive industry throughout the years, often assuming a leadership role for both product and process innovation within the industry.

Global macro trends in the realm of environmental protection, resulting regulatory requirements and urbanization exert pressure on automotive manufacturers to increase the share of electrified cars in their product portfolio. The emerging market for electrified mobility gives rise to new entrants, partially due to lower barriers of entry for electrified powertrains as compared to combustion powertrains. This increases innovation pressure for incumbents to reduce development time and to augment the customer benefit with inventive product features. With product and process complexity experiencing an ongoing rise, the mature new product development organization faces growing challenges.

Electrified powertrains consist of two major components: electrified engines and high-voltage batteries. While the fundamental technological concepts of both components have been known and employed for decades, their adaptation for powerful automotive applications with corresponding durability and range requires NPD efforts on a significant scale, with both product and process innovation necessary to allow for series production.

For CarCo's electrified powertrain NPD, the time period during which the author engaged in research on the field site is particularly critical. A first generation of electrified powertrains has been developed a few years ago and is currently still manufactured in small volume production. However, both product concept and process concept are not suitable for expected high volumes in the near future. Therefore, an entirely new product concept has to be developed, with all resulting consequences on manufacturing, such as the build-up of entire new plants with new production concepts. The research period covers the time before and after target agreement for this generation, which is one of the most critical phases in NPD as will be explained in the next subchapter.

7.1.2 New product development of electrified powertrains

The new product development process of CarCo follows a complex stage-gated structure typical for large-scale industrial corporations. Details on involved stakeholders and actions taken in each stage are described in the following.

The product development process consists of four phases with intermittent stage-gates stretched along a total duration of roughly five years. The first phase, called strategy phase, is concerned with feasibility concerns and provides as output an operational framework from a strategic perspective. Stakeholders of this phase are mostly corporate and product strategy representatives, with high-level representatives from product design, procurement, production and sales involved for feasibility inquiries. In addition to that, an approximate product design concept and financial target area is developed.

When a project reaches confirmation after strategy phase, the subsequent initial phase is commenced. During this phase, product design develops the objective framework and requirements for product design are formulated. In addition to that, concerns of modular product design are taken account of: Quite typically for large-scale industrial environments, complex products with innumerable components are developed as product families with a maximum share of communal parts to increase design efficiency and reduce the number of variants. In the initial phase, it is decided on which product platform the new product may be established and which communal parts may be shared. Involved stakeholders consist of strategy representatives and product design specialists.

With the beginning of the next phase, denominated product concept phase, the operational development process begins. Product designers launch the actual design process by creating first CAD models and formulating technological requirements that may or may not require further innovation activities. Product costs are projected based on material costs and estimations for purchased parts on side of the procurement function. Likewise, process designers join the development activities to derive process innovation requirements and reflect process feasibility for envisaged innovative product features. Towards the end of the product development phase, when the first

CAD models and bills of material are compiled, production planning comes on board. Their main task is to estimate projective production costs based on the developed product design. This is necessary, as the end of the product concept phase entails one of the most important stage-gates, the target agreement (three to four years before start of production). During target agreement, projected costs for the serial product are summarized, including material costs, purchase part costs and production costs. In accordance with a catalogue of product design features, these costs are fixed. This means, that after the start of serial production, functional partners will only receive compensation for costs in the amount that had been settled during target agreement. For instance, production plants responsible for serial production will receive a fixed amount of money for each produced product, which is fixed the in target agreement. If production cost projections are insufficient, production plants will have to bear financial losses during serial production. As a consequence, changes in product design are difficult to attain after target agreement, as cost impacts of such design changes are required to undergo a complicated approval process after the target agreement.

The last phase of new product development is also the longest one: From target agreement to start of production, series development takes place with intermittent stage-gate milestones for different maturity levels of series development. All details of product and process design are developed and tested, with hardware prototypes being produced and virtual feasibility assessments taking place. Product design still takes the lead in series development, but functional stakeholders from production planning become increasingly involved to plan the manufacturing process and to buy required production equipment. One year before start of production, manufacturing is assigned to the NPD process, as the production facilities are built and ramped-up. As manufacturing formally takes over the production facilities from production planning around the start of production, this leads to an intensified phase of coordination and adjustments at the end of series development.

The NPD process is formally concluded with start of production.

7.1.3 Involved stakeholders during new product development of electrified powertrains

A detailed overview of all stakeholders from involved functional areas in the new product development process as described above is provided in the following.

Figure 25 offers a graphical illustration of the most important interfaces as well as how they are connected in CarCo’s hierarchical organization. This is in so far interesting, as CarCo’s hierarchical organization of functional areas deviates from the typical structure offered in mainstream literature (see for example Albach’s (1994, p. 206) division of process and product development from production functions). Similar to the NPD process itself, however, the division of functions and their respective roles correspond to other large-scale automotive manufacturers, reaffirming the typicality of the case to be examined.

Product design, as the formally dominating stakeholder within NPD and as an essential part of the R&D department, takes care of technological conception, product innovation, construction and functional design testing. The overall product design process is performed in-house, albeit formal design of subcomponents is frequently outsourced to design service providers after having been drafted as technological concept in-house. Product designers are required to fulfil product requirements from an extensive specification sheet that is defined by the product strategy team (formally part of the R&D department as well). These requirements sheets contain mostly product-related specifications, as well as requirements to ensure communality with related products and processes on the same vehicle platform. Due to typically high shares of purchase parts (~80% of all parts in the car), product design also needs to consider inputs from procurement. They are incentivized to do so, as product design assumes formal responsibility for material costs which include procurement costs of purchase parts. In later phases of the design process, production planning and process design likewise interact with product design to demand process-related requirements.

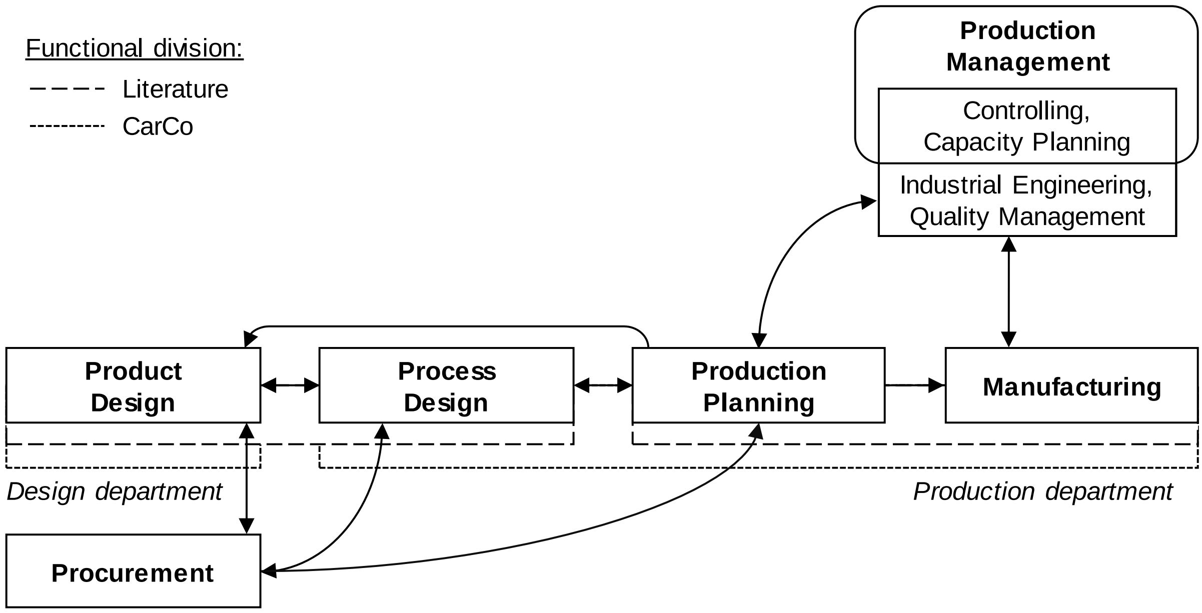

Illustration 25: Involved interfaces in CarCo's new product development

Process design is accountable for process-related innovations, trials of new production technologies and the building of product prototypes. To the largest part, process design reacts to requirements emerging from product design; proposing process innovations independent from product requirements would be an exception. Consequently, product design is their most important input provider. During series development, interactions with production planning are manifold. At CarCo, process design's different tasks are divided between different functions, with prototyping and process innovations assigned to one functional unit and the early conception of the process design being integrated with production planning. Organizationally, all process design units belong to CarCo's production department, which differs from the functional division taken in literature.

Production planning, entering the NPD process shortly before target agreement, is responsible for the realization of the manufacturing facility. This includes in parts tasks of process design, but mostly is concerned with defining specifications for plant engineering suppliers, calling those for tender and accompanying construction and ramp-up of the production facility. Production planning likewise includes process technology specialists, who establish and adjust production facilities' control engineering. Production planning is held responsible for manufacturing costs that are agreed upon in target agreement. Consequently, large parts of their daily business consists of projecting and detail-planning plant and labour costs related to manufacturing. In early phases of their engagement in NPD, production planning has its most important interfaces to product design and process design, while later phases require frequent interactions with manufacturing. Throughout their engagement, production planning works together with different stakeholders from production management as well.

Manufacturing operates the production facilities from start of production onwards and is held responsible for all production matters, be it quality or costs. For each produced part they receive the financial amount that has been agreed upon in target agreement and they administer, expense or cover those in their own responsibility. Production management provides several supporting functions for them, be it controlling, quality management or industrial engineering. In principle, they are the operators of production facilities, but for larger changes or disruptions in the production process manufacturing may call on production planning for support. Formally, they enter the NPD process at the last stage to prepare take-over of production facilities from production planning.

Production Management offers support functions with the production department for series manufacturing and activities in NPD. They are endowed with a checks-and-balances-role within manufacturing and supervise controlling, quality management, industrial engineering and lean production consulting matters.

Procurement takes accountability for all purchase parts during NPD and series production. This includes supplier selection, price negotiations, supplier administration and the purchase-related quality and supply management. As purchase prices determine large parts of material costs, product design is the most important interface to procurement during NPD. Likewise, procurement has a role during process enablement and therefore maintains interactions with process design as well.
Procurement is part of neither design nor manufacturing, which are interface functions central to this study. Therefore, the interface of procurement to design and manufacturing functional areas is not explicitly analysed. Nevertheless, procurement as a functional division is included in the broader scope of the case setting description. This is because procurement's influence on the design-manufacturing interfaces

appears repeatedly in the case study data, and thus cannot be excluded in the study's analytic scope.

With regard to spatial distance between the different functions of electrified powertrain NPD, three major locations are relevant. At the headquarters, product design, process design, procurement and large parts of production management and production planning are located. In total, there are two manufacturing plants, both located roughly an hour drive from the headquarters. Parts of production planning and production management are situated at the manufacturing plants as well.

At CarCo, employees that are actively involved in the manufacturing process on the shopfloor are denominated direct functions, whereas others are summarized as indirect functions. Following this classification, *manufacturing* as described above is a direct function, with all others being counted as indirect functions.

The description of functional divisions in the empirical case shows that there are many more functional representatives of both manufacturing and design than just these two. With context sensitivity being of particular importance for the study at hand, the author chooses to embrace this complexity in the empirical analysis.
Therefore, interfaces between the mentioned functions are analysed in the fanned out structure provided by the empirical case, instead of summarizing them to reflect literature's simpler division into design and manufacturing. In order to be able to derive theory from the empirical findings, the manifold empirical interfaces will be transferred to the single design-manufacturing interface in the respective final parts of this study. Illustration 26 provides an outline of all empirically analysed interfaces, and how they will be allocated to the literature-based design-manufacturing interface. For this purpose, two interface types are distinguished. The first type refers to interfaces between design and manufacturing, the second type refers to interfaces that are between functional areas within design or within manufacturing. While not being in focus for the study at hand, the latter type is nevertheless integrated within the analytical scope to account for any impacts that those might have on neighbouring manufacturing-design interfaces. In total, ten interfaces are in scope of the analysis; four of them being within design or manufacturing, respectively.

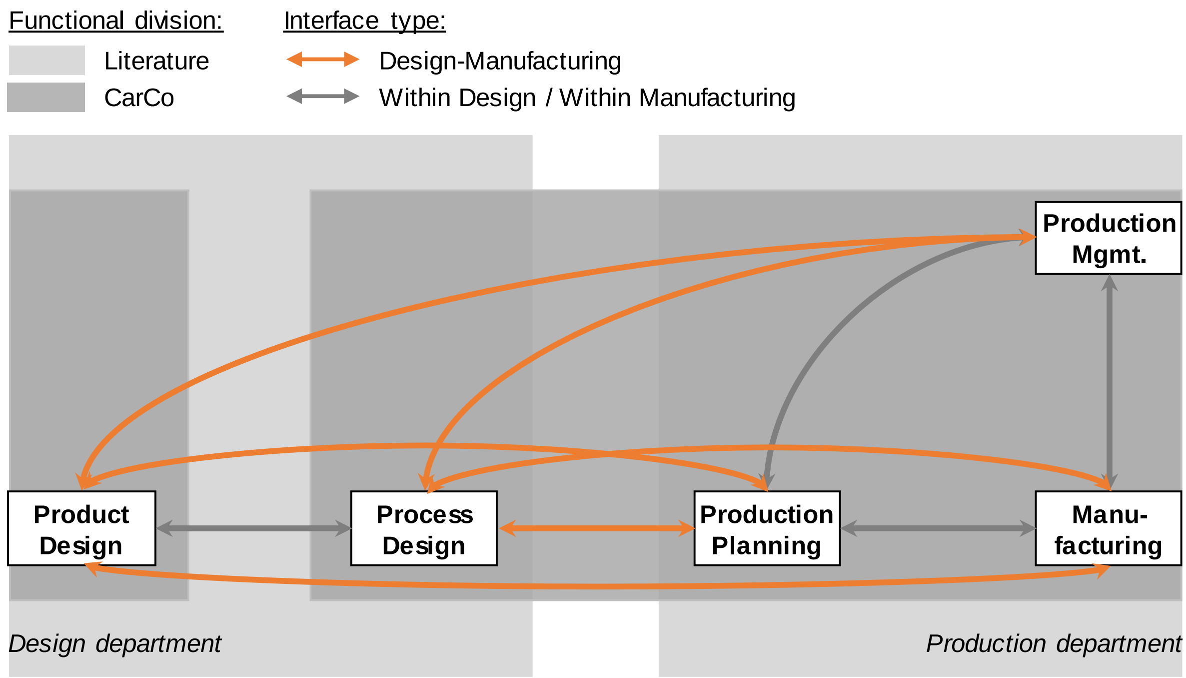

Illustration 26: Design-Manufacturing interfaces in empirical case and literature

7.2 Coopetition at the design-manufacturing interface

The current state of integration at the design-manufacturing interface of NPD at the empirical case was analysed by applying a coopetition perspective at the respective interface. Illustrations 27, 32 and 35 depict the data structure of the findings for each coopetition dimension, namely cooperative intensity, cooperative ability and competition. Eight aggregate dimensions have emerged in total for all three coopetition dimensions. Likewise, their constituent second-order themes are presented, as well as the first-order concepts that led to the themes' formation.

Tables 13, 14, and 15 (in the appendix) provide representative data from interviews and participative observation. The findings are discussed in a descriptive narrative covering all first-order concepts along coopetition dimensions and their respective main dimensions, including additional original data in the following.

7.2.1 Cooperative intensity

Cooperative intensity

1st order concepts	*2nd order themes*	*Aggregate dimensions*
1. Communication intensity at bilateral interfaces 2. Strong informal relations at bilateral interfaces 3. Manufacturing involvement only via interface cascade	*(a) High communication intensity at adjacent interfaces*	***Informal and formal relations***
4. Individual effectiveness dependent on informal relations 5. Informal relations as success factor for integrated NPD 6. Reciprocity of relations and actions	*(b) Importance of informal relations*	
7. Bureaucracy and formal alignment hinder integration 8. Homemade structural complexity 9. Little trust in own formal committees	*(c) Perceived inefficiency of formal relations*	
10. Late involvement of manufacturing and representatives 11. Manufacturability inputs rejected due to late raising 12. Manufacturing involvement either too late or too early	*(d) Late involvement of manufacturing*	
13. Confusion on cross-functional channels and contacts hinders integration 14. Ideas for manufacturability improvements get lost in the process of addressing them	*(e) Compartment-alized nexus of contacts and channels*	
15. Discussion topics focused on series problems 16. Information and coordination prevailing 17. Unpleasant topics in upstream communication	*(f) Discussion topics focused on series issues and coordination*	***Cooperation contents***
18. Discussion tone: Passive in the early phase 19. Discussion tone: Walls between manufacturer and NPD participants	*(g) Communication tone patterns*	

Illustration 27: Data structure - Cooperative intensity

7.2.1.1 Informal and formal relations

High communication intensity at adjacent interfaces

At CarCo, communication plays a vital role. Lively omnipresent open-plan offices, in which private and professional discussions are hosted and a ritualized coffee-drinking culture are visual signs thereof. Spatial closeness between all functions except manufacturing facilitates personal communication, the general rule is to pursue a meeting in person, rather than a phone call, rather than an email. In almost all meeting invitations, a Skype conference invitation is attached, such that the invitee may participate at least via telephone if personal attendance is not possible. All of these may cater to a cross-functionally open cooperative intensity. When looking in depth at communication patterns at CarCo, however, the data reveals that cooperative intensity is indeed high, but mostly focused on adjacent functional interfaces. Illustration 28 plots communication relationships based on their mentioning in interview and participant observation data.

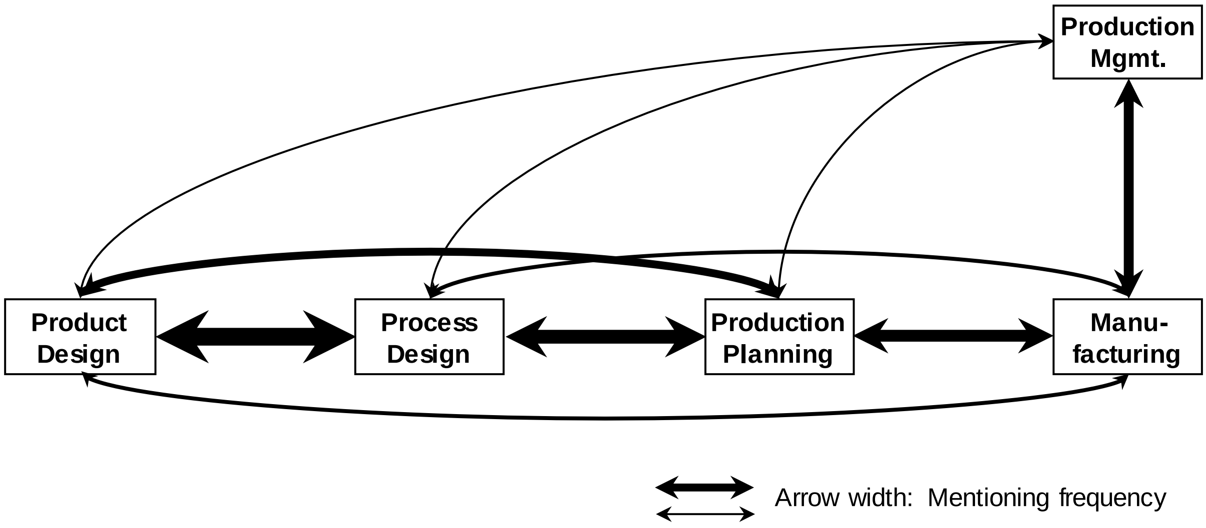

Illustration 28: Cross-functional communication patterns

Communication intensity is the highest between adjacent functions in NPD, such as between product design and process design, while overarching communication between distant functions such as production management and product design is rare. A production management employee reported on his relations with product design: “They didn’t know anything from me, they didn’t even know I was there” (156:6), and a manufacturing employee stating “Actually, the process designer should be on the shopfloor for one day every week, just to be close and effective. I never see him here at the plant, I did not see him once” (178:9). Between adjacent functions, cooperative intensity is high, for example between product design and process design: “I think people look with jealousy on us, how well cooperation works” (170:2).

With regard to informal relations, a similar picture evolves: “I don’t think there’s any product designer who knows someone from manufacturing” (168:2). Likewise, informal relations at adjacent interfaces are strongest. A production planner who had previously been part of the process design team, explained: “Between process design and product design, the connection is closer. When I was in process design, we often watched football together or went to the product designers’ barbecues” (82:66). An incidence at the lunch break of an integration workshop between different functions involved in NPD suggests a similar conclusion. While having discussed and interacted for four hours before, product designers, representatives of production planning and manufacturing did not eat together but separate from each other (7:2). In addition to that, there are few cross-functional workshops similar to the described one. Most of the team events or workshops take place with a function-internal participant group,

indeed not even with functionally related groups, but mostly within the smallest organizational unit.
As a visual representation of this interaction, illustration 29 sketches informal relationships based on their mentioning frequency in the case study data base. Clearly, the appearance of an interface cascade, leading down- and upstream via adjacent interfaces, is restated.

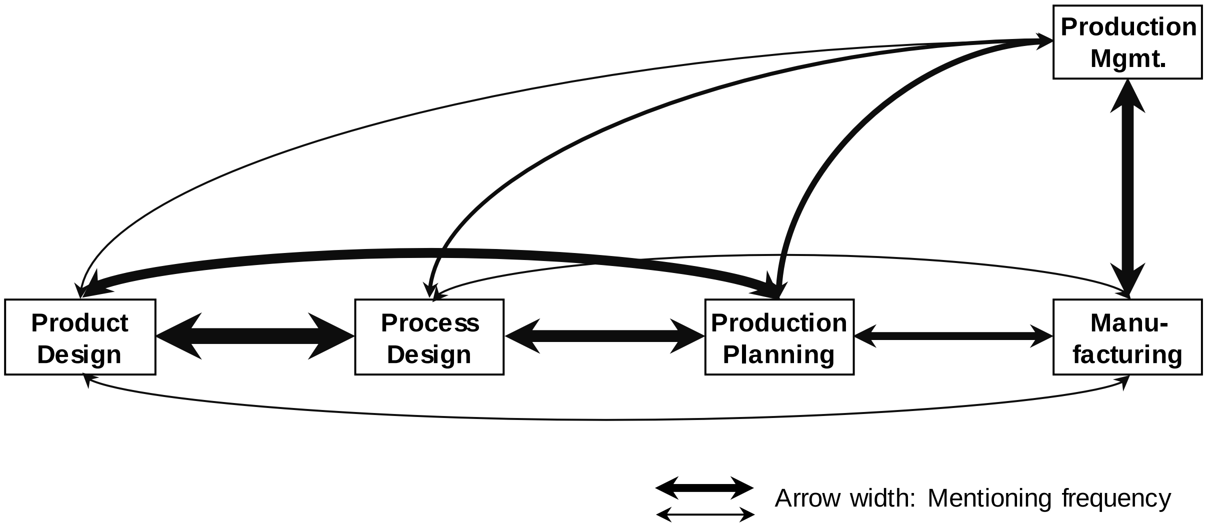

Illustration 29: Cross-functional informal relationships

In this nexus of informal relationships, manufacturing is to a certain extent decoupled from the functions most profoundly involved in the NPD process, namely product design, process design and production planning: “That’s what I meant with the cascade product design – process design - production planning – manufacturing. Production planning and process planning are really close. But process planning to manufacturing, there is a step in between” (82:69). Manufacturing seems to be only indirectly involved via the - often quite long – interface cascade: “No, that’s the production planners, not the manufacturing guys, with them it’s only indirect, it’s always via the planners. Here, the chain from the foreman or worker to the product designer is really long. Really, really long” (141:17). A representative from manufacturing put his view of consequences thereof in a Chinese-whispers-game analogy, with different information getting lost in the process of transmitting: “There are so many filters in between, and now and then they filter away some things” (154:42).

Importance of informal relations
“You bring this to work via processes. CarCo is simply built as a networking association, everything works via people” (160:10). Informal relations are of essential importance at CarCo: This is valid in particular for innovative products such as the new product generation of electrified powertrains, because confidentiality levels are high and information transfer across functions is restrictive. Furthermore, “network is much more important [in NPD than in series production, author’s note], because much in the early development phase works by acclamation and the work is divided among few

people […]. The first thing my predecessor did to train me on this job was to meet up with all the people he knew, and that was the best thing you could do" (148:4).

Individual effectiveness is highly dependent on the individual asset base of informal relationships. On the question, which function would typically emerge as the winner of a discussion, a production manager answered: "On one hand, the person with the best competence. On the other hand, it's rather going to be the person with the best network. In the optimum case, he has both" (126:34). This is valid especially for a cross-functional context. A process analysis, on how manufacturing requirements go into product design, revealed corresponding insights: Depending on how well an individual knows the product designer, his/her requirement goes directly into the product design team or has to take several detours on the official channel via other functions, e.g. production planning or the management hierarchy of the own function (108:1). Informal relations seem to form the glue on which cross-functional integration works or doesn't work. A manufacturing manager explained difficulties in integration between product design and manufacturing: "Because the group leaders don't know each other […]. This is simply a networking issue. If I don't know you, I don't call you. And I need faces with it. We are humans, we work by network" (145:10). Reciprocity is an evident aspect that comes with the strong focus on informal relations: "The principle of one hand washes the other is valid" (147:57).

Ties created by informal relations go beyond the ease of integration that spatial distance offers. In CarCo's shared office building, common rooms between production management and product design are not used together, presumably based on few informal relations between the two functions. They are always someone's "terrain". For example, there is a spacious roof top balcony in the shared building of production management and product design, but production management would not use it because it's next to a product design office.

Perceived inefficiency of formal relations

The typical work week at CarCo is structured around formal meetings. A weekly committee scheme is followed closely, with information cascading hierarchically downwards from the beginning to the end of the week. However, strict adherence to this schedule entails employees' perception of inefficiency. Formal corporate structures are perceived as homemade, as other corporate examples show that less bureaucracy could be possible. "We have a problem with bureaucracy at CarCo" (159:6). "Somehow, the focus on what's important is totally concealed here. I don't know why that is, but that focus on what's important - I don't know, it's because we are in such corporate structures. I was an intern in 2013, and back then [the CarCo CEO, author's note] wrote an email where he said, we have to improve our interfaces. Back then, in my department, assembly production planning, no one understood that. Which interfaces does he mean, they asked, but probably exactly those interfaces that make everything so complex. But I actually don't think it's so complex" (181:8).

Decision-making at CarCo is performed in committees and strongly consensus-driven. As a result, the progress of NPD projects is dependent on formal committee agendas. "Without having understood the entire committee landscape to any extent, what we have as committee, and preparing committee, and another preparing committee […] Until the run through the committees is finished, half a year is over. I think there's too much time frittered away here." (178:31). Trust in the decision-making competence of these formal committees is limited, one comment on project leadership committee is insightful to this respect. "They don't know the real topics, maybe know the status, green, yellow or red, for which you could perhaps as well just roll the dice, it would maybe be closer to reality than what is reported. In my opinion, there's much politics in all of that." (181:15). Furthermore, decision-making authority of formal committees is questioned: "Our steering committees are a bit too weak, they don't succeed in what they're supposed to do, namely to make decisions that are valid. And on the other hand […], we notice every now and then that decisions, when they are finally taken, are just not accepted" (127:7).

Indeed, complex formal committee structures are seemingly taken ad absurdum through the parallel existence of "shadow committees". If formal committees don't reach consensus, the opinion of such shadow committees is followed to allow projects to continue their work. "There is the [names a committee, author's note], that's in fact a discussion platform. All of these do not actually have decision-making authority, nevertheless things are discussed there and directions of impact are determined there, and thus the corporation in fact follows these results" (148:9).

Illustration 30 depicts the perceived efficiency of formal committees, both functional and cross-functional ones, based on their mentioning frequency in the case study data base. Astonishingly, cross-functional committees are perceived as inefficient less often and more decisive than their functional representatives. Cross-functional committees, however, are perceived to be conflict-avoiding, which is a point that will find further confirmation in the discussion of the competition dimension of cross-functional coopetition at a later point in this thesis.

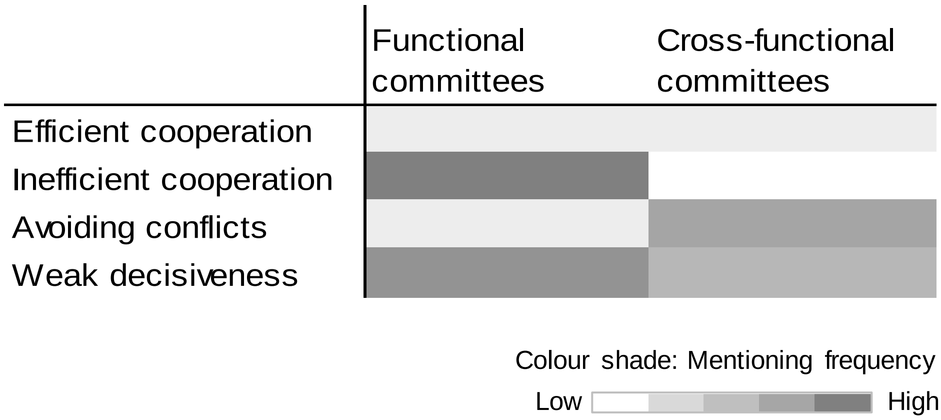

Illustration 30: Perceived efficiency of formal committees

Late involvement of manufacturing

When examining each function's coopetitive intensity in dependence of different NPD, one evidence is strikingly prevailing: Manufacturing is involved late in the process. "At the beginning, in the initial phase, manufacturing is very far away, at most they know that there is a project at all - if they're lucky" (155:1). Naturally, this entails difficulties of voicing manufacturability requirements: "It's crazy what we do, we have our time line and manufacturing representatives get on around 38 months before SOP - although the entire phase takes 72 months. So, the ship to take impact has already departed, and only then we get on with the entire team" (158:43). The result is that functions more upstream in the NPD process have profound freedom without contradiction from manufacturing, who eventually has to live with the result. "I think we can almost say that at the moment, we could pass on to manufacturing whatever we design. Whatever we happen to come up with […]. The manufacturer doesn't have anything to say in NPD" (181:10).

Several aspects account for a late involvement of manufacturing remaining without significant levers to impact product or process design. First, retrospective consideration of downstream functions' requirements would require large efforts from designing functions for a design project that, in their eyes, they have already finished and done. Second, "the responsibility for the product validation, as well regarding product liability, lies with the product design. And as soon as the product is validated, nothing will be changed anymore" (125:30). For security-relevant products with lengthy and regulated authorization and homologation processes, which powertrain designs have to undergo as well, this carries even more weight. "It's all due to the fact that the voice of production is not existent. The product designer has to write a change request, he has to do a new product validation, he has to take the responsibility for a new development draft. Why would he support that? It always leads to the same. The product designer says, beautiful, that's a nice idea. But that would need a new product validation, and this draft is already agreed upon. That's all because today, we start much too late, after target agreement. I talk against a wall if I start this late" (145:24).

In addition to that, a late integration of manufacturing requires the latter to join a discussion where the other participants have great knowledge, while manufacturing itself starts from zero. “We would have greatly needed the input from manufacturing for our [names a product component, author’s note] system, but because they didn’t know the framework conditions they rather held back and didn’t say anything” (143:6). A manufacturer narrated his experience of an integration workshop: “But then, the discussion was on a part that I didn’t even know, and then they used very strange abbreviations. And then they discussed, and then I didn’t want to interfere and ask stupid questions” (159:9).

Alas, involving manufacturing from the earliest point in NPD onwards seems to be no straightforward solution either. When no product or process has yet been conceptualized, downstream functions will have difficulties to provide valuable feedback. “The product designer is dealing with the product many months or even years before production planning […], it doesn’t make sense for him to talk with the production planner because he doesn’t even know what he wants for himself. But when this point in time comes, then the concept is already quite determined in his mind, such that he doesn’t want anyone to interfere anymore” (177:26).

Compartmentalized nexus of contact persons

For cooperative intensity to emerge between functions, awareness of channels and contacts to the cross-functional counterpart is a necessary precondition. In a large-scale industrial setting such as CarCo, this transparency may be difficult to achieve. “We divide everything up to steering functions, and as a result, we have a completely - well not completely, that’s exaggerated - but at least a responsibility model that is very difficult to understand and to see through. Generally, this matrix organization is so broadly diversified that everyone just says it’s not my responsibility” (158:7). Finding contact persons as well as the right channel or tool among many to convey inputs to cross-functional partners seems difficult, particularly for downstream functions striving to direct information upstream. “To begin with, it’s not too easy to find the right product designer, I had to search for a while at first. The allocation of who does what is not totally clear or transparent” (153:4). A manager, who has already been in his position for two years, adds: “I still don’t know, who of the contact persons I have is from production planning and who isn’t” (174:10). An anecdote provides further insight thereof; the setting commemorates of a kafkaesque scene: A process specialist from manufacturing did not know who the responsible process designer for a problematic process is, but he didn’t dare to ask them directly due to hierarchical differences. Instead, he asked someone from production management, who didn’t know either but asked the process designers’ manager for the responsible person. The manager didn’t want to provide the actual names, but sent him to ask another person for permission to provide the names (154:43). Besides, structural complexity seems to be on a constant rise, further decreasing cross-functional transparency on effective channels and contacts. When asked why he perceives cross-functional cooperation as difficult, an interview participant answered “simply because it’s extremely complex […]. I think because, if you look at the formulated stage-gate process here, it’s huge. And to integrate processes into that, it’s not that easy. And afterwards, to understand, well the process, you’ll need an interim result of it for some kind of virtual product validation. And of that, the result again goes into something else, that was just not easy” (184:6).

Given the complex nexus of channels and contacts, ideas to improve manufacturability are reported to get lost somewhere in the process of addressing them. “As it is so often the case, lessons learned disappear on some kind of server or in some kind of drawer, and at the end of the day it doesn’t reach the person that it should reach. Or the requirements are always reset, and that’s a rotten Sisyphus process” (173:13). A production planner’s experience provides further insights: When looking for a suitable fastening concept for a certain use case, she proposed a new concept. Talking to the inventor of this concept, it becomes clear that the concept had already been presented to the relevant product designers. Still, the concept is presented to the product designers finding positive feedback. 2.5 months later, no assessment of the concept has been performed, and the concept is again introduced to product design, again with no outright rejection (12:1).

7.2.1.2 Cooperation contents

Discussion topics focused on series issues and coordination

Illustration 31 provides an impression of interaction topics, recurring in informal discussions or formal communication, along the examined functional interfaces based on their mentioning frequency in the case study data base. Notably, transactional information and coordination play a significant role: “At the interface towards product design, the distribution is rather mutual sign-offs, information exchange. Here I need this info from you, there you have to give me that info, and saying that’s okay, we’ll go on like that. Things like a creative workshop are rare” (151:21). Indeed, the analysis across the case study data base shows that creative ideas or problem solving are mentioned only occasionally as topics.

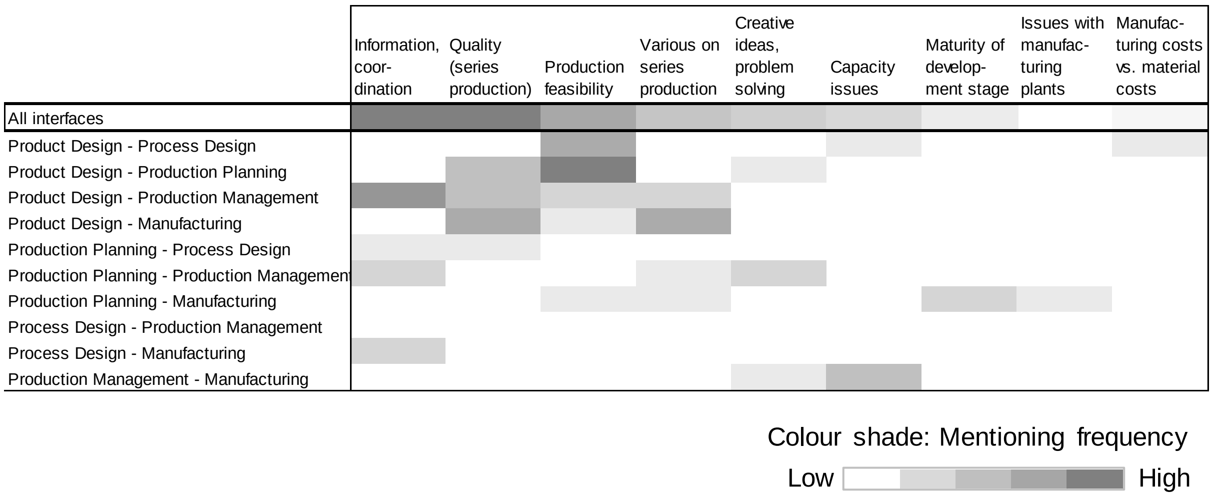

Illustration 31: Discussion topics of different functional interfaces

When disregarding the prevalent mere transactional alignment and focussing on the controversial discussions that take place, the following can be concluded: A strong focus on series production becomes visible, whereas products in the development stage are discussed less frequently. Various topics on series production, in particular if there is a reference towards quality, are brought to the table. “The only platform that we have where I’d say we are in a discussion mode is the quality steering circle” (173:28). At the product design-manufacturing interface, this restricted topic focus is particularly evident. The answer of a production representative on the question which discussion topics exist between manufacturing and product design is representative thereof: “In the series at first, always if there are quality problems” (145:27). This reflects the earlier observation of manufacturing being involved only in later NPD phases approaching the start of series production.

Notably, production feasibility, meaning a dichotomous assessment whether a product is producible or not, is more often discussed than the more delicate weighing up of manufacturing costs versus material costs. For the latter, production representatives (although not manufacturing themselves, as noted above) may simply lack the argumentative power, whereas a new product which is indeed impossible to produce constitutes an incontestable argument.

There is an interesting notion from several informants regarding the unpleasant nature of most discussion topics that are brought to surface in the upstream communication, i.e. from manufacturing to process design or from production management to product design. Two production management employees articulate it as follows: “We have the rather unpleasant job of - I usually say it like that: you have a carnival party, and we are the cleaning wagon, party is over, and then we clean up the garbage and then we have to say to the people [to product design, author’s note], by the way, you’ve forgotten something there” (130:5). Another informant described upstream communication content as follows: “It was actually only about escalation topics, there was never something like I have a content question. […] That means that you’ve always talked about problems. It’s always, we are either not allowed to or not able to” (130:24).

Communication tone patterns

Another focus of analysis within cooperative intensity is the discussion tone or atmosphere in cross-functional interaction. As a first observation, there seem to be inherent differences in communication tone patterns that prevail in early phases of NPD contrasted against those of later phases: “That’s depending on the phase, so in an early phase it drags on, it’s only heating up when you slowly approach calls for tender [during series development phase, author’s note], and when you’re at SOP it becomes heated” (82:47). With reference to early phases, the discussion tone is described as “more passive, rather listening and receiving” (82:14), with the discussion heating up the closer the NPD process approaches its finalization.

This phase-related pattern seems to be valid for all interfaces that are actively involved in NPD, with the exemption of manufacturing. For them, one communication attitude seems to persist throughout different NPD phases: The case study data base contains manifold instances that suggest a blocking or wall-building communication pattern between manufacturing and other functions involved in NPD, no matter if they belong to the production or the design department. Markedly, these blocking tendencies are perceived by both sides of the interface. For example, a process designer described the following: “There was a bit the topic that the manufacturers - that was a bit the problem in plant [names plant location, author’s note], we had quite some problems to build up contacts. Look, we don’t work against you – but it’s not that easy to make all of that work. What was a bit the case is that, their expectation was, maybe not arrogance, but it definitely is like ok, process design, you have looked through all of that and when I get this now it all has to work” (170:15). Quite similarly, a manufacturing representative perceives a similar arrogance on side of the production planner in this quote: “Those in the plant, they are the stupid ones. The production planners from the headquarters, they look at you from above, look at you as a manufacturer, just asking dumb questions. That is quite a certain arrogance. For example, if I ask the product designer something, he wouldn’t say simply that’s not possible because of this and that. Instead, they start discussing, and then he just says no. That is quite a certain arrogance.” (159:17).

7.2.2 Cooperative ability

Cooperative ability

1st order concepts	*2nd order themes*	*Aggregate dimensions*
20. Awareness of cultural differences between functions 21. Diametrical mindsets of design and manufacturing	*(h) Different mindsets of design and manufacturing*	***Differences in functional predispositions***
22. Availability of precise specifications and hardware 23. No advocacy of production topics without detail knowledge	*(i) Manufacturing demands reliable specifications*	
24. Clothing and language as means of differentiation 25. Manufacturer walling off towards indirect functions 26. Perceived distance of manufacturing	*(j) Social differentiation of manufacturing*	
27. Limited cross-functional insights 28. Unawareness of downstream consequences 29. Perceived supremacy of indirect functions 30. Aura of artistry around development functions	*(k) Upstream functions over-valued, downstream under-valued*	***Manufacturing not at eye level***
31. Manufacturability difficult to define 32. Manufacturing-ready design as production's obligation 33. Downstream requirements not binding 34. NPD process as unidirectional sequence	*(l) Manufacturability requirements difficult to place*	
35. Manufacturability as frequently deprioritized topic 36. Manufacturer without incentive to intervene in NPD 37. Manufacturing costs have no advocate 38. Time lag in NPD distorts responsibilities	*(m) Low advocacy for manufacturability*	
39. Lack of cross-functional experience and contributions 40. Formal NPD process unsuited for innovative products 41. Liaison people lacking due to small size	*(n) Innovativeness inhibits cooperative ability*	***Inhibitors of cooperative ability***
42. Supplier relationship as another difficult interface 43. Required experience lies with supplier 44. Supplier distorts importance of manufacturability	*(o) Supplier relationships inhibit cooperative ability*	
45. Corporate steering mechanisms work functionally 46. Power considerations entrench functional orientation	*(p) Functional structures are self-sustaining*	
47. Trust as success factor for cross-functional integration 48. Lack of trust and openness across functions	*(q) Lack of cross-functional transparency and trust*	
49. Formal process/agreements necessary for cooperation 50. Push-off mentality / no voluntary extra efforts made 51. Dependency on formal process detrimental for innovative NPD	*(r) Cooperation dependent on formal process*	

Illustration 32: Data structure - Cooperative ability

7.2.2.1. Differences in functional predispositions

Different mindsets of design and manufacturing

Functional delineations are visible and tangible in daily interactions at CarCo. This includes not only organizationally cultivated differences such as vertical structures or functionally oriented processes, but passes through to differences in mindset and attitudes. CarCo employees are aware of profound dissimilarities between different functions, though emphasizing their intangible nature: “Worlds lie in between, but it’s difficult to put into words” (183:5). Aside from that, mastery of this cultural diversity is acknowledged as an essential precondition for success at CarCo: “If you master the cultural aspects here, then you’ll get by fine” (82:95). Differences in mindset between functional units identified at CarCo confirm existing theory, which emphasizes delineations in culture and belief systems.

Between manufacturing and product design in particular, differences are described as touching upon a multitude of aspects of organizational life. “The cultures are totally different. During the first half year, I noticed it extremely, how different the production department is, the KPI orientation, let alone this strict hierarchy – that’s quite a bit more easy-going in product design, or you could as well say chaotic” (130:29).

Indeed, looking into the depth of different functional predispositions in mindset and attitude, an almost diametrical breakdown can be observed for product design and manufacturing, respectively. Illustration 33 pictures different mindset traits, which found mentioning during data collection. The different traits were not provided, but emerged from their unprompted naming in interviews and participant observation. Product design and manufacturing seem to be at two sides of a spectrum for large parts of the mentioned traits, except from a few categories which can be attributed to both, for example technology-loving.

With regard to product design, traits such as free-thinking, openness towards new things are most pronounced, reaching out to the other side of the very same medal like a chaotic or naïve mindset. “The product designers love to discuss freestyle, they don’t like to be tied down” (125:35), “They want to let off steam, they want to play around” (179:4). Manufacturing, on the other side, is described as displaying a more collective attitude, building on mutual trust and loyalty. “In the case of manufacturing, it’s quite a bit different, as I said, they are much more hands on, they’re wired differently. It’s more about finding a personal access to someone, to a foreman or a worker at the assembly line, you have to act a bit more pragmatic” (127:27). Being pressed for time and having a low abstraction capability are other frequently mentioned characteristics for manufacturing. “Abstracting things, and imagining how something might look like just roughly, picturing something hypothetically, they are not able to do that” (124:7). As another ascribed trait, manufacturing’s consciousness in tradition and experience stands opposed to product design’s innovation affinity.

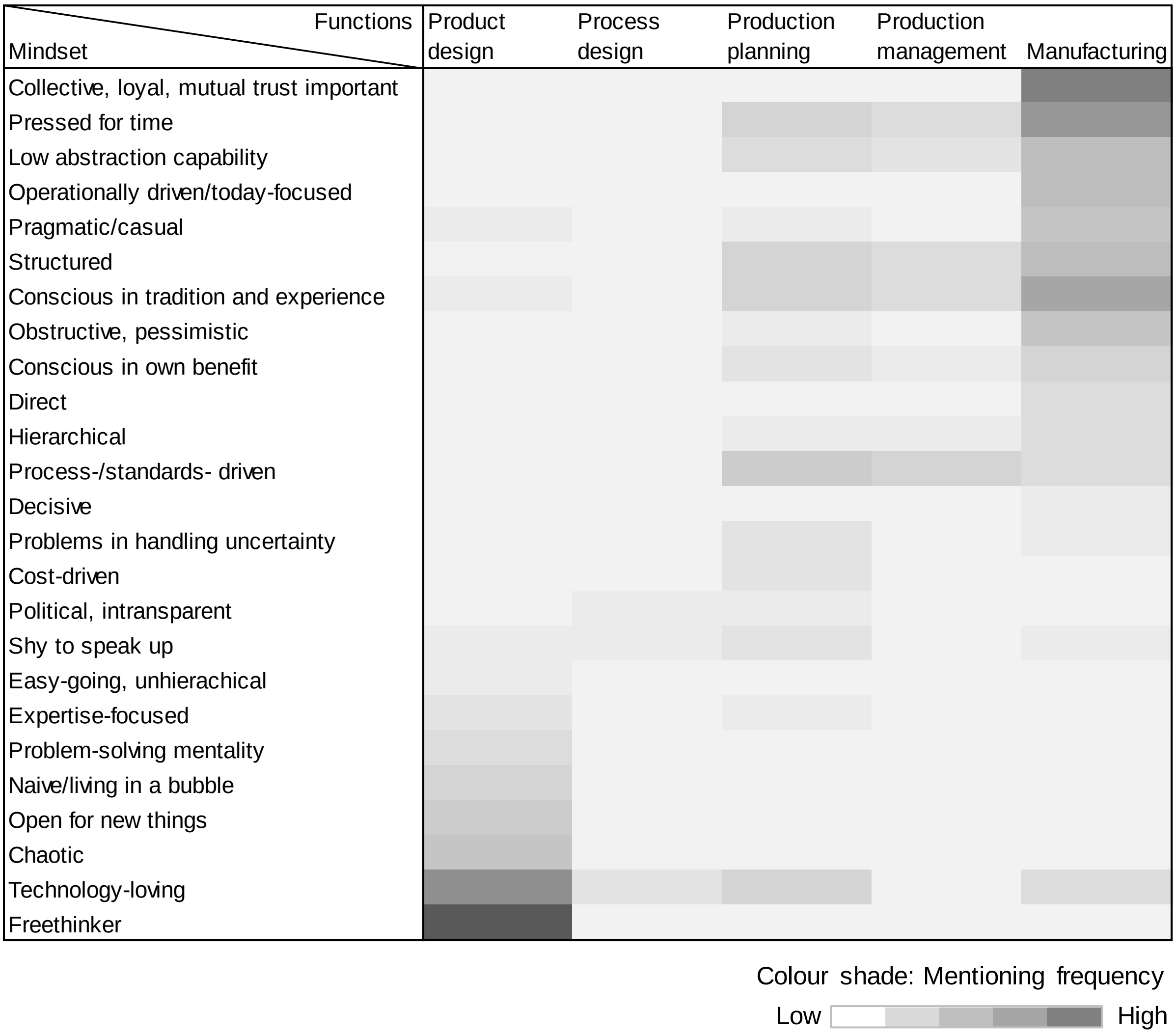

Illustration 33: Mindset traits of functions

Interestingly, bridging functions in between the two poles of product design and manufacturing, such as process design, production planning or production management, find themselves with less clear trait manifestations and rather blurred delineations. Product design and manufacturing seem to be perceived as distinct, clear-cut cultures, which informants find easy to describe and differentiate. Bridging functions, on the other side, are less palpable as a standalone culture, bearing traits from both sides of the manufacturing-product design spectrum.

Manufacturing demands reliable specifications

Another way to look at functional predispositions is to analyse function-specific preferences which functional representatives may demand from their cross-functional counterparts. The degree to which these preferences are compatible can provide information on how difficult cooperative ability is to achieve. Illustration 34 provides an overview of such demands that were mentioned in an unprompted way in interviews and participant observation.

Notably, the largest part of these preferences stems from a series production background, such as reliable processes, maintainability or reliable technology. Only a few topics with relatively few mentionings, such as mature product or manufacturing-ready product design, constitute inherent NPD-related topics. This tendency follows earlier results from the analysis of discussion topics within the cooperative intensity dimension. Remarkably, the availability of precise specifications and hardware is of high importance for several functions representing the production voice, in particular manufacturing and production planning. “A production guy is normally a very very [pauses, author’s note] – a product designer can easily deal with free solution spaces, a manufacturer cannot […]. Production always needs clear specifications. He’s just not able of abstracting and saying I construct my system for an amount of X parts, and it’s good, just for example. Instead, he needs a statement such as I must produce 324.543 machines. And he doesn’t question if this number makes sense or doesn’t. Then this is the famous premise, what do we have premises around here in the first place, it’s a word I’ve never heard as often as here. So this is absolutely sick around here, with the premises.” (82:96). Presumably, this demand is closely connected to low abstraction capabilities that have been identified in the last paragraph. “A production planner, as a man, has incredible difficulties to abstract things, and thus he can’t just say “I assume”, really the word “I assume” is a taboo” (82:96).

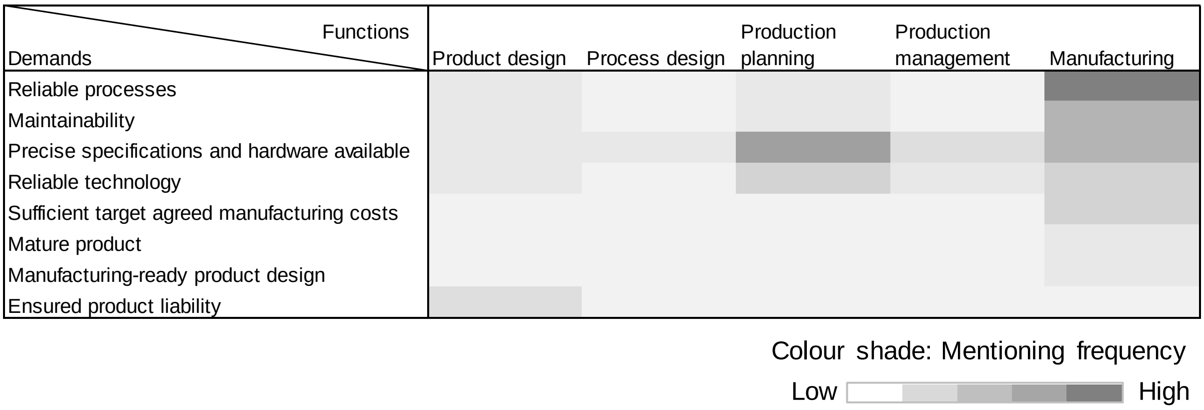

Illustration 34: Function-specific preferences

Naturally, this demand for precise specifications impedes production’s cooperative ability towards product design. “In the early phase everything works only on a virtual basis. Manufacturing, however, they are rather relying on hardware, they have incredible difficulties with CAD models” (141:3). At CarCo, this prevents manufacturing functions from engaging into discussions with product or process design in earlier phases of the NPD process, or as a production planner put it: “Sure, CAD data means something to me. But to really make a methods-time-measurement analysis in all of its accuracy, you at least need a finished and construed product, or some version of it. And to get in even earlier, you’d need at least some kind of database” (176:1).

Social differentiation of manufacturing

Several observations in the case study data base indicate that manufacturing occupies a more outwards position compared to other involved functions. In this regard, clothing assumes an important role, pointing towards a common identity of production and thereby simultaneously differentiating against other functions. At CarCo, employees of production department, even if not working directly on the shopfloor, like to dress in shopfloor clothing. Managers in the production department all have their official photos in the company social network taken when dressed in shopfloor clothing (4:1). On the shopfloor, other attire is looked at with disdain: "I'd never go into production, for example, with a suit and tie and stuff like that, then you'd directly be labelled as a headquarters snot" (178:26). Similarly to clothing, language assumes another differentiating role. In particular, the local dialect that is spoken in large parts of the production plants outside of the headquarters is perceived as a door-opener by many. "If you're at the production plant, if you talk dialect then they'll be your best friends." (124:16).

Some informants suggested a further reaching form of differentiation exerted by manufacturing, with walls being built towards the indirect functions, including design functions as well as indirect production representatives such as production planning. "The product designer always says against the manufacturer I can't do it, it's not possible, my robot can't do it […]. That's how clear front lines have built up. These are front lines that exist" (158:33). An indirect production management employee explains his experience on the shopfloor: "When you get there, they certainly think you're not capable of anything […]. And I had myself trained there, and I assembled there, and I was the object of great amusement, the workers that stood there thinking "well, now we'll see how he'll assemble the things, how he holds the wrench" and so on. […] But at the very beginning, when you get there, you didn't see them before, they do feel like, I don't want to say this so hard, but they do feel like something better, something above you" (124:129). Conceivably, this tendency of walling off might stem from a perceived lack of appreciation of indirect functions towards manufacturing, which will be analysed in more detail in a subsequent chapter. A manufacturer's statement is insightful for this respect: "They always say that the big head (verbally: water head) in the headquarters gets bigger and bigger, and they don't talk the same language. That's precisely why they, the oh-so highly studied doctors or studied somethings should for once come and see how it is produced" (159:18).

The discussed aspects of social differentiation result in a perceived distance of manufacturing in manifold forms of social interaction, which certainly detract from building up cooperative ability at the design-manufacturing interface. "The manufacturer is the furthest away of all functions, he might be invited to one FMEA or to one assessment, but apart from that the manufacturers are the furthest away" (151:37). Likewise for informal social events, such as a fair that comes to headquarters' town in spring, manufacturer employees did not participate although all other functions of product design and production were present (191:1). Indirect functions tend to act with cautiousness when approaching manufacturing employees: “My interns, so far I only took them to process designers […]. Those guys are easy and that wasn’t a problem at all. If we’d go to a manufacturer, I’d sensitize them a bit more” (129:12).

7.2.2.2 Manufacturing not at eye level

Upstream functions over-valued, downstream under-valued

When a manufacturer was asked how cooperation between the functions in NPD works, he gave an insightful answer: “An important reason why it does not yet work is because we don’t know one another’s processes. Product design should come down to production regularly, and the other way round as well. It would be important that manufacturing and production planning know product design’s objectives, but it’s not the case today. In the end, it all boils down to the fact that we don’t know each other, we don’t know what drives the other one” (145:1). Many informants at CarCo reaffirm the importance of mutual insight into actions and motives of the cross-functional counterparts. Likewise, there is broad consensus that mutual insight remains insufficient. A manufacturer utters his view on product design: “They have no idea how things go around here, and what the difficulties are. They have zero insight” (147:55). Illustration 35 displays cross-functional insights that were described for all examined interfaces based on their mentioning frequency. While black arrows signal predominant mentioning of high cross-functional insight into the function they are directed at, red arrows indicate low cross-functional insight. Arrows have been omitted between interfaces where informants provided mixed statements without a clear tendency. Overall, there is great dominance of low insights, except for the production management – manufacturing interface. Notably, product design seems to be the most “unknown” function, with frequent mentioning of lacking insight into it from all other functions. “I have absolutely no clue at all, what exactly they do in product design. Seriously, I neither have any clue how things work internally for them” (156:4).

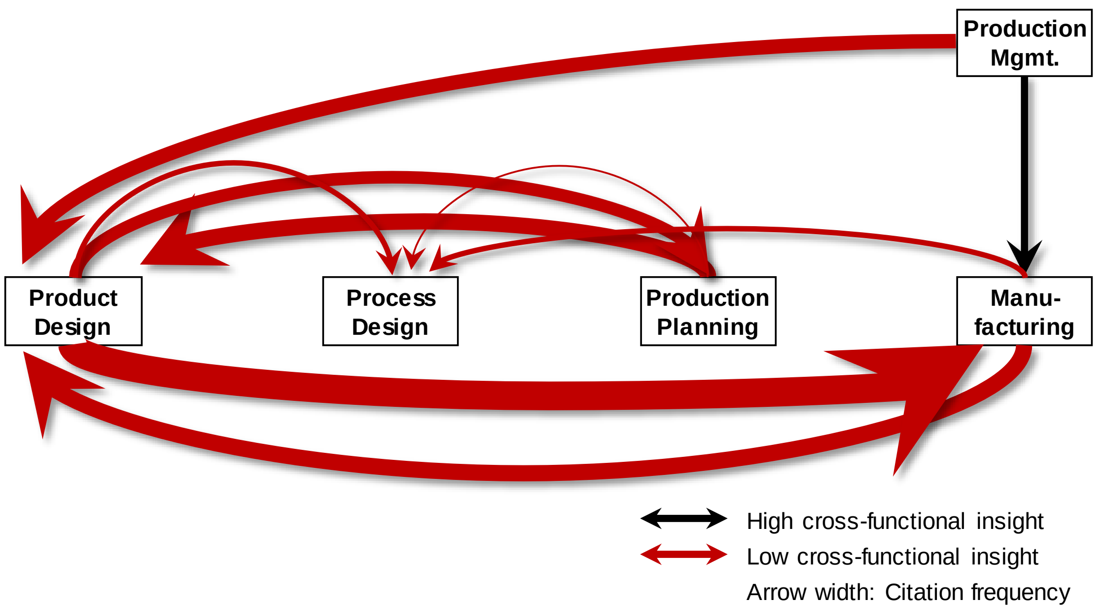

Illustration 35: Insight into cross-functional counterparts

When asked for the impact of own activities on their cross-functional counterparts, informants repeatedly identified one shortcoming: Upstream functions tend to be insufficiently knowledgeable on the consequences of their activities on downstream functions. “It’s also a lack of understanding of the production planner, sometimes he just doesn’t know that there’s a customer out there that he has to satisfy, namely the manufacturer. That happens to other functions that are downstream the process, as well” (131:16). Manufacturing, as the furthest downstream function among the inquired interfaces in this study, was evidently named a frequent victim of this situation. “I don’t want to say that they [product designers, author’s note] live in another world. But they totally lack a comprehension of assembly, they cannot even imagine what happens there” (152:18). Markedly, the accused upstream functions reaffirm this view: “We [in product design, author’s note] have a very limited view on what the consequences [on production, author's note] are of what we commit here” (30:3).

Limited cross-functional insights, in particular with regard to downstream consequences, are indicators for an overarching motive that emerges repeatedly throughout the case study data base: Downstream functions, for instance manufacturing, tend to be considered inferior or less attractive, while upstream functions, such as product design, are often circumcised by an artistic, admired aura. A CarCo employee, who was part of product design, changing over to production management, said: “It took a while until I was respected at the design department with a production department symbol. They think, the production department builds the cars, but apart from that they don’t know anything at all” (134:4). Sovereignty over innovative technology is attributed to upstream functions, and openly demonstrated. “With regard to the people from the production department, the product designers only say they don’t know anything. They can produce it, but with regard to technical competence they have no idea. Technical knowledge, background knowledge, rather like umm, they should just do whatever, and they should let us do our job. They can produce, yes, but they shouldn't interfere in the technology, they have no clue" (179:6). Downstream functions are perceived as less attractive with regard to work contents, even by production representatives themselves: "Of course it's much sexier to talk about products and functionalities, how fast is the engine, what is the torque, how smooth it is to steer, than about, well, how can I assemble this the quickest or the cheapest way" (151:5).

By contrast, development functions and their daily activities are surrounded by an artistic aura. Expressions of arts and mastery are indeed utilized by informants when discussing these topics. While processes and outcomes at CarCo are closely managed, with production volumes and even sales figures neatly projected and called for, the product design process is allowed a less directed, almost nebulous working style. A product designer describes the construction process as to large parts taking place subconsciously, during an "engineering flow", with a strong shift of consciousness away from the outside and little taking-up of external requirements (28:2).On occasion, this culminates in product designers enforcing their original "piece" in acceptance of disadvantages for downstream stakeholders such as manufacturing or marketing. "There is a topic of setting an example. There are always some [product designers, author's note], who want to leave something behind, with some kind of technical solution or development or whatsoever. There are many that are a bit too artsy-fartsy there" (178:40).

Manufacturability requirements difficult to place

Informants recurrently named one circumstance as the prevailing factor impeding manufacturing to encounter its upstream cross-functional counterparts at eye level: Simply, manufacturability requirements are difficult to place, to find appropriate attention in the first place, in the NPD process. Several reasons hereof are provided. First of all, manufacturability requirements are difficult to define such that they could be rigidly called for during design phase. "The problem is that I don't have a structure or something like that, something like the assemble space, how you can define it. That makes the topic so difficult, there's nothing I can say that I can just tick off, simply four or five criteria, and if they're fulfilled it's producible" (141:16). A product designer added to this notion that the innovative nature of a projects makes this even more difficult: "It's important that manufacturing provides a precise problem statement. It has to be well described and quantified. In our project, this is still insufficient, because the technologies are new" (145:30).

In addition to the inherent difficulty to define manufacturability in the first place, it is also perceived to be in the sole responsibility of production, and not product or process design. "Manufacturability is seen as a subordinate topic for most product designers. They see it also like, oh our manufacturing will do that, they'll take care of it. But that it likewise belongs to their tasks, to design the product such that it is manufacturing-optimal, maybe it's due to their academic education, that this is subordinate" (151:4). Given the late integration of production representatives, this almost inevitably leads to a negligence of manufacturability topics. "At the moment, when a manufacturer says that this and that is something we could optimize [regarding product design, author's note], we first have to tear down massive walls before anyone would only hear us" (159:2).

Besides, downstream functional requirements such as manufacturability are not perceived as of binding nature by designers. "Process requirements? We don't really pay attention to them, and we wouldn't write those down in the specification sheet, because they're not real requirements" (104:1). Again, this suggests a perceived inferiority of downstream functions' requirements as described above.

In general, CarCo's NPD process seems to be bound to follow only one direction, namely a strict sequence from up- to downstream. Flexibility to embrace downstream inputs into upstream activities is restricted, be it from manufacturing or other downstream functions. "The rule is that product design predefines everything, and manufacturing is left with the realization and production. For the other way round – well, we try to have an impact regarding product design, but it's much more difficult" (155:21). Evidently, this has an impact on interfaces in NPD other than design-manufacturing as well, such as the design-marketing interaction. "In my opinion, we develop a technology, because we want to develop a technology, and then we try to sell it to the customer, and then we begin to understand what the customer actually wants (162:20).

Low advocacy for manufacturability

Manufacturability of a new product, i.e. how easy, fast and cheap the product can be produced or assembled, may serve as an approximation for the cooperative ability pervading the design-manufacturing interface. After all, manufacturability is expected to find acceptance when design is able to empathize with their cross-functional counterparts and incorporates their requirements. With regard to manufacturability at CarCo, the case study data base features many instances of criticism: "People always say that the product design people, that they are nuts, no one could be able to manufacture something like this. And it is like that. Often, the designs that are delivered from those product designers is - not only does it take a long time to assemble it, but it is also often poorly construed." (182:16).

When continuing the analysis why cooperative ability at the design-manufacturing interface is difficult to achieve, informants' statements suggest an unexpected explanation. While the author assumed that the manufacturer would be manufacturability's natural advocate, it appears as if this holds true to a limited extent only. Indeed, there seems to be not a single reliable spokesperson for manufacturability, with several aspects of CarCo's NPD bearing responsibility thereof.

To begin with, manufacturability as a topic is often deprioritized against other, more urgent topics on the NPD functions' tables. For most cases, manufacturability is not a prohibitive factor in a way that quality problems or acute external deadlines would be. "If you're having acute quality problems, it's very urgent and often pops up in the escalation circle. On the other side, design questions, generally speaking, do not have to be solved in the week XYZ […] that's why it doesn't pop up at my place" (173:2). Notably, many involved functions follow this scheme, including manufacturing themselves: "We have an operational problem, and everyone takes a deep breath when the operational problem is solved. Then you wipe of your mouth and continue your work. But taking the last step in saying, what is it that I can pick up of this for the future product generation, and how can I place that rightly, that's what we don't do anymore […]. In midst of all of the "yes, we've managed the problem", this is forgotten. Because the next topic already superposes itself" (173:14). For product design or other upstream functions, it is similar: "The product designer has always 1000 other problems, for him this one [manufacturability, author's note] is the last one of all."

As indicated above, manufacturing at CarCo lacks an incentive to assume advocacy of manufacturability in NPD: "Sure, the manufacturer is wired differently, he rather says why should I care about what comes in 5 years, if my line stands still today" (145:32). Even if manufacturing representatives would engage in a discussion with product design, they would likely lack the incentive to rigidly enforce their functional requirements. "There is a tendency that they talk about it [manufacturability, author's note], but for lack of time it's just led through on the nod in the end" (154:31).

Even more so, the manufacturer has no advantage if manufacturing costs for a certain product design are kept low. "If I ask who has the benefit, then everyone is happy to have higher manufacturing costs. And most of all the plant, then they have more budget to play around with" (176:13). Because of large-scale corporations' logic of internal transfer pricing, with manufacturing costs being determined during the target agreement phase at CarCo, low manufacturing costs have no advocate. "We've never seen this, that the plant manager holds a product line manager to account, telling him to reduce manufacturing costs. He gets into NPD much too late for that. At a maximum, during launch phase, he takes care of assembly defect risks, maintainability, things like that. But if manufacturing costs are really too low or too high, doesn't help the plant at all, as long as he receives the money for it, he just doesn't have any interest. And neither does the production planner. There is no one, who would actively call for that." (176:4). Notably, production controlling does not assume advocacy, either: "The role of our production controlling is rather to take care that manufacturing gets enough money. Such that they can work. And of course, from this perspective you don't cut yourself saying something like, clearly two Euros lower is possible, we'll get them easily. Instead it's all about building up a bit of a buffer here" (156:19). Indeed, only corporate controlling would be incentivized to assume advocacy for low manufacturing costs, which will be analysed later in this case study.

Lastly, as a problem inherent to all empirical settings with a long NPD process, responsibilities are distorted by the massive time lag between design phase and series production. A process designer of CarCo expressed this aspect as follows: "If we [process design, author's note] really screw something up, then the manufacturer is of course typically the one who suffers. At that point, it indeed is like that, that we're out of responsibility already" (82:74). This time lag may likewise be partially blamed for manufacturing's' lack of motivation to fight for manufacturability. "Manufacturing is only hurt when in series production, there is a problem, he can't deliver parts or his supplier can't deliver parts. But what is in 2019 with the new product generation, he has no pain at all regarding this in his current business" (125:6). Any implementation of an incentive scheme that provides sufficient long-term orientation to cope with this challenge will come into conflict with a large-scale company's business processes. "Actually, you would have to set a target for product design and production planning in a way that, after 5 years, you take another look and really assess their work. But retrospectively, it would be of course difficult in the company processes, it's not possible" (141:38).

7.2.2.3 Inhibitors of cooperative ability

Innovativeness inhibits cooperative ability

As a recurring theme, informants mention that CarCo's formal NPD process and the cross-functional interaction model is sufficiently well working for products with incremental extents of innovation, but unsuited for innovative products. Several reasons thereof are provided. To begin with, cross-functional experience, undeniably important to develop cooperative ability, is insufficiently available in a young innovative organization. "It's an experience that you just have to make as a young organization. People have to learn to work together, and for points where you had problems and conflicts in the first projects, often you learn from them and become wiser, such that you won't make these mistakes again in succeeding projects. But we're not there yet. If I take the combustion powertrain colleagues, for example, a product designer there, he knows pretty well without someone from production having to tell him what the manufacturing requirements behind that product are, and what he has to expect when he neglects those" (148:24).

When dealing with innovation, a young and inexperienced organization can hardly be mitigated by bringing in more practiced colleagues: "Often, you have young people recruited. In particular in innovative fields […]. These are fields that have not been taught for 40, 50 years at university, which means that the specialists that have learned it somewhere, are mostly below 30 or 40, and extremely many come directly from university. In between, they maybe have worked at an institute, and that's why it's

much like *Jugend forscht* [German youth science competition, author's note]. They all have a bit of a disturbed relationship to processes, likewise a disturbed relationship to tight schedules, and they don't like to be restricted" (167:14).
Another problem resulting from innovative projects with long NPD processes is that downstream functions might not even exist at the time when product design starts off. Therefore, there simply is no production representative available, who could intervene or provide her knowledge. "For the new product generation we have to start all over again, it's a whole new product concept, that's why the manufacturer can't really take part in this discussion in an early phase" (147:48). For CarCo, this seems to be a challenge not only for the design-manufacturing interface, but likewise to the design-marketing interface: "We extrapolate from the past, so you try to describe a CarCo BEV [battery electric vehicle, author's note] in a way that it is able to do the same things just as a CarCo combustion car, no matter what it costs. To be more concrete, an example: You have to be able to give a kick-down at any given time, and as many times as possible. A Tesla can do it three times in a row, it hits your head against the seat, that's absolutely sufficient, no one would want that even more often. But we require our cars to be able to repeat this much more often, because for the combustion car it works as well, and that's just nonsense" (160:27).

Large-scale corporations such as CarCo, with long NPD processes and many stakeholders to involve, have developed complex and granular process descriptions. Often, in their complexity, these are difficult to comprehend as a whole for a NPD participant. Therefore, these processes own a certain self-dynamic because participants are unable to scrutinize smaller parts of the entire process. Participants are taught to stick to the process, because consequences of not doing so are incalculable. For innovative products, however, "playing it like all other components, that everyone does one's bit and then it's integrated in the regular process, this doesn't work for completely new innovative topics" (173:16). Requirements of innovation dynamics are in conflict with the formal process: "The requirements, be it product or volume, change quicker than the process would allow them to" (171:2). An example thereof was observed during the critical target agreement phase: The final cost estimation loop, which usually is prepared meticulously because it provides the basis for the target agreement, was entirely re-calculated overnight, because an essential product feature was decided to be changed two weeks before the deadline (171:2, 198:1). Another example was described by one of CarCo's production planners: "For example the product modification process, this really cannot work. If you would go through it just as it is required at the moment, you'd be dead before […]. We start it only when the result is already there. Depending on the complexity, such a process could easily take a year, and officially you wouldn't be allowed to make any modification" (171:16). Another example involves the formal tendering process, which is essential for companies with a relatively low depth of value creation. At CarCo, the formal NPD process sets the call for tender around 3 years before SOP. Because the

innovative high-voltage battery product still changes its concept due to new technological discoveries, this process can hardly be met. As decision processes are bound to the formal process, CarCo has difficulties to access supplier capacity: "This will become correspondingly expensive, it's already more expensive than it was planned, because naturally, in one year, which is how long it took until it was decided at our house, many others say also that they want to do it. If now we come as well, doing a call for tender, not even having awarded it to someone, and the product itself is already outdated… That is quite a bit of a frenzy" (164:8).
Naturally, the obligation to stick with entrenched corporate processes while trying to embrace innovation creates pressure for all participants. A neat integration, building on extensive cooperative ability and aligned interaction, is at risk to fall off the table. When asked for the consequences of frequent product modifications on the cooperation with product design and manufacturing, a production planner provided the following insight: "This evidently makes it more difficult to integrate all interfaces, because most of them are preoccupied with theirselves. It's difficult to manage that you synchronize the result which you have worked out with all interface partners, be it logistics, manufacturing, product design. Therefore, when you've worked your result out, the whole thing is already outdated again because you have new requirements and that's why everyone stews in their own juice. You never have the chance to align with the others" (171:3).

In large-scale industrial setups, integration often is helped by introducing liaison people into the NPD process, who specifically take care of cross-functional needs. For innovative products, where volumes are still small and budget is restricted, these liaison functions often do not exist. An example at CarCo is the inexistent manufacturing equipment designer, as a representative of a liaison role that small projects are not able to afford, although they would be important for seamless integration: "We'd really need a manufacturing equipment designer, but that bears costs for a position. All of these functions are passed on and on like a hot potato, no one wants to have them on his cost centre. And as they sit naturally in between the functions, you push them around" (153:15). A member of production management attributed problems at the design-manufacturing interface to this lack of liaison people: "This goes pretty wrong I would say. If you compare it to the vehicle projects […], they have some kind of interface function between production planning and product design, who exactly cares about these manufacturability topics, [names a person, author's note] is doing this there. This role is too weak at our project, or doesn't exist at all" (157:18).

Supplier relationships inhibit cooperative ability

"Another problem is the high share of purchased parts, which is often a matter of fact for OEMs. There, the cooperation becomes even more difficult because, when the company Bosch comes, you don't know if that's their manufacturer of the two people that are there, it's just the company Bosch. So at the end, I don't know if I talked to the manufacturer or to whom I talked. And even the product designers don't do much by themselves any more, they outsource much to service providers, and there I don't know which cooperation or which alignment took place" (131:12). This product designer's statement introduces an important reality of most large-scale corporations: cross-functional integration within the company is just one issue; integrating external interfaces is even more challenging, and – in consideration of the often low depth of value creation – often even more important. To begin with, cooperation with suppliers simply constitutes another interface, with all the entailed complexity in interaction. Second, supplier interfaces are often more difficult to interact with than internal interfaces, be it due to unclear functional responsibilities as quoted above, or due to restrictions for interference based on legal conditions particular to service contracts, which forbid any close cooperation similar to an employment. With regard to the design-manufacturing interface, a gap becomes evident: "At the moment it is like that, if a part is produced inhouse, the CarCo process [to ensure manufacturability, author's note] is started, but for purchased parts, there is nothing" (141:11). Naturally, the supplier has little incentive to engage in discussions with the OEM's product design to improve overall manufacturability. Due to CarCo's low value-added-depth, it is likely that a manufacturability-improved component will be sourced from a supplier, therefore reducing the suppliers' sales.

As explained above, experience in cross-functional activities is important to develop cooperative ability. With its high share of purchased parts and services, large parts of CarCo's essential knowledge lies with suppliers. Alike other large-scale manufacturers, CarCo purchases development and design services in significant amounts from suppliers. A production management team member complained about the missed opportunity for experience build-up: "What is really sad, is that we really build up so much new, create new production lines, that we are really able to follow a greenfield approach. But in fact, that's just the suppliers that do all that, all the know-how lies with them" (142:28). In addition to that, cross-functional discussions, necessary for a better cross-functional outcome, are at stake of going into the void. "That the product designer is able to say something without directly having to ask the supplier. There's almost nothing they are able to do themselves any more today" (145:29). For production planning alike, this constitutes a problem for effective cross-functional interaction, as the following observation shows: A member of production management comes with suggestions to improve manufacturability to production planning, asking them for corresponding details and timelines. The production planner is barely capable of answering, apologizing for their ignorance and referring to the call for tender for suppliers, which had to be prioritized (99:2).

Lastly, case study informants provide an interesting notion of supplier involvement distorting the importance of manufacturability. At CarCo, this goes back to the trade-off between manufacturing costs and material costs, the latter including costs for purchased parts. With its high share of purchased parts, material costs at CarCo usually outweigh manufacturing costs by a significant factor. Naturally, and economically reasonable, manufacturing costs play “a tangential role. Regarding the battery, manufacturing costs may be XX€ [names financial amount, author’s note], material costs XX€ [names higher financial amount, author’s note]. They [product design, author’s note] wouldn’t even engage in such a discussion” (126:37). As a result, manufacturability isn’t in focus for product design teams: “Just look at the agendas of product design teams, manufacturability is nowhere on that. They have the topic procurability, namely if there is a supplier of whom I can buy this from, but if it’s manufacturable for CarCo itself later, this is subordinate” (151:9)

However, having understood how complex and large NPD processes at large-scale companies work, suppliers may be encouraged to take advantage of this scheme. A production planner explained, when being asked about the dominance of material costs compared to manufacturing costs: “But that’s certainly a problem that we have created ourselves through our good [ironical, author’s note] procurement. The suppliers get the money of course through product modifications, that’s why it always comes out so expensive” (142:10). Another production planner provided a more detailed explanation on the dominance of material costs over manufacturing costs: “We are often just the second winner in this discussion [laughing] […]. But often, there is a problem in this calculation. Material costs are based on the suppliers’ offers, and of course the supplier gives a favourable price at the beginning, which doesn’t cover his costs. He just waits for a product modification, and then holds up his hand, and all of a sudden the offer is becoming much more expensive” (151:12). Additional costs for product modifications, however, appear during a phase after target agreement, when larger product design changes or changes in the supplier network are out of reach. Weighing up material costs against manufacturing costs in a later phase of NPD would probably yield a different result than in the early phase, with manufacturability making a point more often. The point in time for effective action, however, would have long been passed in this phase.

Functional structures are self-sustaining

To large parts, the strong functional orientation at CarCo seems determined by long-standing organizational structures. “Just think about it, all product design teams are led by product designers. In fact, all rounds are led by product designers. The e-drive process chain, a product designer. Sure, someone from production is sitting in there sometimes, but they just sit in there. If you would ask the other way round, why is no one from production ever leading such a round […]. That’s definitely organizationally induced” (179:14). However, employees at CarCo seem to be well aware of the circumstance that a functional organization impedes cross-functional integration, as the following quote shows: “From my past I know that cross-functional integration across product design, production and procurement doesn’t work as it should, simply because the organizational structures don't match […]. These are typical inputs I got from my old boss, coming from a product design perspective, why production has relatively little to say in NPD" (158:1). Despite of this acknowledgement, functional structures continue to be forceful shapers of corporate reality within CarCo. Evidently, these structures have a strong self-sustaining power, therefore re-imposing themselves on a continuous basis and blocking stronger cross-functional moves: "There's much of potential there, but we don't dare addressing this, we're prisoners there, also with the cost centre structure, because much is decided by money and budget, and as long as this is functional you will go on with this power and trench warfare forever, because everyone first sees that he's clean. In particular, when money is involved - and the higher you come in hierarchy, the more money is involved" (125:46). The mentioned "imprisonment" does not only refer to the cost centre structure and the referring budgeting process, but comprises a broad range of fundamental business processes: "All our steering mechanisms at CarCo are functionally oriented. So for departments, or groups, for example, cost centres and personnel planning, follow departments. And the objective management process follows departments, and therefore all our steering and organization mechanisms" (125:16). Taking the functional budgeting processes as an example, an informant explains why these structures have such a large self-sustaining power. "With the cost centres that are structured functionally, the financial controlling works both in crisis and in successful times. We know this from the crisis in 2008 […] it works, he [financial controlling, author's note] brought us safely through the crisis, and certainly we got some bruises but overall we came through it well. So, these mechanisms work, and that's why there's no discussion to change. Saying now let's run the cost centre structure horizontally, and not vertically any more - he [financial controlling, author's note] just doesn't have this pain, he knows that his current system works no matter what" (125:18).

In addition to the self-imposing power inherent to functional steering processes, informants frequently point out to power considerations that management levels cultivate, which help sustain functional structures since more integrated structures would require giving up hierarchical power. "The thinking in the hierarchies, as you have created them, there are just too many well-beloved features that you maybe do not want to give off […]. Because that could mean as well that I'd have flat hierarchies, and therefore possibly not so many hierarchies anymore" (162:12). Naturally, powerful functional features within an organization are hardly able to encourage pursuit of the cross-functional optimum: "That's how the show-offs [verbally: braces-snappers, author's note] just look after themselves instead of the total optimum. But if they'd set back their egos for the good of the company, that would be something very great" (158:54). Indeed, the author was able to observe this tendency to sustain functional power positions during a re-organization effort, according to which some plant managers would end up with reduced power through a lead-plant approach that would strengthen cross-functional power. Soon, the initiative led to political conflicts within the organization, bringing about operative problems to obstruct the restructuring effort (232:1).

Lack of cross-functional transparency and trust

When asked for elaboration on his assessment that cross-functional integration had improved during the last year, a manufacturer of CarCo answered as follows: “The trust has grown, yes, and I think that the trust is there now, that it is said, we have skills, they have skills, now it is even said that the manufacturer has skills – the trust has grown strongly” (179:3). Many informants at CarCo share his opinion. Unmistakably, mutual trust is perceived as an important success factor to build a basis for effective cooperation with the cross-functional counterpart.

Despite of the above quoted individual opinion, mutual trust and transparency overall seems to be hardly prevailing in cross-functional relations at CarCo. For NPD activities in particular, however, this would be essential, as one informant describes: “At the moment, we don’t even know how the product looks like […], therefore it is all the more important that cooperation is open and close. And we do have room for improvement for it around here” (149:2). Another interview participant complemented: “I experience all the time, that on a working level, there’s not the whole transparency provided in some places” (173:6). This seems to be a valid observation for overall corporate processes in general and cross-functional activities in particular: “There’s not enough trust in the whole company given to the individual deciders […]. The first one has to be aligned, and then the second one, and then you have three other decision committees where important decisions are taken […]. It simply takes too long, instead of simply trusting each other. I can’t say that a decision would be that much better simply because more people are looking at it” (184:8). The following statement sheds light on a certain distrust with regard to the cross-functional counterpart: “It was said by product design that this has advantages concerning the assembly space – heaven knows if that’s really the case” (82:88). A lack of cross-functional trust and transparency is criticized most significantly by downstream functions. They feel to be the ones who most frequently suffer from it, as naturally information asymmetry between down- and upstream functions comes into play. Manufacturing in particular feels somewhat left alone to pay for mistakes that were not solved or brought to light during NPD: “He doesn’t care in the end, if the manufacturer has to pay after seven years. In the end, it’s always the manufacturer who pays the bill for everything that went wrong in the entire NPD process” (147:52).

Cooperation dependent on formal process

When talking with case study informants about their experiences with cross-functional cooperation, it is striking to note that a majority starts with formal interface agreements or process descriptions they share with cross-functional process partners. It seems that in large parts of CarCo, cross-functional cooperation is understood to be of formal nature, and only working when a contract-like agreement is signed with a cross-functional partner. “I first asked where is your process- or project description […]? I didn’t get an answer, just a few process sheets, here and there a few things, here some kind of maturity level, there some stage-gates. All of that wasn’t harmonized to each other, there was no guideline […]. It astonished me a bit, and I have a strong conviction that […] with a certain size of a business, you’d need that” (163:24). In fact, informants at CarCo also recognize the described dependency on formal processes in cross-functional cooperation: “I’d say that here, in the e-drive process chain you have people that strongly hold on to the defined process, and they also do this because they’re not skilled and able enough to do differently” (171:9). In particular at the design-manufacturing interface, any cooperation seems to depend on a basis of formal specifications: “Because the standard product designer is not wired to care for process times, this will be the last thing that interests him. Unless you write it at the top of his work order” (167:33).

Taking a broader view, a certain push-off mentality appears common in cross-functional cooperation. This becomes apparent through a widely perceived low willingness to perform additional efforts apart from the formally agreed service level. “It’s exactly the CarCo approach, at first I try to find out how it does not work. I try to find out how to get the topic off my desk. That’s really a problem here, it makes cooperation more difficult” (149:28). This behaviour recurs with regard to all examined functional representatives, be it production, “that’s so extreme in the production business, that people really say, this is my field and I simply won’t go any extra mile” (165:22), or designing functions: “Everyone looks after his own business, taking care that it is done. So the production planner ensures that his job is done at first, and the product designer ensures that his job is done at first. And beyond that – well, you’d have to talk with each other, and some people are having difficulties to do that” (152:25).

For innovative projects, such as the electrified powertrain development of the case study at hand, the dependence on formal processes entails unfavourable consequences. Since additional efforts, new ways or shortcuts would be quite necessary to succeed in innovative endeavours, this behaviour is perceived as being obstructive. An interview participant explained how dependency on formal processes results in cooperative processes collapsing like a house of cards when imposed on an innovative project: “We handicap ourselves structurally, I think the NPD process is very well structured and well described, but we can’t live these processes, I don’t know any generic schedule that has been adhered to” (162:9). Formal processes for cross-functional checks and balances at the design-manufacturing interface are difficult to be kept alive when innovation requires quicker and more frequent modifications: “Production has started to notice that these quick modification loops bring many problems with them […], because we get a more and more rapid pace, and we never really know what to expect as modifications and what is important to look at there" (130:22).

7.2.3 Competition

Competition

1st order concepts	***2nd order themes***	***Aggregate dimensions***
52.Few conflicts on the cross-functional optimum 53.Design requirements with predetermined hierarchy 54.Functional orientation deters cross-functional optimum 55.Call for more competition on cross-functional optimum 56.Cross-functional structures create no competition	*(s) Little competition on the cross-functional optimum*	***Competition at the interfaces***
57.Sparsity of conflicts at bilateral interfaces 58.Informal relations inhibit competition	*(t) Informal relations inhibit competition*	
59.Upstream functions sit out conflicts playing for time 60.Upstream functions play out information asymmetry 61.Path dependency from preceding products impedes competition	*(u) Upstream functions wait out conflicts*	
62.Bridging functions don't live challenging role 63.Downstream functions react with cynicism 64.Targets bring downstream functions to the table	*(v) Downstream functions avoid conflicts*	
65.Cross-functional conflicts are escalated quickly 66.Management avoids conflicts for political reasons	*(w) Cross-functional conflicts are escalated away*	***Leadership-related situational factors***
67.Instances of weak decisiveness in NPD 68.Time pressure impedes competition	*(x) Low decisiveness holds up competition*	
69.Financial steering logic induces buffers 70.Border walk of handling complexity	*(y) Complexity allows for smokescreening*	***Complexity-related situational factors***
71.Governance functions with insufficient insights 72.Steering functions versus operational functions 73.Acceptance of target setting process	*(z) Governance functions unable to challenge*	
74.More interface conflicts for brown field projects 75.Path dependency pitfall for succeeding projects	*(ab) Competition scarcity around innovative projects*	

Illustration 36: Data structure - Competition

7.2.3.1 Competition at the interfaces

When analysing competition in the case study setup, the author had to deviate from the original wording because competition at CarCo has a strict external connotation, referring to external competitors and markets. During the interviews, inquiries were made based on a verbal context of conflicts or frictions in order to stay close to Luo et al.'s (2006) definition of competition, which entails rivalry and contesting on both tangible and intangible resources between functions within a company. Henceforth, conflicts and friction are used interchangeably with competition.

Illustration 37 depicts the intensity of competition at all examined interfaces based on their mentioning frequency in the case study database. The categories "existing competition" and "no competition" illustrate how often informants described occurrences of friction or conflicts on tangible or intangible resources, respectively explicitly mentioned the absence of friction or conflicts, both in an unprompted manner.

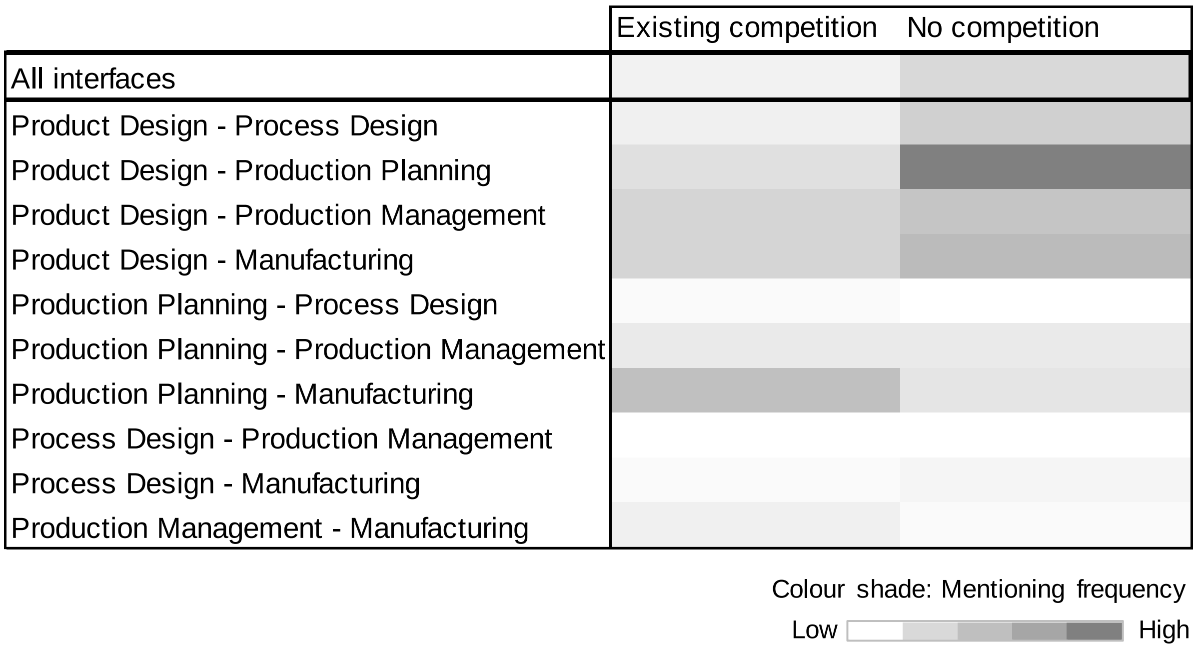

Illustration 37: Competition occurrence of examined interfaces

It is striking to note that overall, informants talked more often about the absence of competition (69 mentionings overall) than of experiences with competition (46 mentionings overall). With regard to the individual interfaces, conflicts between production planning and manufacturing were most frequently mentioned, followed by a few mentionings of conflicts at the product design – production management and at the product design – manufacturing interface. Other interfaces that would have been assumed as important competing functions during NPD, such as the interface between product design and production planning, with the latter one being the production representative that has the largest insight in early phases of NPD, are described as astonishingly harmonious.

Besides the mere occurrence of conflicts or tension, topics and reasons were likewise inquired. Illustration 38 shows their relative importance, with topics being named in an unprompted manner by participants and shadings in the illustration reflecting their mentioning frequency.

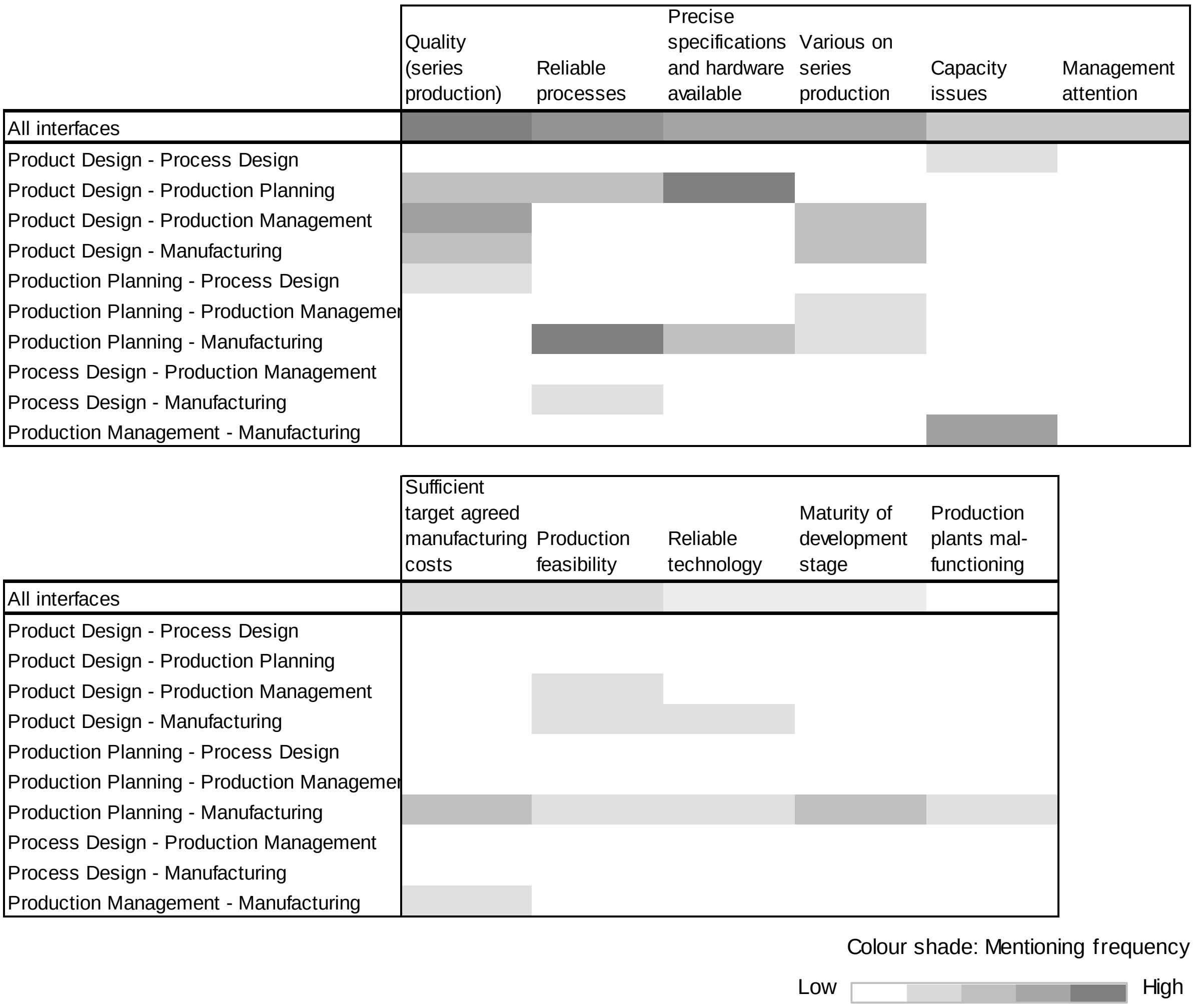

Illustration 38: Topics for cross-functional competition

Notably, topics affirm previous results from the analyses of cooperative intensity and cooperative ability. Quality topics of series production and other series-related topics dominate the discussion between design and production representative functions and account for the occurrence of most conflicts between product design and manufacturing. While process-related topics, such as conflicts around the reliability of processes, are mentioned relatively often, production-ready product design is rarely discussed. Production feasibility, as a dichotomous expression of whether a design is producible or not, is the only representative of this category. This is in so far astonishing, as this could be assumed to be a production representative's most important task in the NPD process. The occurrence of conflicts on sufficient target-agreed manufacturing costs reflects the low advocacy of manufacturability that has been analysed before. Remarkably, conflicts on management attention as a representative for competition on intangible resources finds recurrent mentioning. This may serve as an indication for a political, power-based environment.

Little competition on the cross-functional optimum

The analyses on occurrence and topics of cross-functional competition at CarCo show that there is relatively little conflict between design and manufacturing representatives on what the outcome of the NPD process should be in an overall optimum. There are conflicts that concern interaction on a meta level, such as capacity issues or the availability of precise specifications, as well as conflicts that concern individual functions' preferences, such as reliable processes or sufficient target-agreed manufacturing costs. However, there are few conflicts on the overall optimum for the company, during which design and manufacturing would outweigh their individual preferences to achieve a NPD result that is optimal for the company. An example thereof within the case study context would be a conflict on manufacturing-optimized product design, in which production representatives would urge product design to construe their product in way that does not only satisfy the dichotomous production feasibility, but strives for a quicker, easier and cheaper production than a comparable design.

Another indicator for a shortage of competition on the cross-functional optimum can be found when analysing priority and importance of design requirements in NPD. As in other large-scale industrial NPD processes, several types of design requirements exist at CarCo. For instance, this includes requirements for function, performance, design, weight, safety, producibility, sustainability, and so on. At CarCo, there seems to be a strict prioritization of these requirements, with product-related requirements being top priority, and other requirements finding themselves neglected on occasion: "They take care that their product fulfils all functions and fits into the assembly space, and the rest actually doesn't matter" (176:18). Another informant explained in more detail: "I don't believe that we [production, author's note] are the first one he [product designer, author's note] thinks of, he couldn't care less, he has to bring a product to fly. He throws it over the edge to us, and actually asks us for things that are so expensive that it almost topples a requirement. But CarCo is wired like that, that if it gets extreme, in doubt they decide in favour of the product. And with manufacturing it's similar: As a production planner, you think of unburdening the manufacturer somehow, setting up a lean process, clearly, it's one of your main tasks, as little manufacturing costs as possible, as little indirect staff as possible. But if you're really after something, exactly the same approach [as described above, author's note] is valid for us" (82:72). The sheer amount and complexity of design requirements might also contribute to product designers neglecting requirements of other functional counterparts. "The product designer has 1000 boundary conditions, therefore production topics are rather a nice-to-have thing than anything else" (146:16).

Unsurprisingly, functional structures are identified as one of the main reasons why the cross-functional optimum is deprioritized against the own functional optimum. “Missing my own objectives, in favour of my neighbour or for the success of the entire company - even if it would be better for the cross-functional optimum – no one would do that” (125:15). Of course, this does not necessarily mean that a cross-functional optimum is impossible - with every function contesting for their own respective functional requirements, the cross-functional optimum could as well emerge at some point. At CarCo, however, this competition seems to be suspended, because upstream functions would likely win all such contests. As a consequence, downstream functions do not seem to engage in such contests in the first place. When asked for the power structure in CarCo’s NPD process, a production management employee described it as follows: “In any case, it’s product design [with the strongest power, author’s note]. The production department is less esteemed, and manufacturing indeed even less so” (156:11). An overwhelming majority of informants confirms this impression when asked for the power structure, with product design perceived as the most powerful function, and manufacturing seen as the weakest one.

Notably, informants acknowledge that the identified lack of competition on the cross-functional optimum is unfavourable, and express their wish for more such competition. The following statement of a product designer, who reflects on design’s obligation to check for manufacturability, is insightful thereof: “Actually it’s wrong to have that together in one organization, after all you lack a system of checks and balances. The danger is, that you get some kind of cuddle-solution, but not the overall optimum. For this, it would have to be possible that they can crash at some point, and are not organizationally bound” (141:10). Another informant phrased his desire for more competition on the cross-functional optimum as follows: “The overall optimum has to be the focus, and for this you have to talk to each other. It doesn’t help if we only optimize manufacturing costs. Product design has its focus, production planning has its focus, but it needs to be the overall optimum, and for this we have to talk to each other" (152:24). Even more so, a chance for a win-win situation for both sides of the interface seems achievable, as long as a discussion takes place: “There are some things that we could get indeed at zero cost, there are some win-win-situations that both the production planner and product design would benefit from. But you have to talk to each other to reach that” (152:23).

Furthermore, informants recognize that competition on the cross-functional optimum is insufficient, although required cross-functional structures for discussion and argumentation are in fact existent in many instances. “That’s exactly the point, where I say, I now sit here, having my project work, having this theoretically cross-functional topic, having this cross-functional team with selected people from manufacturing, with a production planner, a process specialist… all of these people that should in fact be key figures for manufacturing, having the big overview and also the expertise. But nevertheless [pauses, author's note] - that's what I say, that's where it suffers" (163:8). It seems that it's all there - CarCo disposes of many structures to encourage cross-functional discourse to pursue the overall optimum – nevertheless competition seems to be rarely emerging from it. One prominent example for these structures within the case study setting is represented by the hardware concept workshops. They constitute a core element of cross-functional integration, allowing for competition on the cross-functional optimum, but appear to remain below their potential. Typically, product designers let the workshop roll off their back, and production representatives have either insufficient knowledge or insufficient incentives to really challenge their design counterparts (66:1). An interview participant described the same dilemma in reference to another existent structure that ought to encourage cross-functional cooperation: "So these walls and borders, actually we've invented the simultaneous engineering for it, that you do not just throw things over, but these walls still stand strong. That's why they introduced the simultaneous engineering teams, to make the functions sit together. But only product designers are sitting in there" (181:23).

Informal relations inhibit competition

When searching for patterns in competition occurrence in dependence of the examined interface (see illustration 37), it becomes evident that adjacent functions experience relatively less friction than others. For example, the adjacent interface between product design and process design has a high share of mentioning for "no competition", while the non-adjacent interface of process design – manufacturing has barely any informant arguing for "no competition". Exemptions to this pattern include non-adjacent interface of product design – production planning, which receives high shares of mentioning for "no competition", and the interface of production planning – manufacturing, for which "existing competition" is mentioned relatively frequently. Overall, competition seems to be on the rise, the more downstream functions are involved. This might help explain the two mentioned exemptions.

Notably, adjacent interfaces were found to have the strongest informal relationships in earlier analyses and exhibited the most pronounced cooperative intensity. Possibly, informal relationships and resulting mutual sympathetic feelings impede the emergence of conflicts, frictions and therefore competition in the sense of the study at hand. Indeed, informants at CarCo described a similar behaviour from their own experience: "The production planner is only product design's attorney in the end. That's because the two of them discuss, against each other, but at some point they have to find an agreement. When the planner discusses with the manufacturer later, then of course the planner has to defend the result he achieved, and that's how he automatically defends the product designer's opinion […]. On a hardware concept workshop they are aligned to the point that also the process designer defends the product designer's concept just like an attorney. And certainly, the planner also takes the product designer's position. You see the sequence here" (131:33). Also, from the author’s own experience, such a tendency is comprehensible. In her participant role in production management highlighting potentials for manufacturing cost optimization, the author engaged in discussions with all functions in NPD. While in the beginning, it felt easy to raise evident potentials and critically address designers, it became more difficult in the course of time, when informal relations had been established (200:1). This potential dilemma of a possibly detrimental consequence arising from strong informal relations is well represented by an interview participant’s quote: “You do a lot of networking, and I notice that I learn more for myself, but the product is not necessarily becoming better through that” (154:36).

Upstream functions wait out conflicts

A production representative, being asked how conflicts are handled with product design, provided the following insight: “There are often cases, where I sometimes have the feeling that people play for time. Then the design freeze is over, and it is what it is then. That’s a sentence which we hear from time to time, the “it is what it is now”, and regarding that, you’re often given quite a lot of rope from product design, and then they say well, now there’s nothing I can change anymore. Instead, only with much pressure and escalation and back and forth, you get into it, actually a bit is always possible, it’s just quite tedious” (170:22). Indeed, many case study informants share this impression of upstream functions defensively sitting out potential conflicts with downstream functions, or ignoring downstream requirements until the NPD process requires moving on and the resulting design freeze makes further design changes impossible. Notably, upstream functions themselves appear to be aware of this tendency, as this product designer’s quote indicates: “I don’t want to say that I’d wait this out, that I discuss a bit longer and let time play for me, but if things are time-critical [pauses, author’s note] […] - you always have to weigh it up” (163:33). Several observations make an affirmative contribution to this assumption. In different rounds of hardware and virtual concept workshops in the course of a year, the same points regarding manufacturability were discussed all over again. Although for each workshop, a to-do list was derived and measures were being tracked, these measures did not seem to be worked off by product design (65:2). Another scenery from a several hours long hardware concept workshop sheds more insight. Different functions discussed a high voltage battery hardware draft, with participants ranging from product design, process design, production management and production planning, and no manufacturer being present. During the workshop, product designers were rather defensive, rarely actively raising critical or arguable points, waiting for production representatives to notice any process-critical aspects. Product designers mostly stood in groups a bit behind the product, while production representatives went around to examine the product for any aspects critizable from a manufacturing, quality or service perspective. Comments like “Oh, I hoped this would go unnoticed” (63:1) by the product designers show that they rather saw the hardware concept day as a gauntlet running, where they hoped that this cup passed from them, instead of using the workshop to receive feedback and sparring, or at least pro-actively explaining and promoting their design (7:7, 63:1). Other representative answers from product design on critical feedback from production representatives included the following statements: “This will look different in the end anyway”, “This is going to change until the next prototype phase”, “This won’t stay like that, we’ll take the cable harness from a different supplier anyways”. As a consequence to these statements, any discussion finds an end. Naturally, production representatives can’t say anything against these answers, but have to wait for the indicated product change (66:2), after which the design freeze may already have suffocated any room for discussion.

Naturally, compared with functions more downstream the NPD process, upstream functions such as product and process design dispose of more information on a certain design stage, its strengths and weaknesses, as well as its consequences for other functional stakeholders in the company. Case study informants shared their impression that upstream functions make use of this information asymmetry to block away potentially uncomfortable inputs from other functional stakeholders. “There are always discussions that we wouldn’t achieve our development or production goals [by implementing a manufacturability optimization, author’s note], but I don’t always believe that. Then it shows through, that it would be indeed achievable, it would just be a new way” (162:5). A respective participant observation was also made during discussions in a product design team, when optimization potentials for manufacturability were discussed. Several of the optimization potentials were rejected on a technical basis without further explanation. As an example, an alternative mounting concept was precluded because it would not correspond to stability requirements. Present production representatives were unable to technically challenge this statement, therefore accepting the explanation and ending the discussion (2:2). A similar observation was made during a hardware concept workshop, where product design rejected criticism by insisting that the part is required for product performance, which neither could be refuted nor challenged by the present production representatives (17:3). At times, playing out information asymmetry might even be perceived as a kind of admired skill in a large-scale industrial setting, as this informant’s quote suggests: “I’ve heard from employees from different functions, that in the NPD business, you simply have to learn how to throw around bones. […]. Then the internal controller comes, then you throw him a bone, go and hunt that, and that’s how I got myself a bit of free air to get the work done. I’ve heard it from a rather high-ranking product designer. It’s his greatest art, that’s what a product design team manager said. As a product design team manager, you simply have to know how to throw around bones, such that your men can work.” (158:36). An employee who started in product design and later changed to the manufacturing department, described the following experience: “Product design still acts in a way which makes them the most important ones, and that’s the problem, clearly. For me, it was a meltdown at the time when I came from product design to production planning and then to manufacturing.

Before I brought my employees to the point where we'd set the tone, not dancing to the bidding of product design anymore. One example was about [names product name, author's note]: I always flatly contradicted the product designer, and then he, by purpose, invited me to a meeting on a Friday at 9am, of which he knew exactly that I'd be having a meeting by that time, but of course I nevertheless appeared there. By that time, my people had already fell over and had themselves dictated another variant, but I did not fall over. Then the product designer just grinned, saying well yes, in the background we'll change that" (131:22).

Another aspect that appears to be impeding competition at CarCo's design – manufacturing interface is rooted in modular product design concepts, building on product platform architectures, as they are often utilized for complex products such as cars or airplanes. Within modular product design, individual products are not construed from scratch in every NPD effort, but strive to share as many common components with preceding products on the same platform as possible. Evidently, this limits downstream functions' voice to change a certain product design, e.g. to improve manufacturability. "What you've seen in product design is that […], manufacturing tries to optimize, for understandable reasons, as much as possible in the new product generation, what they didn't like in the old one, what was inconvenient. However, on part of product design, there is the statement that we've got order to design a technical overhaul of the old generation, in which some things are changed but the rest is take it or leave it" (167:20). Of course, being aware of an occasionally opportunistic usage of information asymmetry by design functions, production representatives may be unsure if their improvement ideas are rejected due to a well-reasoned platform argument, or rejected on this ground because it is the easiest way to go for product design. A pertinent observation was made during a discussion between product management and the product design team on manufacturability optimization potentials. Little feedback was provided regarding the ideas, few conflict or discussion arose. Frequently, the only comment was "Well, that's a carry-over part from the preceding product generation", put forward as an indisputable argument suffocating any further discussion (33:1).
As a result, so-called lead derivatives, which are developed as the first innovation-leading product on a platform architecture and which determine large parts of succeeding derivatives, should be granted particular attention by downstream functions to ensure their requirements are considered there. However, in the light of the analysis of innovative products as potential inhibitors of cooperative ability, this might be difficult to achieve.

Downstream functions avoid conflicts

As described above, the functional distribution at the design – manufacturing interface of CarCo includes so-called bridging functions. These are functional representatives of design or production, who are situated closer to their cross-functional counterpart with regard to the temporal sequence of involvement in NPD. For example, production planning clearly is a production representative, but engages quite early in the NPD process, interacting with product and process design counterparts quite closely. As another example, process design, as a design representative, interacts closely with production representatives to develop reliable production technologies. Presumptively, such a bridging role entails a responsibility to challenge upstream functions as spokesmen for their downstream functional relative. However, bridging functions at CarCo appear to avoid the alleged challenging function: “Process design does it just the other way round, so he doesn’t live the role but even rather backs off, and, as you say, rather takes sides with product design instead of manufacturing” (157:18). Bridging functions sometimes seem to be engaged to create an atmosphere of harmony in the discussion, as the following experience at a hardware concept workshop suggests. Production representatives repeatedly emphasized gratitude towards product design, for them taking part in the workshop and being available for discussion. A process designer stated: “We illustrate so many problems here, and this all seems so negative, but in fact so much works really nicely between us” as well as “We don’t have problems here, we have challenges” (63:2). The author later asked the process designer about his intention for these statements. His answer emphasizes that production feels that such cross-functional cooperation is quite a concession on the part of product design: “After the last workshop, we got the feedback that so much negative things came up, and product design felt a lot like being under attack. That’s why it’s important to praise, in the end it’s great that product design participates at all” (63:3). Possibly, this might be related to the above analysis of strong informal relations between adjacent functions that encumber competition. An informant provided insight on such a potential inner conflict: “And that’s where process design with its prototype factory is caught in the middle between two stools. On one hand, they are close to the headquarters, close to the product designers, knowing them much better than the manufacturer which is simply due to the spatial closeness, and due to the closeness to the decision committees around here they know how it looks like. So they just can’t stab in the back of the product design teams, where they sit in themselves. Simultaneously, they also can’t stab the back from the manufacturer. So they sit in some kind of hermaphrodite role, that’s true” (167:18).

Interestingly, instead of engaging in discussions with upstream functions to challenge designs for their suitability to be manufactured, production representatives appear to react with sarcasm to designs that are unfavourable for them in some instances. At hardware concept workshops, there was an ironic, sometimes even cynical atmosphere prevailing, when manufacturability problems appeared. Notably, production representatives contribute to this atmosphere. “That’s certainly poka-yoke”, was an ironical statement of a process designer to an evidently not poka-yoke cable harness, while no measure was derived to address the topic. Another example was an ironical statement of a prototype worker to a seemingly not well thought-through plug:

“That is all well thought-through”, without any further call to the present product designer to change it. “Oh man, I hoped no one would notice this”, was another process designer’s comment on additional manual activity that could have been avoided by manufacturing-ready product design (68:1).

While downstream functions appear to be deterred from engaging into intense competition with product design to speak up for their functional requirements, compulsory targets may be able to bring them to the table. One example in the case study context were service representatives involved in NPD to take care of service requirements, for example ease of disassembly in garages. At CarCo, service representatives have strict quantitative objectives regarding the amount of time and effort a service employee needs to dissemble a component. As a result, they are permanent members of hardware concept workshops, and service requirements are as well quite present with product designers, even in product design team discussions where the service representative is not present in person. A production planner commented on the topic: “We know exactly what it costs to insert a screw here that might have to be disassembled in service. And that under no circumstances may it happen that something more or less has to be done there. But with regard to production, I’ve never seen a similar discussion” (161:25).
Similarly, downstream functions at the design-manufacturing interface may be engaged by compulsory objectives alike, as their increased engagement with target agreement coming closer suggests. “The closer we come to target agreement, where it’s all about agreeing targets long-term and irreversibly, the higher is the own incentive to join the discussion (155:6).

7.2.3.2 Leadership-related situational factors

Cross-functional conflicts are escalated away

As already described, CarCo cultivates a consensus-driven corporate environment. If conflicts emerge, they are typically handled and solved on an operational level. With regard to cross-functional conflicts, which have been found to be rare anyhow, this does not appear to hold true, though. “I’m not involved in any conflicts between the product design and the production department at the moment. I have the feeling that these are relatively quickly handed over to the management hierarchy, maybe because the interlinking on the operational level is not the closest” (127:38). Cross-functional conflicts seem to be escalated towards the management level rapidly. This appears to be true for all involved functions at the design-manufacturing interface of CarCo. A product designer described his experiences on conflict handling: “I wasn’t dealing with the manufacturer himself, instead it was always already a project leader or plant project leader that I had to deal with, who were putting on the pressure” (130:26). A manufacturer pronounces what he thinks helps in handling conflicts with product design: “Being penetrant. Escalating” (159:4).

Management levels at CarCo tend to be similarly conflict-avoiding as operational levels, though potentially for other reasons, as informants suggest: "What I notice are topics that are discussed on a management level – well it's political there, [...] and many conflicts are avoided […]. On the working level, or the group leader level, I didn't notice any real clashes with product design" (127:29). The experience of a production planner, who escalated manufacturability concerns, which, however, were not brought to discussion with product design, is insightful in this respect: "Regarding manufacturability, there was one example for the battery, [names production planning person, author's note], he had quite some ideas, where they always said yeah yeah, it's alright. Who was quite ignored, in fact. And then, at the SOP of this battery, we really had these problems […]. So [names production planning person, author's note], he could tell you quite some things. But in the end he was made a victim of all that." (179:11).

Low decisiveness holds up competition

"We are a bit weak in decision-making. But that's not because the facts are not on the table, it's because we don't dare to decide" (160:14). During data analysis at the case study's empirical setting, similar statements were perceived repeatedly. Informants explained weak decisiveness in some cases with CarCo's consensus-based decision-making culture: "We have a remarkable committee culture here, the committees decide, no individual person decides. That's quite nice if you can hide behind a committee decision" (162:15), allegedly often connected with a negative perception. "We divide up responsibility as long as nobody is responsible anymore, and only then we decide" (126:17). The existence of shadow committees in itself, as it has been identified in the analysis of cooperative intensity, is a strong indicator for low decisiveness. At times, formal committees are insufficiently decisive, but nevertheless the organizations needs guidance and therefore follows unofficial decisions taken by shadow committees.

Remarkably, this seems to be less an issue of cross-functional nature, but more within functions: "The department interfaces, you need them, and they're not super-efficient, but internally we go around in circles more often […] but that's related to the decisiveness around here. Because we analyse the same topic 100.000 times" (82:35). Time pressure from throwing over already-made decisions, or waiting out decisions until a last possible point in time, is perceived as a detrimental consequence. "In a later NPD phase, we start throwing over everything that we've defined in an early phase, we're incredibly bad at this" (82:45).

What makes this observation interesting in relation to this study's central research questions, however, is low decisiveness' impact on cross-functional integration. Indeed, the case study data permits the conclusion that time pressure resulting from weak decisiveness impedes cross-functional competition. A production planner's statement on time pressure's consequences on cross-functional interaction is representative thereof: “This evidently makes it more difficult to integrate all interfaces, because most of them are preoccupied with themselves. It’s difficult to manage to synchronize the result that you have worked out with all interface partners, be it logistics, manufacturing, product design. Therefore, when you’ve worked out your result, the whole thing is already outdated again because you have new requirements and that’s why everyone stews in their own juice. You never have the chance to align with the others” (171:3). On competition in particular, time pressure appears to have a paralyzing effect, as two quotes from production representatives suggest: “At the beginning, they did it really well [to discuss manufacturability concerns with product design, author’s note] but since we came into this rush mode, all they say is, the main thing is that the product’s okay” (82:103). “By now, there’s not much you can change anymore, anyways. If you now start to run at each other [at the cross-functional counterpart, author’s note], you’ll get your stuff done even less so” (128:18).

7.2.3.3 Complexity-related situational factors

Complexity allows for smokescreening

Insufficient transparency towards cross-functional counterparts has already been identified in the course of this analysis. When looking for underlying reasons, the case study database suggests that complexity inherent in large-scale industrial settings with multi-composite products and multi-layered corporate processes provides a setting that makes transparency harder at most, and potentially nurtures deliberate smokescreening, i.e. hiding certain information under a veil of complexity.

Financial steering processes at CarCo represent a frequently mentioned field of non-transparency. “Somehow, we always reach our objectives, however this works [laughing, author’s note]. And just in case, there is a bit of turning or discussing until we arrive there” (153:34). During budgeting processes, non-transparency translates into buffers. An interview participant describes how the logic of financial steering processes in large-scale industrial settings educates stakeholders to use complexity for their own benefit: “The largest problem that production planners have is, that in large companies as CarCo, you’re always praised when you give back budget. And you always get hit at the head if you calculate your product very sharply, hoping if it’s really on the edge you’ll receive another few millions. If we would manage to introduce a shift in this thinking, I’m sure that cost-efficiency would raise by 10% in the next years. I’m a 100% sure, because we hide 10% and we are educated by top management to hide this 10%. […]. It’s a two-sided medal, I’m aware of that, but sadly it’s steered like that, that every, and really every reasonable project leader relies on buffers. And for the manufacturer it is the same (158:15). Another quote sheds further insight on the topic: “We’ve made ourselves naked once, saying we plan really sharply this year. But everyone saw what happened to this colleague, he came on the hit list […]. Because he made himself naked, he got really into trouble, because he couldn’t give any more [savings, author’s note]. This watering can principle of controlling kills us. Every year, you bring your 2.5% and the other side brings it, because you're already wired like it. If, as a vehicle project leader, I get a new vehicle into the plant, he splits his ratio topics up for the next six years, because he knows exactly he has to deliver them, and keeps them in respective drawers. That's a core problem, that's why a planner cannot act as he likes, and why a manufacturer cannot act as he likes, because he has to keep in mind that if I do that, I'll be naked next year, then I'll get into trouble when the watering can comes" (158:16).

Indeed, handling inherent complexity at environments such as CarCo is challenging for all involved functional counterparts. In order to be able to comprehend, and potentially challenge, a cross-functional counterparts' statement, a stakeholder would be required to dive deep into the factual background and permeate the attached complexity. Naturally, this contradicts work-economic possibilities, as full comprehension would require an extensive effort and time. However, giving up on full comprehension risks to bring the cross-functional counterpart into a position where he has to accept potential smokescreening and risks to overlook consequences on his own function. "In an early phase, you need a certain abstraction level, where in the past it was said that you shouldn't simplify it to the point where it becomes wrong. And here we are at a point, where you can't give a generic answer. It's a border walk, a certain simplification is necessary, such that things stay manageable, but on the other hand, the things you simplify can lead to large problems, and we've experienced masses of them ourselves" (148:42).
And with all the inherent complexity at all involved functions, in all involved processes, blurs from resulting non-transparency add up and dilute the overall analysis. "You have a huge problem in such a large company, you have to ensure economic profitability. Now you have multi-projects, meaning you have one development platform […]. Now the board looks at it when it is said that we want to have a new derivative, and is this derivative profitable. Now there are so many factors that influence this product [….]. From my gut feeling, I'd say until today we don't manage to calculate a true business case […]. We make the best of the given facts, and build up a huge catalogue of premises and assumptions, saying assembly times are such and such, the plant is such and such, and further assumptions are such and such. And we go from one assumption to the next one. And in reality, it all comes differently" (158:14). Informants are convinced that achieving transparency in the light of a large-scale industrial environment's complexity is an essential challenge for all similar organizations. "That's a bit the crux of the entire matter. We stand in our own way with that way of calculating [the business case of our products, author's note]. I discussed with the other OEMs, and they all have the same problem. Although the solution is so close. It's damn complicated, you barely get to achieve any transparency" (158:37).

Governance functions unable to challenge

As has been been analysed above, complexity makes full comprehension and a resulting ability to challenge statements of cross-functional counterparts difficult, even for stakeholders that are involved in the NPD process of a certain product. For governance functions, such as central financial controlling, it is clearly even more difficult. “The controllers have a completely different focus on it than someone from product design or from production, and it’s just not possible to clear up all questions to 100% […]. It’s quite complex, and quite cumbersome across so many hierarchical levels” (143:23).

In the light of the above analysis at the design-manufacturing interface, which indicated that involved stakeholders, even from manufacturing, have low advocacy of the cross-functional optimum in general and manufacturability in particular, this becomes important for the analysis of cross-functional competition. Namely, according to the analysis, central governance functions may be the only spokesperson for these topics. “Controlling, as the guardian of the entire product-related costs, has a large interest in minimizing them, and with them we have most discussions around manufacturing costs. They’re always too high in their view, in general, and likewise the calculation methodology. We had a discussion with one of the controlling colleagues earlier this year, and they have not a clue of an idea how we calculate that” (155:8). Indeed, this responsibility of governance functions is acknowledged within the organization: “The controller is of essential importance, around all of these product areas […] because they’re wired very differently than the product areas, they’re very different from these people, who usually just want to have fun with their robots, products, or whatever” (158:28).

Unsurprisingly, the inability to challenge functions on a factual basis creates discontent, as challenge approaches are perceived as arbitrary. “Procurement controlling for example, they countercheck our planning. But we have production processes at the new product, which they just don’t have […]. What came out at the end, we talked about it, and they just took our values minus 5%. Well, thank you. Because they just don’t know any better” (163:22). In the case study database, repeated evidence for such discontent can be found, with operational functions differentiating themselves from governance functions. “The designer himself does barely arrive to do his job, because he’s permanently externally steered and controlled, because we pack on a product design team, with two to three designers on board, we pack seven to eight controllers on it” (158:2). “Sadly, we had more hand-raising functions than people that actually do the job” (158:2). Furthermore, a vicious circle that slows down and further increases complexity of NPD appears to emerge: Governance functions may start to distrust operational functions, as they cannot challenge their statements. In an effort to grasp potential pitfalls, they take more time to analyse statements. Consequently, as operational functions need to provide explanations to their governance colleagues, they have less time to work on their statements and need to take assumptions, which further increase blurs and non-transparency. “There are departments that take more time for themselves than you as a value-creating department have. For example controlling, It’s really like that, they sometimes have four weeks of time to evaluate and you yourself have only two weeks to do the work” (171:12).

As a direct consequence thereof, discontent and the mentioned consequences are translated to the target-setting process, which is a representative of a process steered by central governance functions and takes uttermost importance in CarCo’s NPD process. “Controlling derives a target for product-related costs from different methodologies. Implicitly, a target for manufacturing costs is included in there, mostly via preceding products, profitability ambitions and so on. Controlling derives that out of the blue, just as it likes” (126:36). In particular, it was criticized that targets are not set early enough on a sufficiently granular level, such that any building up of buffers would be prevented. “Before target agreement, they [targets, author’s note] are rather spongy, but as soon as the product steering committee gives its okay to the overall sum, then the whole thing is through and the target is set. They’re measured hard against this target, but before, they have the chance to build up endless buffers” (143:64). “The target guideline, actually it’s there relatively early on the vehicle project level and on the platform level, but just not as granular as it would be of relevance for us” (155:25).

Competition scarcity around innovative projects

The analysis of cooperative ability revealed that for innovative projects, it is more difficult to develop effective cross-functional structures at the design-manufacturing interface. A similar tendency seems to hold true for the analysis of cross-functional competition. For innovative projects, there seems to be less cross-functional conflict when building on a green field, both for product and process design, than in a brown field project, where product design has to integrate with an existent platform or known technology, and process design has to work with existing plant structures and production technologies. Several reasons thereof are provided. To begin with, cross-functional counterparts may not be sufficiently familiar with new technologies to provide critical feedback, or do not yet exist at all. “When I started here, there wasn’t anything, there was no manufacturer who could have intervened in product design […]. And likewise production planning, they had never planned an electrified engine before, they just had no clue” (147:2). Second, manufacturing’s involvement is naturally higher when the newly developed product has to be integrated into plant structures and production technology which they already operate. For green field developments, this simply is not the case. In this respect, the analysed innovative, green field case of electrified powertrain development contrasts strongly with brown field development projects in CarCo’s combustion engine departments. “I know that my colleagues from the combustion engine, they have conflicts [between manufacturing and production planning, author's note], but there the starting point is a different one. You have a grown structure there […]. For us, at the end of the day, everything we plan is on a green field and therefore there are less conflicts" (148:35).

Evidently, this tendency has the potential to become a pitfall for succeeding projects. If as a green field project, competition had been scarce and design functions had their will with no significant feedback from downstream functions, the project outcome stands at risk of being suboptimal with regard to downstream requirements. With production volumes being still small, the green field project is likely to receive not the same scrutiny and rigor as larger projects. "I think what is very important are the volumes. In the case where we start a new project and are in the early phase, volumes are still quite manageable when compared with other projects at CarCo […]. And I think that product design still has that perspective, that those few high voltage batteries, we'll get them manufactured somehow" (170:36). In the aftermath of the smaller innovation project, however, when the innovation project was successful and succeeding products are decided to be built on the same product platform or within the same plant structures, the design space is limited to accommodate downstream functions' requirements, which now come to light due to more intense involvement and increased pressure due to higher production volumes. Product designs are required to share communal components with the first product, process designs have to cope with existing technologies and production lines. The possible pitfall is evident, as the following statement expresses: "Actually, at the beginning, you should invest a lot more of thinking into it, I have the chance to make it right for once – because when an idea has been established at some point we're in the same situation as all are, that you say I've created a solution somehow, which emerged from out of my guts or on short term, then it's perhaps not the optimal solution, but nevertheless I have to live with it in the long run" (148:36).

7.3 Summary and theoretical model

7.3.1 Summary of analysis

In the previous chapters, coopetitive behaviour at CarCo's design-manufacturing interface was analysed in order to be able to draw conclusions on cross-functional integration. In the course of the in-depth analysis of all coopetition dimensions, social dynamics were discovered that continuously shape integration at the examined interface. The coopetitive perspective enabled a deeper and more comprehensive view, than an analysis following typical empirical measurements of cross-functional integration would have allowed for. While cooperative intensity and cooperative ability seamlessly cover behavioural structured facets of integration as well as the more attitudinal, intangible aspects, the competition dimension allows to conceive conflicting aspects inherent to integration, which find mentioning in Kahn's (1996) two-pillar model but seldom are operationalized in measurements of existing studies. Critically weighing up different functional requirements is undoubtedly part of any effective cross-functional integration and seldom remains frictionless. Coopetitive behaviour therefore allows to analyse integration from a more extensive angle, and therefore helps to explain inconsistencies inherent to cross-functional integration research.

From the analysis of coopetitive behaviour at CarCo's design-manufacturing interface, the following conclusions on cross-functional integration may be summarized that reflect the identified second-order themes.
Communication and informal interaction are strong, but mostly focused on adjacent interfaces (a). The simultaneous occurrence of perceived inefficiency of formal relations (c) and importance of informal relations (b) cause a particular reliance on informally closely integrated adjacent interfaces. Manufacturing, connected to design across a long chain of adjacent interfaces, is therefore on the sidelines during the design process, which is shown by its late integration (d), causing frequent rejections of manufacturing inputs. Based on intensive efforts to foster cross-functional integration, channels, contacts and processes to that end are manifold. Indeed, their abundancy tends to lead to confusion, with manufacturing inputs sometimes getting lost in the multi-layered processes to address them (e). When analysing those contents that eventually are discussed and addressed between design and manufacturing, relevant findings suggest that these are focused on series topics and information purposes, with little controversial discussion on development projects (f). Communication patterns at the design-manufacturing interface accumulate mostly at two ends of the spectrum: Either, communication is transactional and passive, or conflict has risen to a point where walls have built up. Content-focused, constructive discussions appear to be the minority (g).

With regard to cooperative ability, cultural differences between design and production representatives, which are broadly assumed in existing literature, can be confirmed. Between product design and manufacturing in particular, mindsets seem almost diametrical for a broad range of aspects (h). A particular mindset trait from manufacturing is brought to light, which particularly contradicts design's requirements: the former demands reliable specifications and hardware, having difficulties to work with assumptions or abstract models (i). Mechanisms that seek to establish a social differentiation against indirect functions can be observed strongly with manufacturing representatives, with a resulting perceived distance of manufacturing (j).
Overall, manufacturing does not seem to be recognized at full eye level for matters concerning NPD. Limited interest and estimation for manufacturing activities is accompanied by the admiration of design activities (k). Manufacturability requirements are difficult to place in NPD, due to their elusive nature and due to a perceived obligation of manufacturing to ensure manufacturability, not design (l). Notably, however, manufacturability has low advocacy also with production representatives for different reasons that range from the manufacturer not benefitting from low

manufacturing costs in the transfer-price-based system of large corporations, up to the time lag distorting responsibilities in long-term NPD projects (m).
A series of dynamics was identified which impede cooperative ability at the CarCo interface with its particular situational conditions. Astonishingly, innovation appears to make integration more difficult, inter alia because cross-functional experience and contributions often are yet absent for innovative projects (n). Extensive supplier involvement, as it is typical for large-scale industrial endeavours, constitutes a further hindrance factor (o). Functional structures, which are known impeding factors for cross-functional integration, are found to be strongly self-sustaining based on corporate steering and management power considerations typical for large-scale corporations (p). In a similar manner, a lack of cross-functional transparency and trust continuously undermines efforts for enhanced integration (q). Likewise typical for large-scale industrial operations, cooperation is dependent on formally defined agreements and processes, which often cannot be sustained for innovative projects, hence impeding integration (r).

Concerning competition, little conflicts or controversial discussions on the cross-functional optimum of different design requirements is found, be they driven by manufacturability or design. Informants are well aware of this circumstance, calling for more competition, but seem caught in a functional orientation with a predetermined requirement hierarchy. Cross-functional structures do exist, but they do rarely succeed in creating critical competition, thus remaining coordination and information exchanges (s). A lack of cross-functional competition can be explained by strong informal relations at adjacent interfaces, building on reciprocity and avoiding conflict (t). Moreover, there appears to be a tendency of design functions defensively waiting out conflicts with downstream functions, as they benefit from information asymmetry and have time on their side (u). Furthermore, downstream functions tend to avoid conflicts as well; often only brought to the table when organizational targets enforce them to (v).
Further, leadership-related aspects deter competition from more frequent occurrence. For power consideration reasons, management levels tend to avoid conflict, which is disadvantageous in so far as cross-functional conflicts, if they emerge, are often escalated to management levels and not solved at the operational level (w). Furthermore, repeated instances of sluggish decisiveness, typical for mature large-scale companies, impede competition because of the time pressure that results on NPD when eventually a decision is taken (x).
The complexity inherent to large-scale NPD projects makes it difficult for involved individuals to critically challenge their cross-functional counterparts (z), allowing for smokescreening (y) at the interface. Lastly, innovative projects find less competition at the design-manufacturing interface as manufacturing representatives often are not yet existent to utter controversial inputs (ab).

7.3.2 Theoretical model

The analysis of cross-functional integration by taking a coopetitive perspective allowed for an in-depth understanding of underlying dynamics at the design-manufacturing interface. While the manifestation of cross-functional integration analysed from the empirical setting of the case study is naturally case-specific, identified dynamics that shape and produce cross-functional integration allow for theoretical generalization. Aiming at a higher-level theoretical reflection of the analysis at hand, the three categories of coopetition are abandoned and second-order themes that emerged from the data are built upon. When looking at those free from prior categorization, interesting conclusions may be derived from combinations of content-wise related themes. Eight overarching dynamics emerge, which are believed to be valid for other cases beyond the examined empirical context. They can be classified into three broader categories, as they are specific to a certain functional interface (interface-specific dynamics), specific to a certain context or situational setting (contextual dynamics), or inherent in the social nature of involved participants (social dynamics). Together, they form a model of cross-functional interface dynamics at the design-manufacturing interface, which will be described at the end of this chapter. In the following, every identified dynamic will be described as part of their respective category.

7.3.2.1 Social dynamics

At its core, cross-functional integration is a bundle of social activities, with human beings interacting, cooperating and even competing. A series of identified second-order themes assumes expression thereof, describing social conditions and motives for action, which essentially seem valid for all cross-functional integration dynamics independent from involved functions or the situational context. In the following, respective overarching themes are described that may be derived from combinations of second-order themes.

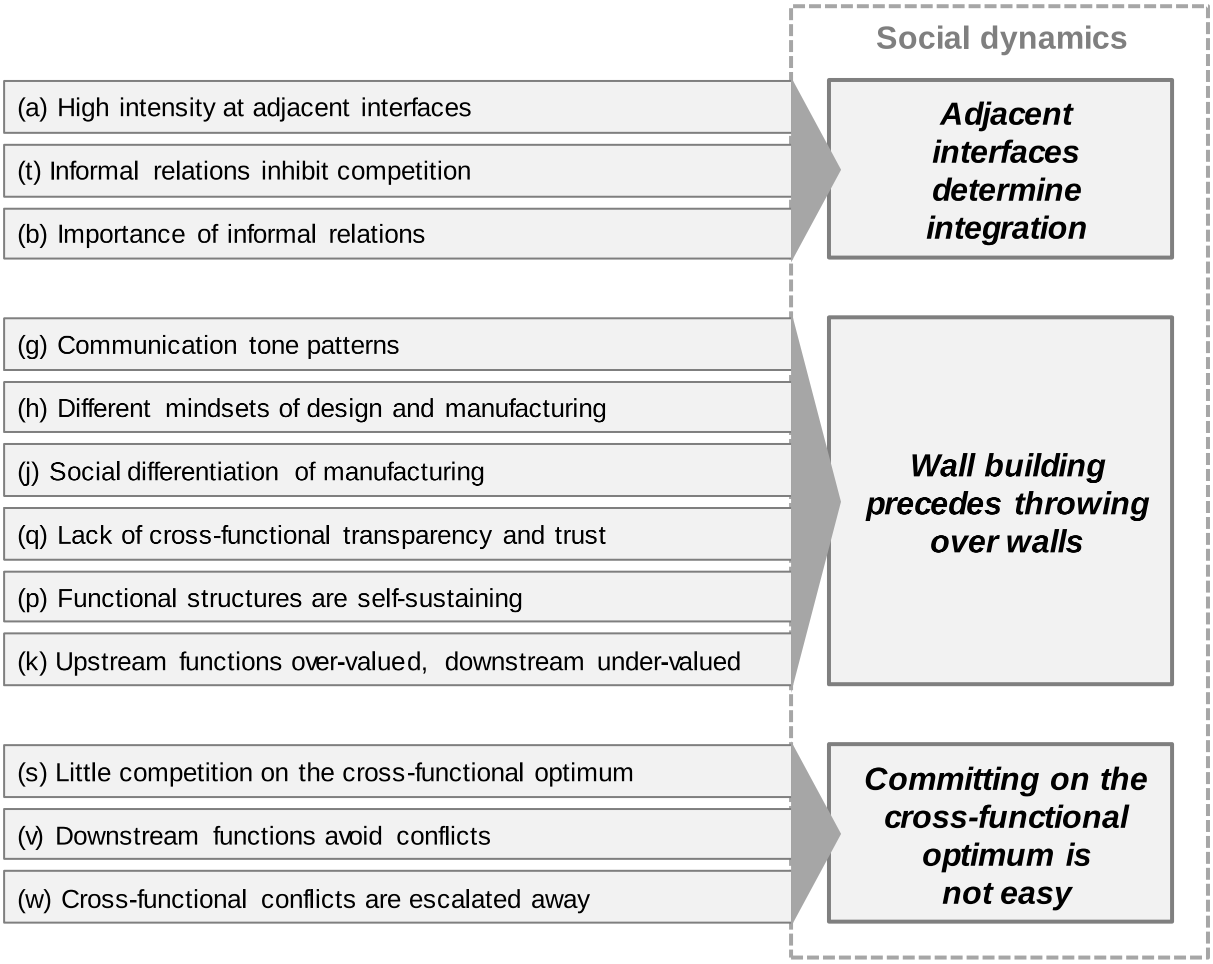

Illustration 39: Social dynamics at cross-functional interfaces

Adjacent interfaces determine integration

In the empirical reality of cross-functional integration, many more functional units are existent and participating than the often discussed triad of marketing, design and manufacturing. Certainly, additional functions may be grouped into one of these three categories; however, they empirically act as separate functions with their own respective interface dynamics. The research at hand has shown that these dynamics are of high relevance for the empirical reality, as integration occurs mostly on adjacent interfaces of small-cut functional units, such as between process design and production planning.

Many of the important preconditions for cross-functional integration identified by research, e.g. (formal) interaction and (informal) collaboration, seem strongest on adjacent interfaces and significantly less so for non-adjacent interfaces. Informal relationships, which build on these cooperation schemes, have been identified to be essential for individual effectiveness. Cross-functional integration has been confirmed to be a social activity at its core, with reciprocity in cross-functional relationships as a central motive for action.

On the other hand, building on coopetition research, the study at hand also identified that close social relationships between adjacent functions stand at risk to impede effective integration. Identified social dynamics to explain this are as follows: Strong social relationships discourage from conflicts that would be required to shape the product in development such that it respects all functional requirements. Instead, a “cuddling” culture, coined by reciprocity and relationship harmony, is emerging. Requirements of non-adjacent interfaces tend to go by the board. By the time that these non-adjacent interfaces become active in NPD, it could be too late to still integrate their requirements. In addition to that, if interaction is high with adjacent interfaces but not with non-adjacent interfaces, information transfer from e.g. design to manufacturing is slow and insufficient, similar to the dynamics of a game of Chinese Whispers. For the case analysed during this study, it could be shown that indeed, knowledge on consequences of own actions to functions downstream of NPD tends to be low.

As a conclusion, informal relationships are able to undermine required cross-functional competition under certain circumstances. In this case, cross-functional interaction is given, but it risks to remain ineffective, and the dynamics at adjacent interfaces are essential root causes for this.

Wall building precedes throwing over walls

The typical allegory to describe a lack of cross-functional integration are functional units sitting between high walls, who work at their individual tasks without interaction or feedback from others, and throw their result over to the next function as soon as it is finished. The existence of these walls has been proven repeatedly by academia and practice, but few academic efforts have analysed the factors that lead to their emergence. Social dynamics identified from the study at hand contribute to explain why these walls keep on building up.

The existence of differences in mindsets and cultures between functions are an unquestioned feature of corporate reality, again reconfirmed in the study at hand. Such differences naturally lead to group building dynamics, as it is deeply entrenched in human nature to strive for identification in being part of a group and to differentiate against others. As in all social collective phenomena, status and prestige thinking exist, and some groups will be perceived as being more attractive and valued higher than others. Findings suggests that these differences in status may occur between different functional groups, further enforcing group building. In particular, functions who perceive themselves as undervalued, may increase their efforts to differentiate from others, building up walls that block cross-functional integration and that are difficult to tear down. The resulting lack of cross-functional trust and non-transparency may lead to a vicious circle, as it contributes to building up the allegorical walls between functions.

Another social dynamic occurs at management level: Upper hierarchies in organization tend to benefit from functional structures, as these strengthen their individual power base and maintain evolved hierarchical structures. Therefore, power-conscious managers may deliberately contribute to entrenching functional structures within their organization.

Committing on the cross-functional optimum is not easy

Overall, social dynamics at cross-functional interfaces do not necessarily encourage the pursuit of the cross-functional optimum. Even if structures to support discussions on the overall optimum are given, functional incentivization to engage in such discussions remains low. Functional units which are involved in NPD from early phases onwards, such as product design, are in a default position to impose their functional requirements, therefore functions more downstream need to be called for to speak up for their functional requirements in order to reach a cross-functional optimum. Downstream functions, however, tend to avoid conflicts with their upstream counterparts and lack personal incentivization due to factors that are presumably given in all NPD environments: the time lag between early NPD phases and the point in time where downstream functions would benefit from their engagement. Indeed, in the case analysed in this study, conflicts appeared to be more frequent for later phases in NPD when this time lag is shrinking. In late phases, however, leeway for integrating downstream requirements into product design is small; discussions would need to occur in early phases to be effective for the cross-functional optimum.

If at some point cross-functional conflict yet arises, it may be escalated to management levels. For organization-political reasons though, management avoids open friction with their cross-functional counterparts. Cross-functional competition for power considerations on a management level is rather handled covertly; the cross-functional optimum for a certain product in development, however, cannot benefit from such covert power competition. As power considerations are undeniably an inherent part of corporate reality, a similar mechanism can be expected for other organizations as well. There may well be industry- or culture-specific reasons for a power imbalance for one function to another; the outcome on integrated NPD, however, is always negative.

7.3.2.2 Contextual dynamics

The findings suggest that there are contextual factors which impact cross-functional integration independent from involved functional partners, but dependent on the context-related features. Based on the empirical circumstances of the study at hand, two essential context features were identified: Innovativeness of the NPD project, and scale of the industrial environment in which NPD takes place, i.e. large organizations with multifaceted processes. Other contextual factors may well be impactful alike; the scope of the study at hand, however, allows only for demonstration of these two.

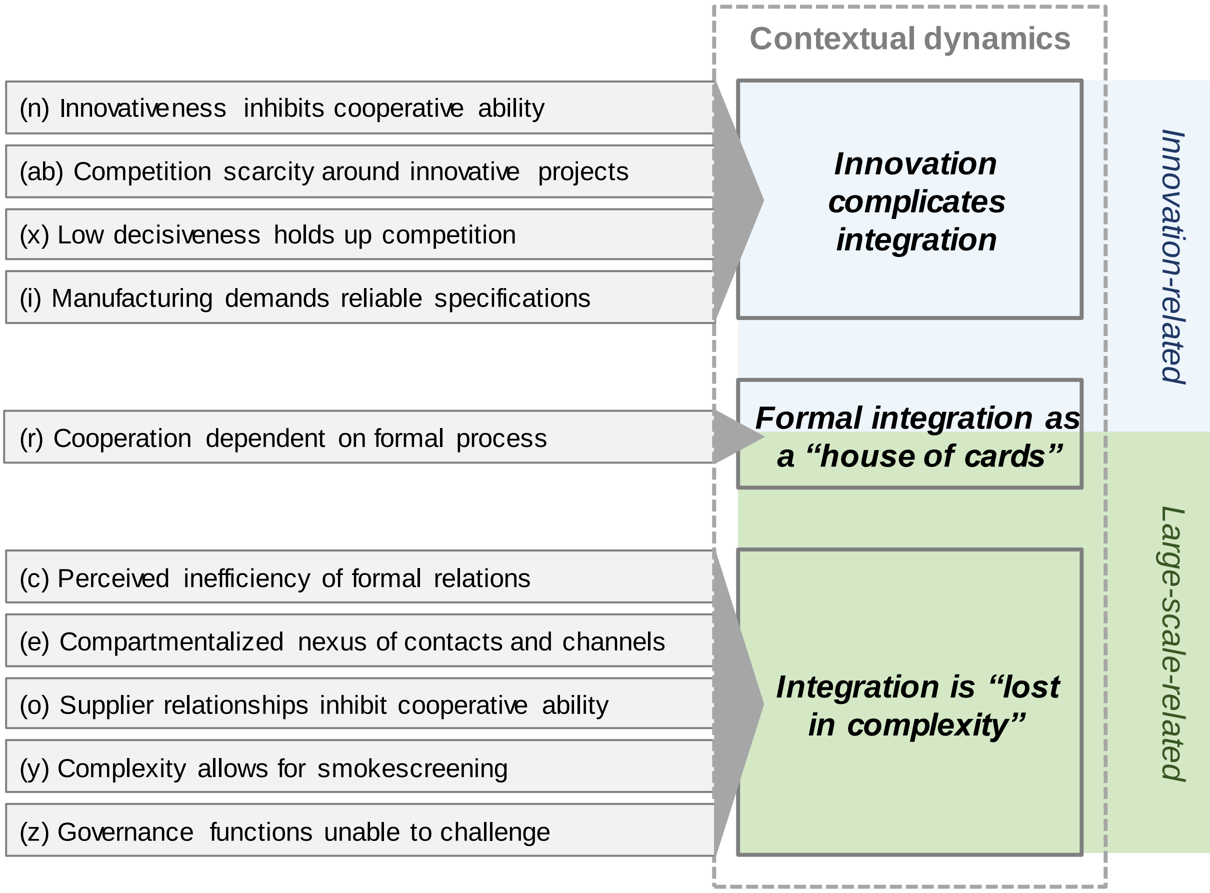

Illustration 40: Contextual dynamics at cross-functional interfaces

Innovation complicates integration

Several aspects of innovativeness of NPD projects were identified which make cross-functional integration more difficult and are likely to be valid in similar innovative contexts. To begin with, required preconditions for interaction and collaboration are available only with limitations in innovative contexts. Cross-functional counterparts, in particular those downstream from functions that are involved already early in NPD, may not be existent yet, making interaction and reception of their inputs simply impossible. Second, innovative teams are often young and unexperienced in what cross-functional requirements might be and how to prioritize those. Due to the small organizational size and volumes that are typical for early innovative projects, liaison people who support cross-functional integration may not available and general attention by functional partners may be less pronounced. Furthermore, as could be observed in the case at hand, green field projects, typical for innovative endeavours, experience less cross-functional conflict and critical feedback from cross-functional counterparts than incrementally innovative brown field projects, thus risking to be offside the cross-functional optimum.

Innovative projects usually undergo quick product modifications, sometimes they are even required to pivot entirely. Proper alignment with cross-functional counterparts under these conditions is naturally more difficult, in particular given the identified need

for downstream functions to work with reliable specifications instead of handling assumptions and abstract concepts.
Time-to-market is critical in NPD, for innovative projects even more so. Resulting time pressure may discourage stakeholders from extensive alignment with their cross-functional counterparts, and might also force the latter to swallow critical feedback from their functional angle to avoid hold-ups. Insecure technological and market dynamics may postpone decision-making as it could be observed in the case analysed during this study, which further increases time pressure with the mentioned negative consequences on cross-functional integration. A potential pitfall resulting from this dynamic is that, if cross-functional requirements have been neglected to the extent that NPD fails at some point, time-consuming correction loops are particularly detrimental in the light of time-to-market pressure and high development investments. If marketing requirements, representing another essential cross-functional partner, has been insufficiently considered, the product may fail entirely.

Besides these dynamics complicating cross-functional integration at innovative projects, they also have consequences on cross-functional integration of succeeding, less innovative projects. Path dependency of these projects from their innovative antecedents, e.g. from modular platform architectures or existing production plants, limits the possibilities to improve these projects' cross-functional suitability.

Formal integration as a "house of cards"
In large-scale industrial environments, cross-functional integration tends to be based on formal processes and contract-similar agreements. Based on the complex and multi-layered nature of large-scale NPD, this is an inevitable consequence of governance mechanisms in large organizations: For enterprises and NPD efforts of a certain size, formal integration is a reasonable necessity, as processes and structures in their entirety exceed the level of complexity that individual stakeholders would be able to see through themselves. Therefore, employees acting in large-scale structures are obliged to follow formal processes - and only formal processes, otherwise the entire system risks to break down in chaos. Educated in such structures, employees are unwilling to take additional efforts apart from their agreed-upon performance schedule. Cross-functional integration, by nature requiring to integrate requirements from functions other than the own one, therefore depends largely on these formal processes to occur in large-scale industrial settings.

These formal processes tend to work reliably for the rather incremental innovations that dominate large-scale enterprises. For innovative projects, however, several aspects identified from the case study at hand may lead to a sudden collapse of formal integration, which the author therefore denominates allegorically as a house of cards.
To begin with, decision structures in large-scale industrial contexts often are driven by committee structures, in which boards or steering circles take important NPD-related

decisions rather than individual persons. Innovative endeavours, often more controversial and hazardous, therefore require more time-consuming discussions to reach consensus. This may result in ongoing time delays, which are particularly detrimental in the described contextual environment as bullwhip effects to downstream functions are enormous: As stakeholders stick to the formal processes, unable to compensate for time delays with own additional efforts or taking deliberate shortcuts, the entire system comes under significant time pressure. In this case, it is likely that pursuance of formal integration processes will be given up. Rapid and frequent product modifications, which are likely to occur for innovative products, may have the same effect, first creating time pressure and then leading to a collapse of formal integration. Eventually, when breaking away from formal integration under time pressure, it is likely that stakeholders educated in large-scale structures neglect alignment efforts with their cross-functional counterparts.

Integration is "lost in complexity"

In large-scale industrial environments, with their multifaceted processes and compartmentalized nexus of responsibilities, finding cross-functional contact persons or effective tools and channels to transfer functional requirements is not trivial. The study's findings suggest that the sheer multitude of channels and contacts is well able to keep the organization in general and cross-functional efforts in particular busy, but potentially without any effective outcome. Inputs from cross-functional counterparts may easily be lost in endless lists and systems. Allegorical comparisons with Kafka's piece *The Trial* or Gallic *Asterix' search for permit A38* do not seem entirely unjustified.

Besides complexity in processes and contact nexus, product complexity and resulting consequences on its stakeholders complicates integration in a similar manner. In this sense, observations made from the case study at hand seem transferable to other large-scale contexts featuring complex products. Managing complexity is challenging, as gaining transparency on the validity of statements of the cross-functional counterpart requires an in-depth understanding of their work. While this full comprehension would require significant efforts, insufficient comprehension would let other functions benefit at own costs. Managing this border walk of too much and not enough comprehension of complexity is challenging, in particular for central governance functions, whose overarching activity scope makes it more difficult for them to challenge functions' results. Leaving this narrow path of managing complexity can easily result in a vicious circle, as it could be observed in the study at hand. Controlling functions may require closer steering to get a better comprehension of operation functions' statements. Consequently, the latter have less time to perform their operational work and have to rely on assumptions, which again decreases transparency and may distort the overall picture to a significant extent. As a potential consequence, formal processes steered by central governance become undermined with the risk of buffers emerging in operational functions' statements.

Integrating suppliers into this already complex network is an empirical reality for most large-scale industrial enterprises with their high share of purchased parts and services. Complexity rises further and relative shares of steering functions increase, as the operational work is outsourced to suppliers and needs steering. The underlying antagonism between operational and steering functions, which blurs transparency and complicates integration, is thereby exacerbated. It is therefore likely, that the desire for control and the amount of bureaucratic tasks in such context will rise continuously.

7.3.2.3 Interface-specific dynamics

From the data at hand, there seem to be some dynamics emerging which are closely related to functional peculiarities of design and manufacturing, as well as their interplay, respectively. Those dynamics are believed to be valid for other instances of the design-manufacturing interface and will be described in detail in the following.

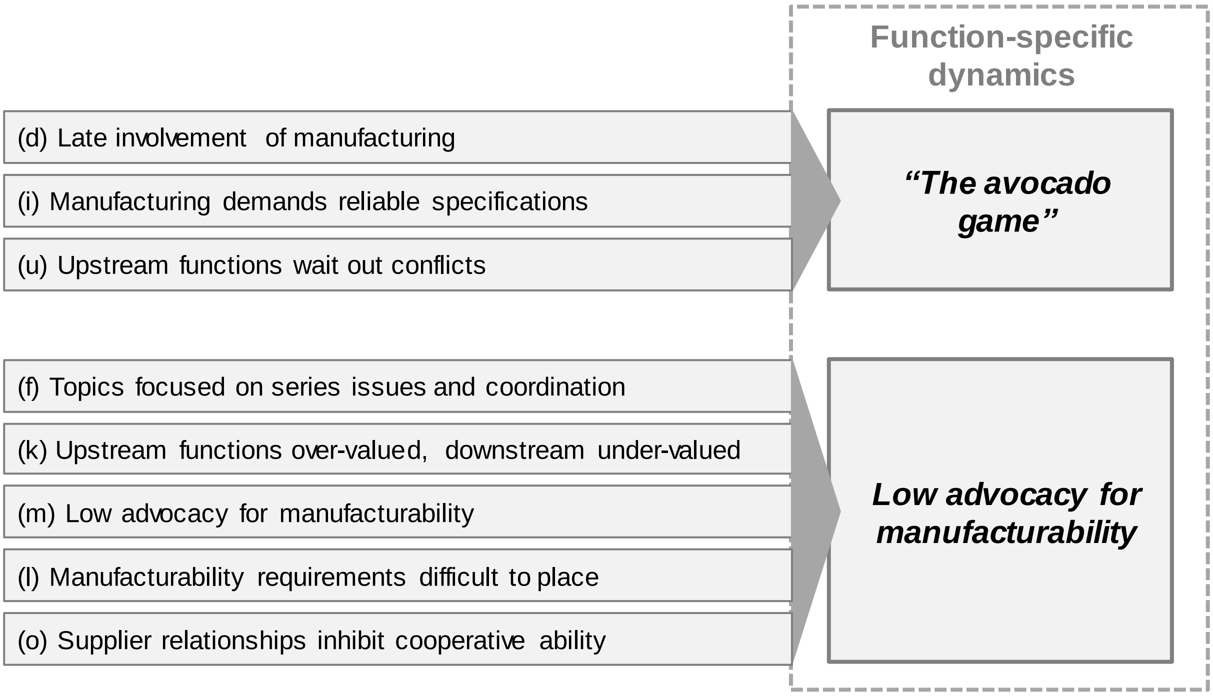

Illustration 41: Function-specific dynamics at cross-functional interfaces

"The avocado game"

For avocados, there is a popular saying that they remain unripe for a long time, but in the second they turn ripe, they become overripe and brownish. Just as it is almost impossible to find the right moment in time to eat an avocado, findings from this study suggest that it is almost impossible to find the right point in time where manufacturing should be involved in the product design phase.

In early phases of NPD, when it would be most easy for product design to integrate manufacturing's requirements, the latter is typically unable to provide them. Manufacturing requires drawings and specifications or even hardware to be able to provide feedback. In early phases, however, abstract concepts and assumptions are the only available basis. As soon as product design comes up with a draft construction, a CAD model or possibly even a hardware prototype, however, the scope to integrate manufacturing requirements is already limited. Not only would changes mean significant efforts on the part of product design, but also are product validation requirements a prohibitive factor to retrospective changes. Complex products in particular, such as typical large-scale industrial goods as cars or airplanes, have tight schedules in which point in time product validation has to be performed. As soon as a product is validated, changes are even more cumbersome to impose.

Furthermore, design functions seem to know quite well how these dynamics work. The case study data provides manifold instances that at times, designers deliberately wait out conflicts with their cross-functional counterparts and act defensively, as they know that they have time on their side. They seem as versed players of a game with time, which provides the denomination for the described dynamic.

Given the complexity of many products and processes during NPD and the circumstance that manufacturing becomes involved only in later phases of NPD, it can be easily understood that manufacturing employees are likely to have difficulties to get to know all relevant details to join the discussion with their cross-functional counterparts at eye level. As a consequence, they remain quiet for fear of saying something embarrassing, or are rebuked for any such. The study's findings suggest that design functions are well aware of the information asymmetry and able to utilize it, rejecting cross-functional counterparts' proposals for reasons untraceable for the latter.

While the mechanics of this social game have been discovered in the CarCo case study and a generalizability to other cases cannot be conclusively proven, the author believes that relevance is given for many other cases where the design-manufacturing pairing is involved: Required preconditions of information asymmetry, time lag and responsibility distribution between design and manufacturing are necessarily recurring for all NPD activities between design and manufacturing; likewise, inherent mindset differences that trigger the identified dynamic have been recognized widely in theory and empiricism.

Low advocacy for manufacturability

Findings from the case study at hand suggest that there is little competition or even talk about manufacturability, however, pertinent social factors do not explicate the entire picture. Indeed, some factors seem to contribute which are specific to the functional pairing of the design-manufacturing interface and may likely be transferable to other contexts beyond the considered case study.

To begin with, manufacturing across industries is broadly perceived as a less prestigious field of engagement, with its narrow allowances for creative work, high portions of standardized repetitive work, and its high share of less educated manufacturing personnel. By contrast, the cross-functional counterpart at the examined interface at CarCo is granted an almost artistic aura. Assembly in particular, often is not of uttermost interest for technologically skilled professionals. With it comes less interest in manufacturability, but likewise, and more impactful also, a presumptuous belief of manufacturing topics being easily solvable and thus not being granted much attention. Furthermore, due to the absence of urgency in the nature of their issues, considerations of manufacturability during NPD are at risk of deprioritization. In contrast, as an example, material costs tend to be determined by external suppliers, and considerations thereof are required to fulfil certain deadlines. Manufacturing costs, however, are determined by internal, less contractual dynamics, with less strict deadlines to break. Difficulty to place manufacturability requirements, as they are less easy to quantify than other design requirements represents another hindrance.

Notably, not even manufacturing representatives themselves take advocacy of manufacturing costs in the CarCo case for two identified reasons, which seem transferable to other cases: First, based on the inherent nature of controlling processes within organizations, there will be some form of transfer pricing to remunerate a company-internal manufacturing department for its production performance in most companies. As it was learned from the case study at hand, as long as the transfer pricing covers required costs, manufacturing has little incentive to reduce those already during NPD. Involved suppliers share this thinking; to improve manufacturability their feedback to product design would need to be stated long before supplier prices would be negotiated, so they would not be able to benefit from their engagement. Therefore, this seems plausible for large-scale companies as well as for smaller companies, with the former producing themselves based on a transfer price system and the latter relying on suppliers.

Lastly, due to the long time period between product design phase and start of production, a production representative engaged in NPD discussions would quite certainly not be able to benefit herself from any discussion success. This responsibility-distorting time lag certainly constitutes a major root cause for low advocacy.

Eventually, central controlling functions are likely to be the only possible advocate for the cross-functional optimum and therefore manufacturing costs alike. However, as was discussed before, they are often unable to assume a challenging role.

7.3.2.4 A model of cross-functional interface dynamics

The in-depth analysis of dynamics at the design-manufacturing interface of the incumbent, successful CarCo has shown that even in well-established organizations, there is more than rational information and resource transactions occurring in the daily work environment at cross-functional interfaces. A significant share of what was observed at CarCo can neither be explained by rational decision-making behaviour, nor be directly impacted by management directions or organizational processes. By and large, actions were observed, which are to large parts impacted by socio-organizational or contextual dynamics. Setting out from identified shortcomings of the existing research on cross-functional integration in an NPD context, underlying hidden dynamics were exposed, that have not yet been captured in existing theory, but which may help to explain inconsistencies and contradicting results of existing empirical efforts. While individual dynamics have been explained in the previous chapter, an aggregated model, depicted in illustration 42, will be presented in the following.

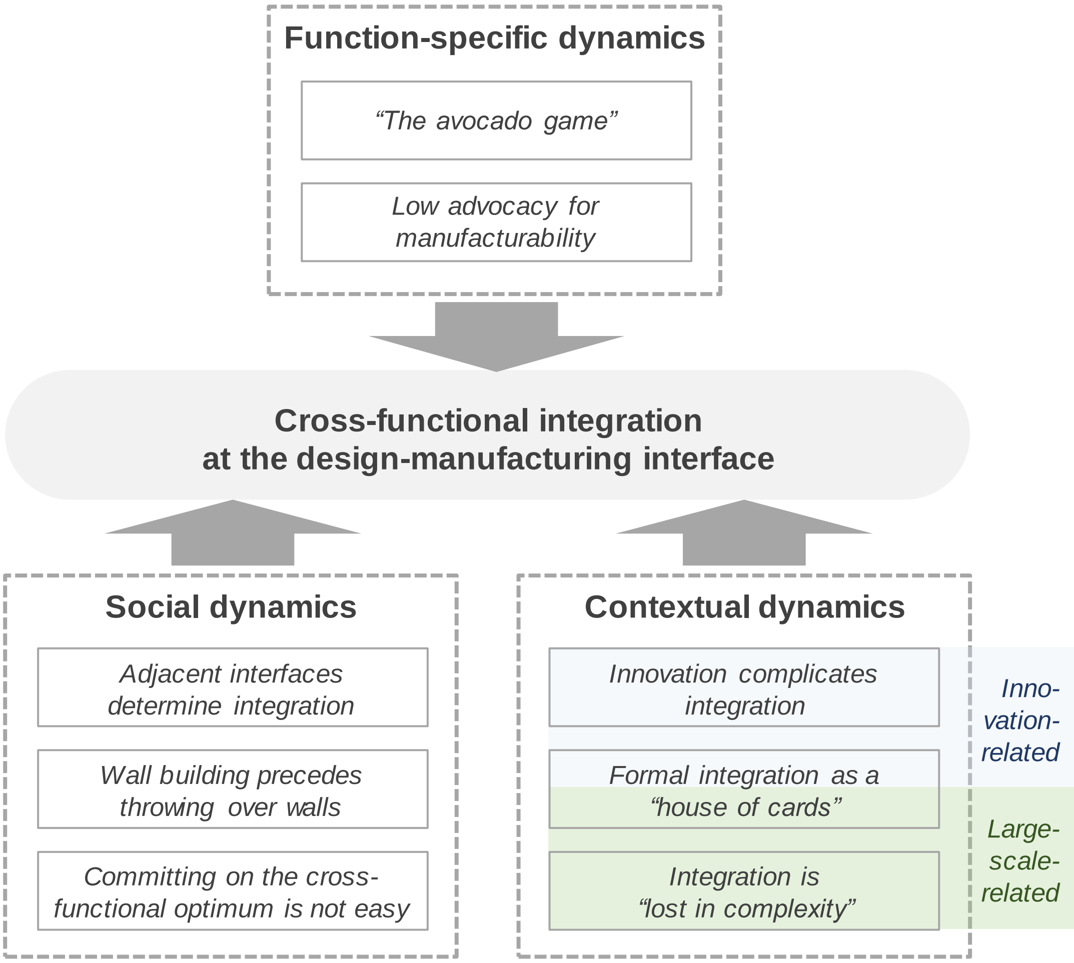

Illustration 42: Model of cross-functional interface dynamics at the design-manufacturing interface

Observed dynamics have been grouped in respective categories that reflect their origin, be it social, contextual or function-specific. To begin with, there is reason to assume that the identified function-specific dynamics will only occur at the design-manufacturing interface. For other functional pairings, the dynamics will likely be of no relevance. For a functional pairing of design and manufacturing in another case in whatever context, however, the dynamic is expected to be observable.
With regard to contextual features, identified dynamics reflect the two context features that were observable and therefore analysed in the empirical setting at CarCo: The context of an innovative project, as well as the context of a large-scale industrial setting. The dynamic *innovation complicates integration* can be attributed to the innovation context, whereas *integration is "lost in complexity"* is driven by a large-scale industrial context. *Formal integration as a "house of cards"* has its origin in both contexts. The author believes that identified contextual dynamics are valid for different

interface pairings apart from design-manufacturing, as long as they share contextual frame conditions.
Social dynamics are independent of a certain contextual background or functional pairing. Cross-functional integration at its core is a social activity; it is therefore believed that social dynamics may be observable in any cross-functional context.

Evidently, the model presents dynamics that influence individual actors' actions and motives, but it does not claim to fully predict these actions. Of course, rational decision-making, organizational targets and managerial directions will guide actors at the interface as well. However, there is an "error term" of significant size whenever the object of analysis is subject to socio-organizational and contextual behaviour, as it is the case for cross-functional integration. Presumably, this causes some of the inconsistencies in existing research on the topic. The suggested model of cross-functional interface dynamics is able to explain this "error term" in a structured way. It reveals typical dynamics that shape actors' behaviour, which may appear under the specified preconditions. In this sense, the model contributes to existing literature by being the first in-depth structured analysis of social and situational aspects, which existing research so far has, though conceding their importance, handled in an unspecific way which would neither allow to understand their mechanism of action nor to categorize their impact based on defined preconditions. In addition to that, the model identifies function-specific differences to barriers or supporters of integration, shedding light on the often neglected interface between design and manufacturing.

Of course, the model does not provide specific directions on whether a certain dynamic influences cross-functional integration in a positive or negative impact. This can only be concluded by analysing the manifestation of identified preconditions in a certain setting. For example, looking at the *adjacent interfaces determine integration* dynamic, it could have a negative impact on cross-functional integration between design and manufacturing for companies with widespread functional structures such as CarCo, because the chain from manufacturing over many intermittent bridging structures to design is long. For plainly structured companies, for instance where design and manufacturing are represented by one respective individual in the same team, the dynamic would have a positive impact on cross-functional integration: In this case, design and manufacturing are adjacent interfaces, and are therefore likely to share strong attitudinal ties with a resulting close integration.
In this sense, the model can find application with both academics and practitioners, as it allows them to identify dynamics that may impact the cross-functional interface they are looking at depending on its preconditions in the social, contextual or function-specific setting.

The model summarizes and categorizes identified individual dynamics according to their role in the CarCo case study, but each of these provides a profound impact pattern which certainly allows for transfer and potentially enhancement in other case settings. To begin with, function-specific dynamics have been derived for the pairing of design and manufacturing within this study. Certainly, other dynamics for other functional pairings can and should be identified. Moreover, innovation and large-scale industrial contexts are part of this model because the case study context allowed to analyse these. Other contextual dynamics which might be observable for start-up or different cultural context would of course be interesting to analyse and integrate into this model.
In the *"avocado game"* dynamic, the interplay of time lag, information asymmetry and responsibility creates an interesting social game, which potentially is transferable to other settings where these forces come to play.
With regard to contextual dynamics, *innovation complicates integration* is an interesting hypothesis that has not been identified so far. Whereas the inversed question, how integration impacts innovation, has long been a central research issue, potential counter effects which also might have an impact on NPD success have gone unnoticed. The new findings can potentially provide a research impulse.
Formal integration as a *"house of cards"* may represent an important challenge for both researcher and practitioners, namely how cooperative structures can be institutionalized in large companies that are resilient and flexible enough to support innovative projects.
The dynamic suggesting that *integration is "lost in complexity"* certainly is an interesting insight for managers, promoting transparency in cross-functional relationships and advocating for a less is more attitude when it comes to integration-supporting structures and governance control. For research, this may represent empirical evidence for complexity research.
In consideration of social dynamics, the important role of *adjacent interfaces* has been neglected in existing research, which typically focused on aggregated functional structures of marketing, design or production. The fact that empirically existent bridging functions, standing somewhere between these high-level functional delineations, are important actors in cross-functional integration, could be insightful for other matters in organization or innovation research.
Wall building precedes throwing over walls attaches importance to the mechanisms that build the functional walls, which cross-functional integration approaches are keen to remove. It may encourage further research efforts and create practitioners' awareness to take a profound look into this topic in order to create a sustainable approach of removing walls without new ones being built simultaneously.

7.4 Introduction of manufacturability constraints

After having analysed the underlying dynamics of cross-functional integration at the design-manufacturing interface by taking a coopetition perspective, the following part of the case study is concerned with the theoretical grounding of a new approach: introducing manufacturability constraints to enhance cross-functional integration in NPD. According to the qualitative methodical foundations of this case study, this is explored in close engagement with social and contextual aspects of the empirical setting. For this purpose, the initial idea as described in chapter 5.2.2 needs to be translated into the empirical setting of CarCo's design-manufacturing interface, which is to be described in the following chapter.

Furthermore, the author is interested in exploring moderating effects, that different constraint types and different constraints' organizational embedding may have on the examined relationship. To this end, categorizations of these two moderating effects will be developed in the following chapter that suit CarCo's empirical context and maximize empirical insights for the research effort at hand.

7.4.1 Defining suitable constraint types

As discussed above, constraints are formulated from a manufacturing perspective to be integrated with different stakeholders involved in NPD, e.g. product design, process design or production planning. This presupposes the use of constraint types that refer to manufacturability. Going back to the classification of constraints used in applicant studies of constraint research, manufacturability belongs to the group of product constraints. To be more concrete, it can be categorized among product properties, as manufacturability cannot be directly influenced by the designer as opposed to product characteristics, which would allow for direct influence.

So as to excite insightful distinguished feedback from the case study informants, three different manufacturability constraints are deployed, all of them quantifiable measures. While all represent a proxy for manufacturability, they differ with regard to their abstraction level from the product itself. First, *number of fasteners* is chosen as a manufacturability constraint staying at close range to the product. Second, as a succeeding abstraction level, *assembly time* epitomizes a manufacturability concern that can be directly attributed to product specifications, as it is fully determined by design decisions, yet abstract enough to express a measurement that product design usually is not concerned with. Third, *variable manufacturing costs* take another step away from a direct relation to the product. While still being largely determined by design decisions, other factors, such as wage levels or shift models enter the calculation.
Building on iteratively increasing abstraction levels from the product to distinguish different constraint types allows for generalizability to other interfaces alike. For

functional constellations other than design and manufacturing, the same logic could be applied.

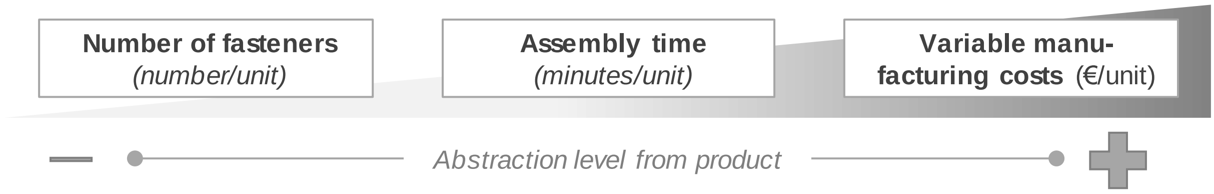

Illustration 43: Types of manufacturability constraints and measurement units

According to the qualitative research methodology, contextual and social factors constitute essential parts of the analysis, which is valid for this part of the case study alike. Therefore, the introduction of manufacturability constraints has to be explored as closely to empirical reality as possible. Consequently, designated manufacturability constraints are to be calculated based on CarCo's usual conventions. To assess potential difficulties that might be related to the establishment or visualization of the manufacturability constraint, fully functional tools are designed and programmed to deliver real time quantification of the examined constraint type. In the following, respective tools and calculations of the individual manufacturability constraint types are provided.

7.4.1.1 Number of fasteners

The choice of fasteners that product designers make for the functional design has a significant impact on manufacturability. Overall, they account for the largest part of the assembly time for a given product. While certain fastener types are easier to assemble than others (e.g. clips as compared to screws), the total number of fasteners should simply be minimized from a manufacturability perspective.
The fundamental idea of the constraint is to limit the number of certain fastener types that are incorporated into the design of a specific product. Minimizing the number of fasteners would require implementing many manufacturability-optimizing design alternatives, e.g. combining several components into one to decrease assembly operations overall or finding alternative joining mechanisms that do without cumbersome manual operations. Naturally, simply omitting fasteners without a constructive alternative is no acceptable solution, as stability requirements have to be complied with.

The calculation of the measurement is of uttermost simplicity, as it is simply a count of different fastener types. A tool, which is able to derive and visualize these in real time from a drawing or CAD model is not trivial, though. Simply taking a drawing and manually counting different fasteners or combing through bills of materials, often not yet existent in early NPD phases, is not feasible. Any of CarCo's products certainly comprises up to 1,000 components, thus any manual metering would be no satisfying solution for the research application at hand. Such a manual constraint calculation risks

to undermine empirical credibility of the approach and may distort informants' actual feedback.
For these reasons, the author developed a tool able to analyse type and respective number of fasteners from the CAD model itself. It works as an add-in in the toolbar of CarCo's CAD program, which is not mentioned herein due to confidentiality reasons. The tool is based on the CAD program's specific programming language, allowing for seamless integration within the product designer's daily work environment.

7.4.1.2 Assembly time

Assembly time at CarCo is a strictly defined measurement which is used in different corporate processes, such as calculating production pace at a manufacturing line and deriving production schedules and shift planning. It is measured in time units of minutes, seconds and TMU (time measurement unit), with the latter being the equivalent of 0,036 seconds. Overall assembly time covers three categories, construction-related assembly times, handling-related assembly times and quality-related assembly times. Construction-related assembly times account for the largest part of overall assembly time. They are the measurement for assembly time which is caused by the actual product design. It will thus be used as manufacturability constraint.

Assembly time calculations at CarCo follow a strict standard based on motion-time systems used in industrial engineering, which allow assessing the required assembly time for a certain product design in a standardized and reproducible way. CarCo follows the approach of the methods-time measurement analysis (MTM analysis), which is an industry standard also used at other automotive OEMs. At its core, MTM is a system of standardized assembly time building blocks that may be attributed to standardized component types and assembly processes. Based on the high granularity of these building blocks, which allows for taking into consideration different reach distances, screw types, plug types and similar features, MTM analyses enable detailed estimations of assembly time.

To allow for real time estimates of the construction-related assembly times, the fastener analysis tool described above is complemented with a matching algorithm that attributes MTM building blocks to the identified components. Naturally, this covers not only fasteners, but all add-on parts, cables or plugs that require manual assembly. To countercheck plausibility of the matching algorithm's results, they are compared to MTM analyses of four of the same respective product designs that have been analysed manually by one of CarCo's industrial engineering specialists. In the course of several optimization loops, in which the underlying matching algorithm and MTM building block data base are readjusted, accuracy increases to a corridor of +/- 10% deviation from the manual analysis.

7.4.1.3 Variable manufacturing costs

Alike assembly time, variable manufacturing costs are a strictly defined measurement used for manifold corporate processes at CarCo, including the target agreement process as an essential element of NPD.
Calculation according to CarCo's conventions involves several steps and a series of input measurements with dependencies on product design and process specifications. Obtaining a real time multivariate approximation of variable manufacturing costs depending on the chosen product design requires a tool able to combine calculation steps and account for input dependencies. The author developed a VBA-based script to render quantification requirements with automated interfaces to external input sources. Illustration 44 shows the generic program sequence and essential input measurements. Assembly time estimates based on the MTM method are sequenced based on input production process parameters, such as production volumes, relative variant distribution or overall equipment efficiency. An automated line balancing allows allocating tasks to individual assembly workers, thereby deriving the required number of workers. Adding controlling parameters, such as wage levels or shift parameters, allows the calculation of variable manufacturing costs. To enhance plausibility, these estimates undergo a sensitivity analysis. Together with sensitivity measurements, the most plausible variable manufacturing cost estimate is displayed on a user form.

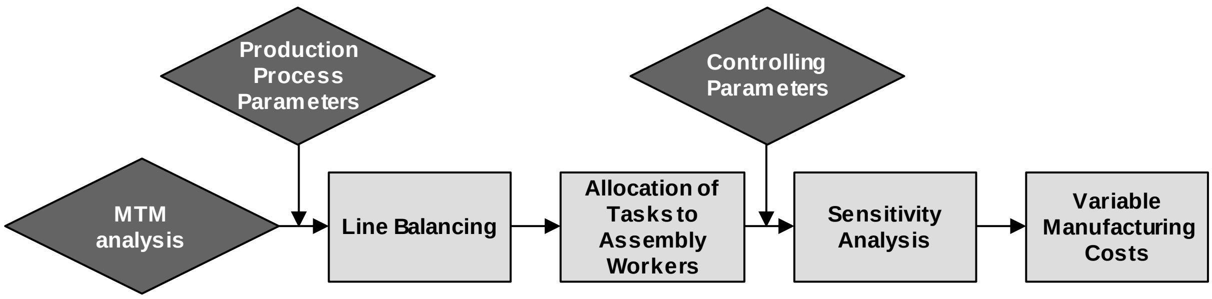

Illustration 44: Program flow of variable manufacturing cost estimation tool

Together with production planners and controlling representatives of CarCo, the tool was tested and optimized to increase accuracy and real time capability.

7.4.2 Defining suitable dimensions for organizational embedding

Organizational embedding spans a wide field of empirical inquiry, with its broad array of potentially relevant factors for the introduction of constraints within management, incentivization, process-related aspects and organizational frame conditions. Following this case study's explorative intention, however, the goal cannot be to derive all possible dimensions from pertinent theory and to test them in a rigorous order. Instead, the author sets out to adopt an approach that allows case study informants to shape the analysis by naming and prioritizing aspects that they find to be important grounded in CarCo's empirical setting.

A methodological approach which allows and even explicitly asks for this way of social interaction and which represents a well-proven format for modelling complex social, organizational and political systems is the general morphological analysis (GMA). Originally conceived by Fritz Zwicky, a Swiss astrophysicist and aerospace scientist at the California Institute of Technology, GMA allows to model not meaningfully quantifiable factors that are interlinked in non-linear systems, which is true for many social systems. It therefore represents an alternative to formal or causal modelling relying on judgmental processes and internal consistency rather than causality (Ritchey, 2011; Romeike, 2018).
Facilitated group interaction in form of a moderated discussion, similar to what is applied in semi-structured interviews of the study at hand, constitutes a central pillar of the GMA modelling process. Based on participants' inputs, the problem to be investigated is structured into its most important dimensions. With regard to organizational embedding, an exemplary dimension could be incentivization. Subsequently, for each of the dimensions, relevant values, called parameters in GMA, are assigned. As an example, for the incentivization dimension, one parameter could be monetary incentivization. A morphological field is the visual representation of this problem analysis. Essentially, it is a table of all parameters along their respective dimensions (Ritchey, 2011). As a structured illustration, the morphological field is known to foster creativity for further problem exploration in moderated interaction, as dimensions and parameters can be complemented and combined at will (Romeike, 2018).

During this study‘s exploration at CarCo, facilitated interaction with interview participants is employed to build up and evaluate a morphological field of organizational embedding of manufacturability constraint introduction. Starting with an initial draft of possible dimensions, the morphological field is developed based on participants' inputs in an iterative manner. To support spontaneous complementation of dimensions and values, participants are handed a print-out of the current state of the morphological field and are encouraged to mark their opinions on it, making it possible to combine or complement existing fields.

7.5 Manufacturability constraints' impact on coopetitive behaviour

Having translated the manufacturability constraints as explained above, their impact was explored in extensive discussions with respective functional representatives from design and manufacturing. In order to understand the full bandwidth of this impact, different scenarios were consulted, in which different functions upstream of manufacturing in the NPD process would be recipients of the constraints. This includes product design, process design, production planning and production management, with resulting insights on constraints' impacts on the respective interfaces up- and downstream to the functional recipient. Moreover, it is believed that all examined functions should be involved to provide their reflection, as the idea of introducing constraints may well be perceived differently by a production representative as compared to a design representative. Therefore, manufacturing representatives were likewise inquired, who would not be considered natural constraint recipients, to explore the idea in different scenarios and provide their input.

Notably, the English expression *constraint* would not be understood by the German-speaking interview participants. Therefore, the German word “Vorgabe” was used, often repeated as requirement, value or goal by the participants. Henceforth, these expressions are followed and reproduced in the translated quotes.

In accordance with this study’s second research question, the impact of manufacturability constraint introduction on coopetitive behaviour at the design-manufacturing interface of the empirical setting at CarCo is examined. For the resulting codified data, as displayed in illustration 45, a structure emerges which largely follows the coopetition dimensions. Representative data for the dimensions and their respective second-order themes is provided in table 16 in the appendix.

Impact of constraint introduction on coopetitive behavior

1st order concepts	2nd order themes	Aggregate dimensions
1. Increased interaction downstream 2. Increased interaction upstream 3. Increased interaction of non-adjacent interfaces	*(A) Increased interaction*	**Impact on cooperative intensity**
4. Constraint should be trigger for discussion 5. Constraints should not be thrown over the wall	*(B) Interaction required to be effective*	
6. Encourages manufacturer to get involved 7. Pressures manufacturer to get involved	*(C) Manufacturing pressured to get involved*	
8. Prioritizes interaction topics	*(D) Focus is set to interaction*	
9. Increases understanding of manufacturing 10. Increases interest in manufacturing 11. Increases mutual respect across interfaces	*(E) Increased understanding and interest*	**Impact on cooperative ability**
12. Constraint leads to internalization of manufacturability 13. Interest for consequences of design on manufacturing	*(F) Internalization of manufacturability*	
14. Immediate feedback for constraint consideration 15. Immediate feedback for constraint optimization	*(G) Immediate feed-back on constraint fulfilment important*	
16. Encourages production to critically discuss with design 17. Optimization first within production, then design	*(H) Discussion on cross-functional optimum encouraged*	**Impact on competition**
18. Quantification allows for transparency on optimum 19. Encourages systematic approach for optimization 20. Discourages from including non-transparent buffers	*(I) Transparency on cross-functional optimum increased*	
21. Risk of neglecting trade-offs to other design requirements	*(J) Risk of overemphasizing constraint*	
22. Additional effort for product design 23. Risk of prolonging the design process	*(K) Additional effort for design functions*	**Increased design effort**

Illustration 45: Data structure - Impact of constraint introduction on coopetitive behaviour

7.5.1 Impact on cooperative intensity

Increased interaction

With regard to both formal and informal interaction, the introduction of constraints appears to have a noteworthy impact. Summarizing all different functional scenarios as described above, there largely seems to be consensus that interaction increases:

Overall, 31 mentionings state an increase of interaction, opposed to 5 mentionings denying an increase of interaction. Illustration 46 condenses all answers with regard to their mentioning frequency based on participants' subjective estimates.

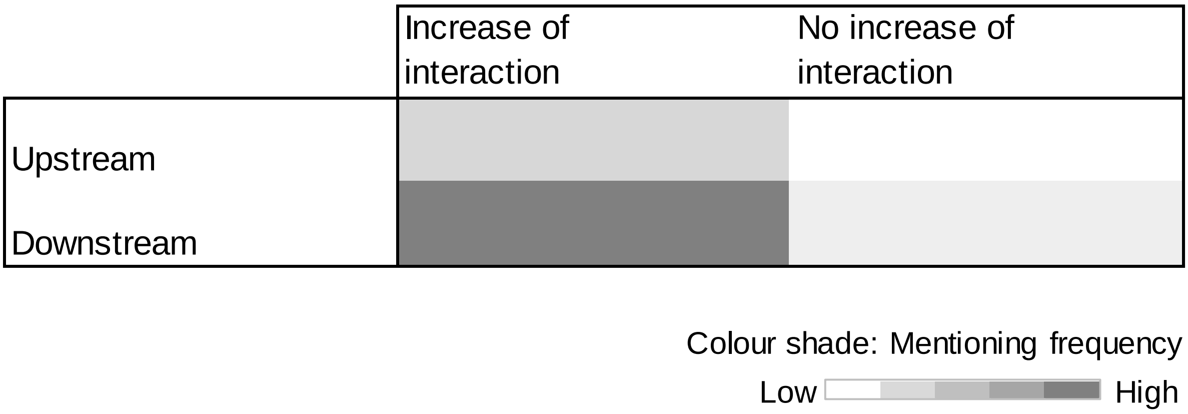

Illustration 46: Impact on cross-functional interaction

Accordingly, downstream interaction in particular is on the rise, for example communication initiated by product design to their downstream functional counterparts in production planning or manufacturing, as the following designer's statement shows: "Definitely more, after all I'd first have to find out how I can win the highest amount of time [assembly time, author's note]. So I'd call them [manufacturing, author's note] surely, and in this moment that would already be more than I ever had to do with manufacturing before" (161:1). In another scenario, where a production planner was the constraint recipient, a similar notion emerged: "I, as a production planner, would have to sit on the manufacturer's lap […]. I'd go to manufacturing to get my own impression, how does it look like, do you have enough workers, where does the shoe pinch, where doesn't it, let's be clear here […]. Transparency, as early as possible, that's the first step towards optimization, but so far we often don't have it" (158:45). Although representing a minority, some informants did not project any increase in interaction. "I think I would have talked to them as much as without the constraint. But what I might have done more, is the transparency. I would clearly bring to the table, that it's not only my goal, it's our common goal. And I'd try to reinforce the whole topic with that" (163:38).

With regard to upstream interaction, interview participants seem to agree on an increase of interaction, though confirmed less frequently in the case study data base than downstream interaction. As an example, this category would include cases of production planning receiving the constraint, and being encouraged to talk with their upstream counterparts from product or process design more often, as the following reaction to the constraint introduction advocates: "I'd talk to product design in any case latest by that point in time, when I do not get any further by talking with production planning or industrial engineering, who know the process well. When we say, we just don’t manage to make this leap. With all the optimization we can do, we just come down to 17.50€, and that’s simply because we have a screw here […]. And then you have to talk with product design. Or you even say from the beginning, dear product designer, it has to be like that” (156:37). Similarly, a production representative described how he would start working when given a constraint on manufacturing time: “If I’d see already in the benchmarks with others, 85 minutes is the goal, no one else builds it below 110 minutes, then I’d get the product designer on board, saying I’m your counterpart from production, I’ll be having a huge problem if we don’t work together from early on” (158:42).

Notably, interaction between non-adjacent interfaces, which has been identified to be rare in earlier parts of this study, seems to be explicitly on the rise when introducing manufacturability constraints. The following answer of a product designer, when asked for his actions when confronted with a manufacturability constraint and having problems of fulfilling it, is insightful in this respect. “I’d ask manufacturing, what they would do” (182:7). Similarly, a product designer confirms: “I’d talk with them [manufacturer, author’s note] more often, in any case at the beginning. I’d start with something like, how do you say in new German, a brainstorming, or a kick-off. Sure, the guys from production don’t have to sit side by side with me when I do my lines in the CAD. But as a first input, I’d sit together with them in a workshop. And subsequently, I’d align with them regularly in any case, we’ll see if that would be monthly or weekly. But the guys from production would have to sit in there from the beginning on, quality also. That would really be a good thing. And I don’t try to kiss your feet here, I really mean it” (149:29).

Interaction required to be effective

Remarkably, increased interaction may not only be a desirable consequence of constraint introduction. Pertinent data suggests that it may be a necessary precondition for the constraint to be effective, meaning that manufacturability would indeed be enhanced by the constraints. “If I had a constraint, I’d always rail, are they too stupid to manufacture or what… I don’t care. I think you’d have to explain the big picture to them first, saying, if that takes 75 minutes longer to assemble, it’s gonna cost us that much money. But you have to know that first” (179:35). Trust in one single constraint value, calculated by a tool, is judged as being insufficient to create effective integration: “I don’t trust just modelling everything into one big simulation, it’s not going to be enough to get it into the heads. More than anything else, it’s a mindset topic, that I manage to arouse the product designer’s interest for manufacturing requirements” (138:1). For some informants, the value of the constraint itself lies more in serving as a trigger for discussion at the design-manufacturing interface. “Probably a platform, to convince the two departments to talk with each other, to bring them together” (141:35).

In a similar manner, interview participants emphasize that during their introduction, constraints should necessarily be accompanied by explanations and instructions. Simply “throwing them over the wall”, quoting the common accusation with regard to missing cross-functional integration, should be avoided for this potential method for enhanced integration as well. “If you show them the manufacturer’s view, then it has the potential to be really effective. Sure, if you only execute it in a hard way, if you just hold the gun against their heads… but if you don’t, it has the potential to bring them together” (179:40). On the question if he would be in favour of introducing constraints overall, after having been explained the general idea, an informant pointed towards the risk of constraints being perceived as just another hardly effective KPI: “I’d say we should do it. Maybe starting it initially in a project, but you should accompany it in way that ensures it doesn’t end in a KPI fetishism. Because often, you simply look at the KPI, it’s green, and if it’s green everything’s fine. But the problem is in between. If two departments show they’re green, the problem isn’t solved” (162:42).

Manufacturing encouraged to get involved

From the analysis of current coopetitive behaviour at the design-manufacturing interface, I learned that manufacturing is involved to a limited extent only in CarCo’s NPD. Reasons thereof are manifold, ranging from a lack of incentivization to become involved, up to other functions excluding them from respective activities. According to this study’s empirical findings, the introduction of constraints seems to bear the potential to enforce a stronger manufacturing involvement.

Informants indicated that focused discussions on manufacturability-related values and expressions such as MTM-based assembly time, which are part of the daily thought world of manufacturing, might encourage their involvement more as abstract product design models might be able to do. “I think it’s a fundamental thing that you try to assess it [the current product design, author’s note] from a realistic assembly time perspective, and try to cover the worker perspective. I believe it’s a good thing. And what’s good is that the manufacturer, he’s well acquainted with MTM and the line balancing, and with this method he might be more open to approach future processes from early onwards” (150:16). In addition to that, involving manufacturing from early on might encourage their engagement as well, as the following quote indicates: “In an early phase, manufacturing is still relatively open […], the people from production become angry quite quickly if it’s only about the question whether we can or cannot manufacture it, then they say we can’t do it, because the process is very error-prone. But if it’s about minimizing assembly time, I don’t see a problem, I think they’d be open and would cooperate here” (150:12).

Besides, the introduction of manufacturability constraints seems to enforce a certain degree of pressure on manufacturing to become involved; which some informants see as necessary for manufacturing to engage in NPD. “And it’s quite important, that manufacturing is not able to say that they haven’t been asked” (147:21). When asked for his opinion on who should define height and unit of the manufacturability constraint value, an interview participant stated the following: “It would be the right approach that production determines the value. And of course, then they’d be forced to cooperate, because they know it best” (149:24).

Focus is set to interaction

“Normally, a planner should know something like that [what the discussed constraint value consists of, author’s note], but of course he can’t know everything” (165:23). This quote expresses a common issue for cross-functional integration which had been identified in the first part of the study already. Due to the sheer complexity and multitude of topics that are dealt with in NPD, effective integration has to hit a narrow ridge. Being involved too little, such that cross-functional counterparts’ statements cannot be assessed or challenged, or being involved too much, in a way that consumes large parts of own time and effort. With regard to manufacturing’s involvement in this respect, the following statement describes this dilemma. “The manufacturer is very much focused on today, it’s in the nature of his work, and he has to take care of the parts that he has to deliver tomorrow. And there, it’s not about what’s happening in 2025. But he mustn’t close his eyes, saying he doesn’t care about that, because it won’t work like that either. But it’s very much depending on the topic, where [his involvement, author’s note] is worth it” (156:16).

The introduction of constraints might be able to serve as a focusing device to decide for which topics their involvement indeed might be worth it – the case study data is indicative hereof. As an example, when asked how he would start working if given a manufacturability constraint, an informant answered: “In the first moment, seeing which topics are present, and maybe then, clustering them. These topics, we’ll examine them correspondingly faster and deeper, going down to an operational level here, and screen it in much detail” (163:15). Pressure exerted by the constraint introduction is undoubtedly one of the underlying forces of such a prioritization. “If I don’t have pressure here, I’ll invest my time differently, where I’d maybe have more pressure. And I also invest less thinking effort, and move less” (157:47).

7.5.2 Impact on cooperative ability

Increased understanding and interest

After having run through the exploration of the constraint method, the author asked the informants if they would be in favour of introducing manufacturability constraints into their daily work at CarCo. One of them said: “I’d use it for sure. It’s one of the problems that we have today, that we have to look beyond our own nose. The product designer should know what happens in the assembly, if he designs something, and today, that doesn’t happen enough. What are the volumes we’re talking about with the new product generation, it’s 60 pieces in 60 minutes, so takt time has to be one minute. And this has to be the reference […], the stuff that I design has to be able to satisfy that” (149:17).

His statement is representative for one of the key strengths of the approach of constraint introduction that emerged from the empirical analysis: causing an increased interest for and understanding of the cross-functional counterpart.
As a frequently mentioned example of this notion, the scenario where an assembly time constraint is applied to a product designer's work and increases the designer's understanding of production may be referred to. Being asked how his understanding of the production would change with the constraint introduction, a product designer answered as follows: "Better, definitely. I assume, if I wouldn't have this value, I would maybe have over-engineered the design, I simply would not have cared for assembly time at all. So I would have taken more screws than clips fasteners, I wouldn't have had that in mind" (182:4).
Besides an increased understanding of the functional counterpart's requirements, mere transparency on their individual goals may contribute a lot to cross-functional understanding, as an interview participant's experience suggests: "So, if the two of us have two different goals, you want to go left, I want to go right. Together, we approach a crossing, but I don't know that you want to go left, and you don't know that I want to go right. Then we both will pull on the thing as if we were nuts. And in the case where, let's say, on the left side, 500€ lie on the floor, and on the right side 100€ […] Sure, in this case I'd say you give me 250€ and we both go your way, but I simply wouldn't be aware of it. These target agreements, they are – we're not talking of the personal targets, but the product targets – for me they're not transparent" (166:38).

Besides, the introduction of manufacturability constraints arouses interest in manufacturing by functions upstream in the NPD process. This is in so far interesting, as manufacturing was partially deemed as a less attractive, less interesting function in the first part of the analysis, potentially contributing to their requirements being less considered in NPD. Talking about the impact of constraint introduction on the cooperation with manufacturing, an informant articulated his opinion as follows: "I think that it would indeed raise interest [in manufacturing topics, author's note]. And that you would take care of it a bit – sure, everyone would, even if it's not his target constraint, see how his targets can be achieved […]. But if it's in there as a constraint, the interest would naturally grow" (161:7). Even beyond mere interaction with manufacturing, cross-functional counterparts might be encouraged to go to the shopfloor to assess manufacturing requirements with their own eyes. On the question how he would start working if given a manufacturability constraint, a designer stated: "I'd have a look at previous projects, and then I'd go to the manufacturer, and, with the help of time observations, have a look at how long something like that takes" (181:26).

Other informants believe that increased understanding and interest on the cross-functional counterpart might even grow into mutual respect: "I think they'd had a bit more respect of each other, such that, you think, well, the other one had quite a few thoughts on the matter, and now we'll just have the details optimized […]. That will simplify the whole work" (182:15). Transparency, and potentially resulting trust from this enhanced insight, are suggested as root causes. Being asked if the introduction of manufacturability constraints would weld product design together with production or rather infuriate them against each other, an informant answered: "Welds them together. And that's the interesting point. Because transparency, when the department really says, have a look at it, I know it's annoying. And if you really show them the manufacturer's perspective on it, then it can weld you together […]. It has the potential to make them weld together, saying that, well, the other one is an expert, too" (179:40).

Internalization of manufacturability

A foreseeable impact of constraint introduction is confirmed from the empirical analysis at CarCo: Upstream functions would take manufacturability requirements into consideration, when constraints enforce them to do so. However, case study informants suggest that consideration might even go one step further: Upstream functions may start to internalize manufacturability requirements. Internalization is likely to be more sustainable and deeper than mere consideration, which would probably cede as soon as the constraint is removed. According to case study informants, upstream functions' mindset may be altered, removing existing cross-functional barriers: "But that brings the two worlds [of production and design, author's note] together. I believe the mindset would change completely. If I'd not only have the product design task, but would have to always bear in mind that this thing also has to be manufactured - Because like that, you'll always have it presented right in front of your eyes" (182:24). Proactivity in considering manufacturability is mentioned as another sign of internalization: "I believe that he [product designer, author's note] would notice from early on, ok, what do I have to pay attention to, or what will production condemn me for, what do I have to take care of when handing the design over to production, what would they ask me first".

Other statements suggest that alignment efforts at the interface could be reduced in the long run, because stakeholders would learn to anticipate their cross-functional counterpart's concerns. "I think it would be reduced […]. If I've worked with my counterpart on an operational level in beforehand, then communication will be easier. Simply because I'll know, what I have to pay attention to" (182:11).

As part of the internalization process, case study informants seem to exhibit a risen interest in the consequences of upstream functions' actions on manufacturing. A product designer's statement sheds light on this presumption: "It would be useful if I had some guidance, some kind of sensitivity analysis, which product design or which component needs the most assembly time in manufacturing. At the moment I wouldn't know, how complex these differences are […]. Because actually, without that, I wouldn't be able to construe. At the beginning, some big rubbish would come out of my design, which I would have to entirely discard again. Because I wouldn't know that a clip takes longer than a plug. Thus, actually, I'd need an info how long takes what. At first, I'd need to gather that" (182:6).

Immediate feedback on constraint fulfilment important
Pounding as a prerequisite to achieve the improvements of cooperative ability from above, immediate feedback on constraint fulfilment seems to be an essential feature for constraints to become effective. Receiving an instantaneous notification on how constraint fulfilment changes for a modification in product or process design seems to be important for both constraint consideration and optimization. Being inquired on the suitability of pathways to bring manufacturability requirements to product design, a product design representative stated the following "It's all about the channel. If it's a PDF file, then of course it would be the worst conceivable solution. Then no one would react to that. But if there would be some tool to calculate the fulfilment of these assembly requirements automatically… It would have to be intuitive and playful, then you could introduce as many [constraints, author's note] as you like. Only, controlling and tracing these values should not produce any additional effort for the designer" (141:41). Non-immediate, ex-post feedback seems to be a source of discontent for the product designer, and risks not being considered when it is received only after the design is finished: "At the moment, it's like that, the product designer construes and only when he has finished the design, he gets feedback. Weight, manufacturing costs, eHPV [engineered hours per vehicle, a measure for production-ready design, author's note]. And that's only after his construction is finished. But what it actually should be, is that you have to get improvement suggestions all the time, such that feedback accompanies design. In a sense, you have to co-develop" (176:16).

Besides immediate feedback's importance for constraint consideration, it appears to have particular weight for constraint optimization. "It would be important, well, option 1, that's x minutes and y €, and it has a function of this and that. Then it would be interesting to see where the real pain threshold is […]. Generating options, you can do that super easily with that thing, and see how much you can get down, you'll try out an extreme option. So, generating quick options, that would be the solution" (166:17). Being able to compare and quickly alter options seems to be an important precondition for optimization with regard to a certain requirement. "The cool thing is that you can easily try things out. At some point, you'll start to optimize the thing yourself. You construe it, and I can't imagine that there's only one solution in the end, and then you think you're at a point where you could go left or right. And until now, you would have always gone left, because as a product designer, you'll follow the function. But now, if no big differences with regard to the function are there, and you don't see cost differences in your view, then you might more easily try the other path" (166:15).
Possibly, this response has been triggered by the empirical exploration conditions, which include a tool that is able to deliver this immediate feedback. Potential limitations

of data validity based on distortions from empirical exploration conditions will be discussed at a later point in the thesis at hand.

7.5.3 Impact on competition

Discussion on cross-functional optimum encouraged

In the first part of the case study analysis, a lack of competition on the cross-functional optimum was identified, induced by a dominance of upstream functions, surrounding conditions and avoidance of potentially conflicting discussions on the part of downstream functions. For the latter, the introduction of manufacturability constraints may provide a solution. When introducing manufacturability constraints to production planning or process design, they appear to be more encouraged to engage in discussions with their product design counterpart. “First, I’d look at the product. For example, maybe I could come down from five to four screws, I could set a clip instead of a screw, I could design a positioning assistance tool. Second, I’d discuss the degree of vertical integration, discussing with procurement […]. That’s the topic of product influencing, discussing with design and procurement. Then, I’d look at the process” (155:21). At its core, the motivation to engage in discussions with cross-functional counterparts may not only stem from the pressure, which is naturally exerted by a constraint. Instead, the existence of the constraint itself and its quantifiable nature seem to serve as legitimation to speak up and discuss with them. “I’d have the values earlier, and with them sound arguments to influence something [at product design, author’s note]. Not taking away from him the development function, but helping him to modify his design. It’s not that much more power for me […], but I can help him to reach his targets and I can also discuss his targets” (166:29).

Nevertheless, production planners or process designers at CarCo, both part of the production department from an organizational view, will first pull all levers that are accessible to them within their own department, before approaching product design. “I would first see where I can - which lever I can draw, without having to change something in the product design. Because if I had to fight in the product design teams with product design, and they would have to alter the entire design to make me save 20 minutes... Then, I would have to prepare a presentation, why do I want that, and I’d have to take care that the developers jump on that train, and if it’s not working, I’d have the same struggle again. Thus […] my first step would be to look for the quick wins” (168:12). In the case study data base, few statements mention this sequencing order as explicitly. For many, their tendency to optimize production-inherent levers first can be derived from the order of action that informants describe to engage in when dealing with a constraint: “I’d draw a value stream analysis, from the broad view to the details. Then I’d look at processes which are existent already, asking for expertise from the plants, asking other planners, and I’d get the assembly times out of the plants, of the processes that really match. It has to be detailed, it has to be an exact match, because just a little bit of a different technology has different, very different assembly times.

Then I'd jump into the value stream to identify exactly where I'm too slow […]." "And if you've asked everyone there, if you've taken out everything, and still wouldn't reach the value? If everyone says to you, with that product, it's not gonna be possible to get anything more out of it?" "Then I'd address the product and ask the product designer" (159:36). Alike the participant above, a significant number of informants begin discussing levers of process and production optimization before addressing product-related potentials.

Transparency on cross-functional optimum increased

As already alluded to above, the quantified nature of the explored constraints might serve as an argument in a discussion on the cross-functional optimum. Evidently, attributing numbers to the elusive notion of manufacturability fortifies its strength as an argument. "From a production planning point of view, you could underpin requirements significantly better, saying, look, you have 48 screws and 15 module connectors here. If we'd do it like this, we'd save 5 module connectors and 24 screws, so on hand we'd have savings in the material costs, and we'd have savings in the assembly time. I don't see the material costs here yet, but in the end I'd have a starting point where you can say, from an entrepreneurial, overall perspective, this is the right way to go. Here we should try to find a solution" (162:32). Comparability with other requirements, e.g. material cost minimization, allows weighing up manufacturability against other requirements to reach a cross-functional optimum. "When discussing with product design, get your numbers, data, facts. They prove that, what we are asking for, is the best offer for the overall optimum. With facts, you can convince them. If the topic overall optimum is not visible somehow, you have poor prospects to realize it in product design" (151:29).

Transparency on manufacturability might likewise be supportive of a systematic approach for its optimization. When asked for their actions and thinking, how they would deal with a constraint on assembly time or variable manufacturing costs, many interview participants described a structured approach based on the quantified basis of the constraint. "You'd probably have to allocate the 125 minutes to their respective components based on their complexity […]. In this manner, I'd distribute and in principle, I'd then start to think, which one of these costs me the most" (172:1). Unsurprisingly, pressure exerted from the constraint supports a systematic optimization effort by putting it higher up on the designer's priority list: "If I wouldn't have the constraint target, of course I'd put much less effort in to reduce these times. For me, the effort is increasing, as well as the alignment effort, naturally. But the constraint target would be quite useful, because otherwise, you'll always find something else to do, and it would remain 240 minutes of assembly time or maybe go down to 230, but certainly not to 180" (157:37).

Moreover, transparency and pressure together may also discourage from introducing buffers into design or planning. Relevant quotes suggest such behaviour for several functions. To begin with, a product designer described his experience and a possible behaviour change induced by constraints: “Why do I put the screws, what’s their design-related value-add, and how much security buffer did I maybe plan in. So now, I’d maybe have a factor of three, and it’ll be fine and it will hold - it’s like that pretty much. Because for design, screws are a simple thing, but they didn’t have the assembly aspect in focus. And now I’d look at that, seeing, well, the screws have the highest impact, then I would of course […] now try to reduce the screws to a minimum” (164:20). For production representatives, a similar tendency was observable. The following production planner’s statement is indicative hereof: “It’s all dependent on the kind of analysis that you do, do you grant a longer way time [time designated for walking distances on the shopfloor, author’s note] or an additional walk – of course as a planner, you can eliminate all of that, because you have to achieve the 20 minutes target, which means that you plan to the edge” (168:15).

Risk of overemphasizing constraint

As discussed above, constraints may place requirements, which tended to be neglected by product design, more into their focus. However, there is a risk of this movement overshooting its goal: If the requirement which is introduced as a constraint overshadows all other requirements, the cross-functional optimum is in menace. When asked which drawbacks he sees from the constraint introduction, an informant provided the following description of this potential problem: “Well, that he comes into a target conflict at some point, because he can’t do it all. It’s always a question of what I put first. What do you want to achieve, if you say you want to save construction space, it’s gonna be smaller, then it’s gonna be more complex with regard to the geometry, and then variable manufacturing costs are going to rise. The wider you pull apart the target range, the more difficult it will be to land in the middle of it. And then you’d have to think about what the second priority is instead.” (156:27). Typical trade-offs to requirements, which might be neglected by imposing manufacturability as a constraint, are product quality, material costs, investment levels and even flexibility, due to potential violations of platform requirements: “Looking at the assembly time permanently […], it could be that, because of that, I lose flexibility. It could be, if I only take the cheapest fasteners, that I cut down the platform architecture. That [will happen, author’s note] if I only trim towards time. If, from the start, I take care to only design it simply, but maybe not extendable to succeeding models and so on, there I could lose flexibility” (182:25).

Employees confronted with the task to fulfil a manufacturability constraint might be seduced to work around the constraint in a way that certainly does not contribute to the overall optimum, as the following quote suggests: “If I only look at variable manufacturing costs, it’s absolutely absurd because it’s just a shift of value creation, because I'd produce more externally, because that reduces my variable manufacturing costs. If I'd only consider variable manufacturing costs, I'll simply increase automatization endlessly, whatever the costs, but we'll have manufacturing costs reduced. This means, looking at the variable manufacturing costs alone makes little sense" (160:22).

Certainly, for the cross-functional optimum to be increased, other parameters relevant to it have to be transparent, as well. Only then can manufacturability be weighed up against these to find the cross-functional optimum. At CarCo, other parameters, such as functionality or security concerns, are transparently laid out, therefore an increase of transparency of manufacturability will increase transparency on the cross-functional optimum. For other cases, this may be different.

7.5.4 Increased design effort

While the analysis of the impact of constraint introduction on coopetitive behaviour hitherto followed the coopetition dimensions, there is one empirically observed second-order theme that the introduction of constraints leads to which does not fit into this structure. The case study data base suggests increased efforts on the part of product design, with empirical details provided in the following.

Additional effort for design functions

"At first, this is an additional effort for product design" (149:39). This product designer's spontaneous reaction to the introduction of manufacturability constraints is repeated by several informants. The enlargement of design's usual requirement target range by manufacturability-related topics is perceived as an additional effort. "For the product designer, it's principally an additional effort, because actually he has reached his goals, because assembly time is usually not a goal for product design. Indirectly maybe, because it causes production costs. But now it would be, and of course, an additional target value is always annoying" (171:33). Some designers are likely to react with discontent: "I know some product designers who would be 100% against it. Because they say, I do the design, and the rest is production planning's task" (162:27).

A possible result of additional design efforts caused by constraint introduction is a prolongation of the overall NPD process, as described by the following informant: "It would be critical if it would force it up too much, if people would need too much time to design, and wouldn't simply hand out the component design. That's a general problem, because before [constraint introduction, author's note] you didn't have it. Then, the component was done when it was done. But if I see it now, it's just like a bachelor or master thesis which you want to adjust more and more, and you're unable to stop. And there's the enormous risk that you only optimize for assembly time minutes without looking how long it has taken you to design" (182:22). Indisputably, any prolongation of the NPD process constitutes a critical risk, as a short time-to-market is a well-proven NPD success factor.

7.6 The moderating impact of constraint types

During the exploration of manufacturability constraints case study informants at CarCo provided detailed insight on whether and why they liked some constraint types better than others. With some of them, the author was able to explore all three types in comparison in different scenarios, while others, due to their functional background, were focused on one or two types. Overall, every constraint was empirically explored equally often, using the same qualitative methodology as in other parts of this case study and building on the tool-centered translation of theoretical constraint types into CarCo's empirical environment. The examined constraint type for all empirical explorations was tracked simultaneously with every attributed first order concept. Hence, the author is able to draw conclusions on the constraint type's moderating impact on the relationship between constraint introduction and coopetitive behaviour. In the following, respective qualities of each examined constraint type will be outlined. Underlying dynamics that have been described by interview participants to account for the respective moderating impact will likewise be presented.

Before diving into individual dynamics, a summary of the overall assessment of the three constraint types is provided: number of fasteners (number/unit), assembly time (minutes/unit), variable manufacturing costs (€/unit). Illustration 47 provides the respective mentioning frequency of central second-order themes for coopetition dimensions as described above. The results suggest that *assembly time* receives informants' highest affirmation, strengthening all three dimensions of coopetition. The constraint *variable manufacturing costs* likewise obtains positive feedback for all dimensions, although increased understanding and interest is less pronounced. Apparently, constraining variable manufacturing costs fosters cooperative ability to a lesser extent than assembly time. *Number of fasteners*, as the constraint type with the closest relation to the product, is attributed with a slight increase of transparency on the cross-functional optimum only, while it receives only few mentionings of increased cooperative intensity or ability.
Notably, informants seem to reflect this overall assessment of coopetition dimensions when being explicitly asked for their preferred constraint type. The overall appeal (displayed in the right column of illustration 47) is strongest for the constraint assembly time, which likewise experiences highest affirmation of fostering coopetition dimensions. Similarly, number of fasteners is declared rarely as the most appealing constraint type; neither has it been repeatedly attributed to enhance coopetitive behaviour.

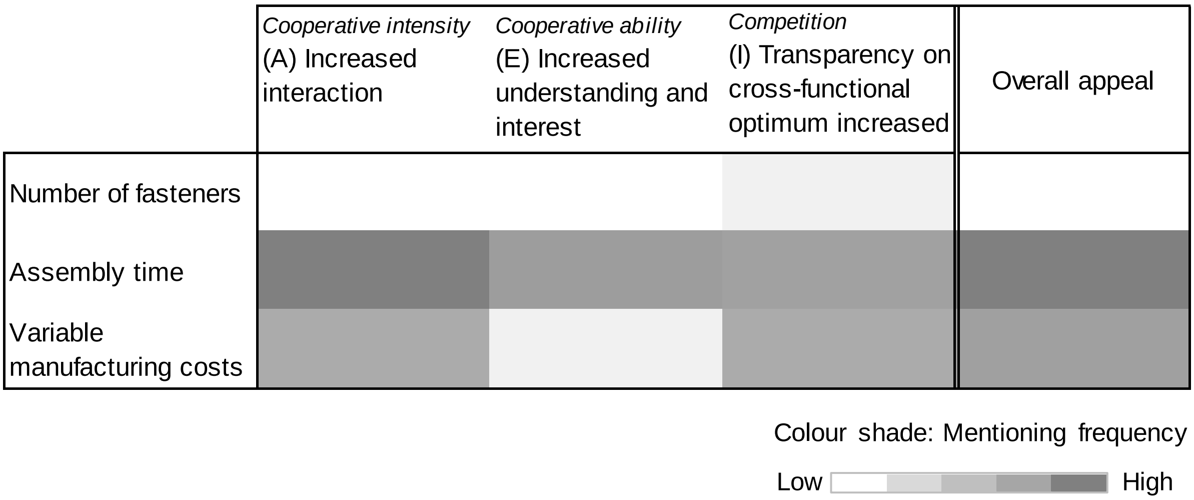

Illustration 47: Overview of constraint type-related differences in impact on coopetitive behaviour

Possible explanations for the overall assessment will be discussed by assessing informants' respective statements in the following. Relevant data is analysed based on the emergent structure shown in illustration 48.

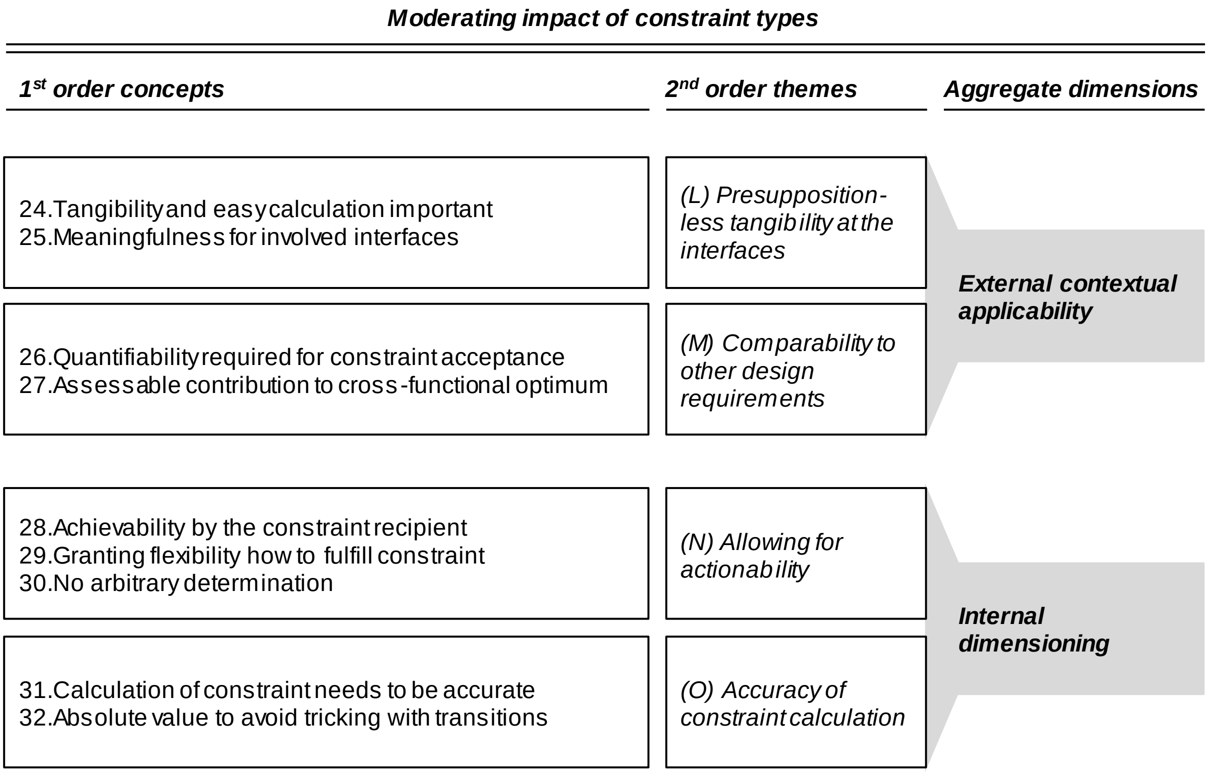

Illustration 48: Moderating impact of constraint types

7.6.1 External contextual applicability

Two emerging second-order themes that relate to the external contextual applicability seem to be important aspects of constraint types. In this respect, external contextual applicability means that advantageousness of a certain constraint type may differ depending on the external context in which the constraint finds application.

As one of the second-order themes, presuppositionless tangibility of introduced constraints (L) has emerged. Logically, it is dependent on the background of the respective interface partners. Manufacturing representatives may judge other measures to be tangible than marketing representatives may do. Second, the comparability to other design requirements (M) certainly differs from product to product. While monetary constraints might often be a feasible option when looking for comparable constraints, other industrial conditions may require other constraints that satisfy this aspect.

Presuppositionless tangibility at the interfaces

When asked why he prefers variable manufacturing costs as a constraint, an informant provided the following explanation: “Personally, I find it more tangible. The value with a € at the end” (157:39). Apparently, it is important that involved employees are able to relate to a constraint measure and to cognitively comprehend it. As the following quote suggests, this may be valid for both constraint recipients and their cross-functional counterparts: “That’s why I like the € goal, it makes it tangible. Everyone can easily conceive €. I can give a € target, saying here’s the deal, variable manufacturing costs are well known in the company, everyone knows what’s in there. There are these [names committees on variable manufacturing costs, author’s note], everyone knows it. That’s why in principle I’d consider it as the right value, quantify it in € and the consequences will be clear to everyone” (172:27). Other interview participants opt in favour for the assembly time constraint for similar reasons. From their perspective, calculation of variable manufacturing costs, as it is done at CarCo, is complicated and difficult to see through, as the following dialogue shows: “I think that time is a good factor. It’s the plain assembly time, and I believe that assembly time gives you a good sense […]. With a time factor, you know more quickly what to do with it than with a money factor. Because with a money factor, you first have to convert, what does it mean in minutes, then you have to know the hourly wage and all of that by heart… With minutes, you have a real value that everyone knows how to handle. That’s why, my feeling is, minutes would therefore be more valuable” (154:21).

Notably, tangibility may be evaluated differently by individuals with different functional backgrounds. As an example, while assembly time is likely to be quite tangible for production-related functions, product designers may have problems relating to it, as this designer’s statement suggests: “What I could imagine to be a main conflict, is that this assembly time doesn’t mean anything to me, and I wouldn’t know what comes next. And as a first experience, it would be a black box for me” (182:26). A similar observation refers to manufacturing having difficulties relating to product-related measures. An informant was confronted with an assembly time constraint at first, leading him to strongly engage manufacturing to help him fulfil the constraint. When the constraint was changed to numbers of fasteners, he would not engage manufacturing anymore, but simply figure solutions out for himself. Reasons provided thereof were that manufacturing is not used to deal with construction-related choices of fasteners, therefore not being able to help him with that constraint (154:11).

Meaningfulness for involved interfaces and tangibility of the constraint type appear to have an impact on both cooperative intensity and cooperative ability. A lack of these features may discourage cross-functional counterparts to engage in an interaction. Presuppositional constraint types, which require a certain level of understanding or calculation effort from functional partners to assess potential consequences on their work, may impede a discussion at eye level, therefore entailing negative consequences on cross-functional integration that have been identified before.

In the empirical setting of CarCo, both number of fasteners and assembly time seem to be disadvantageous constraint types for reasons of tangibility for either design or manufacturing. Therefore, variable manufacturing costs may be seen as the preferred constraint type from the perspective of the CarCo case.

From this identified aspect arises an important question for further research: Which constraints satisfy the external contextual applicability in a way that all functional participants are able and willing to accept them?

Comparability to other design requirements

Comparability of the constraint type to other design requirements appears to be of significant importance for the acceptance of the constraint itself. “Experience tells us that, if it’s justifiable with numbers, data, facts, why it is like that, then they [product design, author’s note] are willing to support it. We once had a case of quality issues, with the interlocking. There, we went together with product design to the manufacturer. And the quality specialists presented information on which defects they’ve had in comparable products, and what it means in terms of rework or defect volume. Then it was decided to do a monetary assessment to see if the design of a new plug would pay off […]. And it turned out to be a big lever, of course it’s always a bit of reading the crystal ball, but the facts and numbers were accepted and the designer said ok. And they did it” (151:28). At CarCo, monetary measurements appear to have the most powerful strength as an argument in cross-functional discussion. This is likely owing to the almost universal comparability of financial units. A constraint type such as manufacturing costs can be challenged against most other design requirements. Being asked what would contribute to his identification with the constraint, an informant answered correspondingly: “The overall amount. Bucks. Saving money. The total sum. Is this only to make the production department’s KPI’s green, or is hard cash, quality or something like that. What’s in it for me, or is it only that [names a production department manager, author’s note] is able to go to his boss to say look at that, awesome stuff” (179:36).

Another feature of constraint types appears to be important, which is related to quantifiability as described above: the assessable contribution to the cross-functional optimum. Naturally, this suggests quantifiable measures in general and financial

measures in particular. Informants at CarCo have recognized that the quantifiable contribution to the overall optimum can well be utilized to convince cross-functional counterparts of considering functional design requirements. Being asked what she would do if the product designer would refuse to make a design change that would bring down the assembly time, an interview participant proposed the following argumentation: “Costs: 10 minutes times 100.000 pieces, that’s much more than a month of [product design’s, author’s note] work. So, expressing it as the overall time or overall money, one way or the other, if you multiply it with volumes, even if it’s only a second, two or three, then it will be coming out of this, that a design change is indeed reasonable. And usually, they will acknowledge that” (157:35).
During the exploration, informants were asked to conceive new constraint types that they believe to be most effective beyond the three proposed types. Often, such unprompted propositions resume the motive of quantifiability: “Actually, the boss should not introduce a manufacturing cost target, but an overall cost target. Because then you can figure out, if you give it into manufacturing costs or material costs. And if you buy finished modules, it’s material costs, and the other things rather go into manufacturing costs […]. If I take minutes or time, if it’s Euros or minutes, doesn’t matter in the first place, it’s basically the same, just converted with a multiplier. But I believe you have to look at the overall […] optimum” (172:10).

Comparability to other design requirements is likely to moderate constraints’ impact on the competition dimension in particular. If a chosen constraint type hardly allows for quantification in general and comparability to other design requirements in particular, it is likely to discourage rigorous cross-functional discussions on the cross-functional optimum. In the case of CarCo, variable manufacturing costs is concluded as the best choice for this aspect; with assembly time following closely due to its easy convertibility into costs: “Time is money, and variable manufacturing costs are nothing else than labour costs” (158:52).

7.6.2 Internal dimensioning

Two second-order themes emerge from the exploration of the moderating impact of constraint types that seem to be less dependent on external contextual aspects. Allowing for actionability and ensuring calculation accuracy are requirements towards the constraint type which appear to be transferable to other contextual environments, as they address the constraint’s internal construction. They will be explained in more detail in the following.

Allowing for actionability

In the theoretical research body on constraints there is much discussion on constraints’ nature as limitators or openers of a solution space. Interestingly, this discussion is resumed by informants during the empirical analysis. While accepting and even advocating the introduction of constraints in a majority of cases, informants attach importance to design the constraints in a way that grants them actionability. To be more concrete, they strive to be able to actively work with the constraint, let it guide their solution finding process and being able to fulfil it lastly.

"So there's one large condition in this company, targets that we set ourselves should be realistic and achievable. It's one of our principal values, and I would like to take this up here as well" (169:28). Achievability of constraint satisfaction by its recipient is repeatedly mentioned. "It should be well substantiated […], he should somehow be able to – how should I say, it shouldn't be too far from reality, this constraint. Thus, the organization who generates it, should be in some way familiar with the product concept and with the production concept" (169:27).

Besides achievability, informants prefer constraint types that grant flexibility with regard to how the constraint is to be fulfilled. Explaining which constraint type he likes better, assembly time or fasteners, an informant stated the following: "So, the 48 minutes of course provide me, as a product designer, freedom in a sense of how I can achieve these 48 minutes. If I directly break this down to the details, then you almost already predefine the solution […]. That's why, saying 48 minutes, if this is explained to me why I need 48 minutes, but then I'm granted the freedom, if I reduce the screws by 90% but have to set 3 clips for it […]. So it would be somehow the designer's freedom, and in the end we'll get to a technically better product, than we would have by just applying a flat watering can principle, that we have to take out 20% of all fasteners" (168:9). Being granted the flexibility of pursuing different options to fulfil the constraint seems to foster the motivation to optimize the design, as the following quote suggests. An informant reasoned about which constraint type he prefers, assembly time or fasteners: "I'd see the time as the more important one. Because if I say I save that and that much material costs if I take only one module connector, and if I have extreme constraints here, it would take a lot of flexibility from me. And then I had the feeling that I wouldn't enjoy designing anymore, because you would feel the limits more. You'd always think, oh man, I have only ten module connectors, why can't I take one more module connector and omit five screws for it. So, I want to be rather pushed by the time, and not losing the felt freedom" (182:32).

There seems to be consensus in the case study database that a constraint which is determined on an arbitrary basis will not find acceptance. Being asked how the constraint should be designed such that it fosters his identification, an interview participants stated that "it should be plausible. It must not be determined by just rolling the dices. It has to be some kind of understandable target value" (149:35). The constraint type number of fasteners in particular appears to be vulnerable to the allegation of arbitrariness, as it cannot be easily related to the overarching corporate goals or the product's overall optimum. During the exploration of a scenario involving the fastener constraint, the following statement occurred: "It would be interesting to see where the value comes from, and if it really has to be exactly these eleven module connectors. Why does it have to be eleven, and not twelve or fifteen? And where's the connection, ok I manage to do it with eleven but for this I'd need 60 screws instead of 48, did I do that rightly? The connection would interest me in any case" (154:13).

In an attempt to relate informants' desire for an actionable constraint to the impact on coopetitive behaviour, requirement internalization is assumed to play a central role. Much of the identified tendency to internalize manufacturability constraints stems from mutual understanding and interest. Only if both awareness and acknowledgement of cross-functional requirements are given, they can be internalized. Mere awareness of a seemingly arbitrary constraint is likely to be rejected by the constraint recipient, and not internalized. Likewise, an arbitrary constraint does not provide the transparency on the cross-functional optimum that a plausible constraint would grant. Besides, a non-achievable constraint lacks the motivational spur to inspire constraint fulfilment.
In summary, if a constraint allows for actionability as described above, it likely will have a positive moderating impact on both cooperative ability and competition.

In the case study's empirical setting, variable manufacturing costs and assembly time fulfil this feature; on the contrary, number of fasteners is prone to be perceived as an arbitrary measure and leaves less flexibility on how to achieve the constraint.

Accuracy of constraint calculation
"The fundamental condition is that it's correct by 100%, and that there aren't any parallel structures where it says well, it says 56 minutes here, but with the 48 nuts I actually know that this is calculated too high. It really has to be strictly specified" (182:50). Repeatedly, informants emphasize the importance of constraints being calculated in an accurate and traceable manner. Certainly, reasons for this claim are harmful consequences on cross-functional interaction if the value is found to be incorrect. "A precondition is of course, that it is well thought through. Maybe you can […] define it with some kind of standard, whatever it is, thoroughly defining these values, maybe if there are some kind of macros or something like that, that these calculations are really clean, because much is based on them. If the production planner relies on them, and the calculation is wonderful but in the end it actually calculates some kind of bullshit, then you'll have even more problems because you cannot straighten it out anymore. That would be my demand, to ensure that" (165:29).

To strengthen accuracy and unambiguity of the constraint value, informants recommend setting an absolute value instead of a relative one: The latter would require transition calculations, reducing traceability and giving room for biased computation of the value. When asked why he would prefer an absolute value as a constraint value, an informant answered: "Because otherwise, everyone would fake that. That would be a big classic […]. It wouldn't be possible with an absolute value" (172:15). This answer relates to the identified risk of smokescreening and non-transparency at the cross-functional interface, which is facilitated by complexity and holds up competition for the cross-functional optimum.

In summary, accuracy of the constraint calculation, whether ensured through a reliable calculation method that used the growing availability of data in the design process or through an unambiguous absolute value, appears to contribute to cooperative ability. If it is correct, it enhances cross-functional understanding. Non-accuracy, on the other hand, can quickly destroy trust at the cross-functional interface and thereby contribute to the emergence of solid functional walls. Moreover, an unambiguous absolute value enhances transparency at the cross-functional interface, again fostering competition on the cross-functional optimum.
Looking at the examined constraint types at CarCo, assembly time and number of fasteners would be most consistent with the identified accuracy requirement. Variable manufacturing costs, with their complex calculation method, bears the highest risk of errors and ambiguity.

Summarizing the findings for the constraint type, this leaves assembly time as the best constraint out of the three tested ones for the CarCo case. Beyond those three, other constraints likely exist which fulfil the identified aspects even better. This will be proposed as an avenue for further research.

7.7 The moderating impact of organizational embedding

Based on the general morphological analysis as explained above, the author was able to develop a morphological field for the organizational embedding of constraints. All identified variables come out of the interactive discussion. Evidently, as it was developed based on the interaction with case study informants, the morphological field comprises of dimensions and values that are relevant to the studied empirical environment.
Due to German-speaking informants, the morphological field was originally developed in German language. The herein presented version is translated.

Illustration 49 depicts the morphological field, with dimensions P to X and respective values in 33 to 66. As an overview, the field touches upon the motivation to fulfil the constraint (see dimensions of constraint rigidity, relative prioritization towards existing design requirements or incentivization), recipients (functions or hierarchy levels), fulfilment tracking (hierarchy and frequency) and introduction (point in time during NPD and introduction mode). Dimensions, values and participants' rationale will be explained in the following. Furthermore, the illustration sheds light on which values within one dimension are favoured by the participants based on their respective mentioning frequency.

(P) Constraint rigidity			
33. Voluntary reference value	34. Binding committee decision	35. Formal organizational objective	36. Stage-gate criterion

(Q) Priority with regard to existing design requirements			
37. Non-binding	38. Inferior	39. Equivalent	40. Superior

(R) Incentivization		
41. Fulfillment monitoring without direct consequences	42. Fulfilment incentivized like organizational objective	43.Fulfilment incentive monetarily

(S) Recipient hierarchy level			
44. Individual employee (0)	45. Group manager (+1)	46. Department manager (+2)	47. Project manager (+1/+2)

(T) Recipient function			
48. Product design	49. Production planning / Process design	50. Manufacturing	51. Strategic product management

(U) Fulfilment tracking hierarchy		
52. Operational level (0)	53. Group level (+1)	54. Department level (+2)

(V) Fulfilment tracking frequency				
55. Less than monthly	56. Monthly	57. Bi-weekly	58. Weekly	59. More than weekly

(W) Introduction point in time during NPD				
60. Strategy phase	61. Initial phase	62. Product concept phase	63. Series development	64. Series production

(X) Introduction mode in existing enterprise	
65. Gradual introduction within existing system	66. Disruptive introduction

Colour shade: Mentioning frequency

Low – High

Illustration 49: Favoured values within organizational embedding dimensions

Constraint rigidity

Informants proposed various ways of exerting pressure on constraint fulfilment: Should the manufacturability constraint be invariably fulfilled, with passing a stage-gate being subject to constraint fulfilment (P36)? Alternatively, should it rather be introduced as a reference value, stating a potential optimum, but which does not need necessary fulfilment (P33)? Otherwise, should constraint rigidity be somewhere in between these two extremes, e.g. resemble a binding committee decision (P34) or a formal organizational objective (P35)?

Overall, most participants argued for a rather rigid constraint fulfilment, with formal organizational objective (P35) being mentioned most frequently and stage-gate criterion (P36) right next to it. “If you want to get things moving, you have to introduce it hard” (167:36). Apparently, this is related to CarCo’s usual business posturing: “If you introduce it too weak, then I’d say it’s like a KPI which isn’t monitored, no one abides to that either. If you don’t track the KPI, it is simply not a KPI anymore. I just try to put myself into the real CarCo world” (164:24). In particular if the constraint reflects a monetary value, a rigid implementation is well appreciated by informants, as it directly contributes to the overall optimum: “I tend towards demanding this quite rigidly. With that background […], there’s more behind this 180€ than just manufacturing the whole thing. There maybe is a market behind that, a sales target and all of that. In the end, it all boils down to this topic, and some things stand or fall with it. That’s why for me, it’s a rigid value” (163:40).

Moreover, organizational pressure resulting from a rigid demand for constraint fulfilment seems to support overall acceptance of the constraint. “If it’s a requirement that comes down from above, and coming down from above meaning that it has been recognized that it’s a very important topic, then they will absolutely attempt to abide by it […]. But otherwise, if there’s no such requirement, then these are demands that they will definitely not accept, because they would feel limited in their creative freedom” (151:27).

Possible drawbacks from a rigid constraint introduction comprise a potential disregard of the overall optimum. Again, informants feel that a too rigid introduction may lead to over-emphasis of the constraint value, while others may become deprioritized beyond the equilibrate optimum: “I’d say an organizational objective, because I believe if you set the value too rigidly, everyone runs towards this value and the other targets get neglected. So you optimize only to this point, and everything else falls off the table” (164:23). Moreover, high constraint rigidity, e.g. as a stage-gate criterion, risks to block progress in the NPD process. “If we demand it this rigidly, as a stage-gate criterion, we’ll just obstruct ourselves” (153:28).

A number of informants judge that rigidity of constraint fulfilment should be made dependent on the respective NPD phase, suggesting that it should increase in rigidity the closer target agreement is approached: “I’d say it depends on the phase, what you enforce in the organization. Even severely, depending on how much uncertainty there is. So in an early phase I'd rather go into the direction of a committee decision. And if you really know what's possible, you would have to look at sensitivities, when you really know what goes on in the system, then I'd go into this direction [pointing at stage-gate criterion, author's note]" (166:32).

When discussing constraint rigidity's impact on coopetitive behaviour, it seems likely that a balanced constraint rigidity may help to stimulate competition: If the constraint is introduced too rigidly, there is a risk of over-emphasizing the constraint dimension at the cost of other requirements, hence impeding a balanced discussion on the overall optimum. If constraint fulfilment is not enforced consequently enough, however, the constraint is at risk of perceiving only insufficient recognition.

Priority with regard to existing design requirements

Naturally, the introduction of manufacturability constraints will need to co-exist with other requirements towards product design, such as functionality, material costs or weight requirements. Should the introduced constraint be considered superior (Q40), equivalent (Q39) or inferior (Q38) to these other requirements, or even be considered as a non-binding reference (Q37)? "In the end, what matters, is the bottom line, the overall result counts. That's why I'm heading towards equivalent, because I have to look at all sides and manufacturing costs are only one aspect of the overall enterprise, and I need to have the overarching overview" (163:41). The majority of case study participants shared this view. In particular, when constraints can be measured financially and hence can easily be weighed up against other financial requirements, equivalence is suggested on a broad basis. "Principally, € are € and that's why it should be equivalent" (172:18). Again, informants argued based on the overall optimum, which requires different requirements to be weighed up equally against each other: often, requirements have interdependencies with each other, partially with inversely proportional relationships: "I'd say equivalent in any case. Between automatization and investment, it's always manufacturing costs, that's virtually inversely proportional. That's why we have to optimize it on the same level in any case" (156:43).

On the other side, a few participants argued for superiority with regard to other requirements, reasoning that manufacturability has little chance to withstand an equivalent comparison with material costs. Probably, this opinion is strongly driven by the empirical reality of the examined case, in which material costs constitute a much more powerful cost lever and therefore often are prioritized compared to manufacturing-related costs. Other informants built on the same aspect but drew a different conclusion, arguing that a manufacturability constraint should be considered inferior to other requirements. "Inferior, because other levers to save costs are simply bigger" (167:37).

With regard to its impact on coopetitive behaviour, priority with regard to existing design requirements appears to have significant influence on cross-functional competition. The majority of informants consented on the essential importance of the equivalence of the constraint dimension with other design requirements, in order to encourage transparency on and optimization towards the global optimum.

Incentivization

Interview participants discussed options for incentivizing constraint fulfilment that range from monetary incentives to simple monitoring without direct consequences. Incentivization similar to an organizational objective (R42) was also included as a middle option; at CarCo, this would be an indirect monetary incentive for managers, because performance bonuses are subject to objective fulfilment.

No clear picture evolved among participants when discussing which option to favour. A slight tendency towards non-monetary incentivization was visible, with simple monitoring emerging as the most frequently mentioned value. A frequent argumentation in this regard was a potential distortion of the overall optimum caused by an overly emphasized optimization of the constraint value at other requirements' cost. Pointing at fulfilment monitoring without direct consequences (R41), an informant reasoned as follows: "Because a bonus system is the worst existing system. Everyone just works for his bonus, and not for the overall view anymore" (158:58). Similarly, an informant mentioned that "I consider a monetary incentive as the wrong path here. It possibly leads to a situation, where you attach importance to the one thing, and what happens at the other side may fall off the table. That's the wrong incentive" (162:36). Another reason provided against monetary incentives (R43) was that it might induce moral hazard of constraint recipients in achieving constraint fulfilment at the cost of other requirements: "I'd maybe see that I take one screw out, even if I'd be responsible to keep the battery watertight. But I'd say perfect, I'll get my €1000 and I'll have changed departments in one year anyway" (166:34).

Furthermore, informants viewed a monetary incentive as potentially demotivating, as in early phases of NPD the achievability of constraint fulfilment is hard to assess. "Bonus in no way, you cannot punish someone if you give him a target, of which you do not yet know if it's realistic" (179:42).

Other interview participants found that the incentivization intensity should depend on the project phase, and possibly even on the ambition level of the introduced constraint, as the following quote suggests: "It depends a bit on how ambitious the target value is in itself […]. If you take a reference product and tighten this value by a not-so insignificant percentage value, I'd be quite a friend of a certain incentive. If you simply say, derive a value and it's only about realizing it, then it would certainly be only monitoring or something like it" (169:25).

On the other hand, the absence of a direct incentivization may lead to non-consideration of the objective. Actors in large-scale industrial enterprises tend to know well how to make initiatives come to nothing if they are not sufficiently implanted, as the following quote indicates: “There are so many topics, if I really want to prioritize them, and really want to introduce them, then I really have to incentivize it.” “What would happen if you wouldn’t?” “It would be waited out. I think that happens quite often. You would simply wait, and hope that it’s not there anymore next year” (182:36).

Like other organizational embedding dimensions before, incentivization seems to have a significant impact on the competition dimension. Similar to constraint rigidity, incentivization may have a balancing impact. If incentivization is strongly pronounced, there is a risk of over-emphasizing the constraint dimension, entailing negligence of other requirements at the cost of the overall optimum. If, however, incentivization is insufficient to encourage constraint consideration, the constraint may fall off the table and the constraint introduction becomes a matter of sitting out for constraint recipients.

Recipient hierarchy level

With regard to the hierarchical level of the constraint recipient, there was astonishing consensus among informants: The majority argued for a hierarchical level one or two stages above the operational level. Besides, almost everyone agreed that the recipient should be someone in the project organization as opposed to a manager in the line organization. Pointing at the project manager (S47), an informant described his reasoning: “He’s responsible for the production system and the value stream that is linked to it. So he’s virtually the custodian of the entire thing, who also needs to keep a project in balance. I have several component areas, and all are somehow interlinked based on the minutes [minutes of assembly time, author’s note], and I need to balance these costs somehow. So he’s the one who needs to adopt a global approach to it” (162:37).

A certain hierarchical power is thought to be supportive, if not indeed necessary to assert oneself at the interface. “The group manager, maybe he can really demand something from the interface partners, an individual employee can’t actually do this” (156:44).

Surprisingly, informants repeatedly argued against the operational level (S44) as constraint recipient, dreading that respective employees would neglect the topic. “I’d make the department manager responsible. Then you’d know – because an individual employee, forget about that, because he’d argue that some other reason was even more important, there surely will be some reason, and then it falls off the table” (181:30).

While the large majority agreed with a management position in the project organization being the right recipient level, a few informants recommended that the hierarchical level should not be too high, as required detail comprehension might be insufficiently

available in these levels. “I believe that the project manager is too far away, he wouldn’t go into detail that much” (182:38)
With regard to the impact of the recipient hierarchy level on coopetitive behaviour, there seems to be a relationship to cooperative ability. If contextual dynamics make cooperation dependent on a formal process, as it has been identified for the CarCo case, the recipient hierarchy level is recommended to be well above the operational level. Hierarchical pressure is necessary to exert sufficient influence on the cross-functional counterpart to be able to impose the constraint.
In addition to cooperative ability, the competition dimension seems to be of relevance, too. Case study participants fear that an operational-level constraint recipient, due to her detail knowledge, is able to deliberately distort the constraint calculation, thus decreasing transparency on the overall optimum. Moreover, informants suggest that constraint recipients should be a member of the project organization as opposed to the line organization, as these are likely to have an overarching view on the cross-functional optimum, thus accommodating cross-functional competition.

Recipient function

With regard to the functional home of the constraint recipient, there was surprising dissonance among interview participants. Both product design (T48) and production planning / process design (T49), both production representatives that are close to product design at CarCo, found frequent mentioning. Interestingly, respondents often argued for a shared responsibility of design and production representatives. “Production should be responsible as well in any case. Because if it’s only product design, they don’t care. It has to be a common responsibility. Either they drown together, or they both swim” (149:42). Reasoning for this shared accountability is often provided on grounds of required input efforts to fulfil the constraint. “I’d say production and design. Because if they don’t talk to each other, it won’t work […]. They both have levers, design and production, that’s why it would be wrong to just look at design, but it would also be wrong to just look at production” (179:43).

Manufacturing, however, was seldom mentioned, not even in the context of a shared responsibility. When asked who would be the ideal recipient function, an interview participant answered as follows: “All together. But there must be a superior one in the lead […]. Design is somehow always the master clock. Making manufacturing responsible is nonsense for the NPD, because they have to concentrate on the series phase. So I’d say design and production planning” (156:45).

In a few data points, strategic product management was considered to be able of performing a parenthesis function to design and production representatives, and therefore should be involved as recipient function. “I’d say it must be strategic project management, because design and production would fight each other anyway. For example, if you would make production responsible, design would say again that he doesn't care. Then these cockfights would start again" (159:43).

In summary, shared responsibility between design and production representatives seems to impact all coopetition dimensions. To begin with, cooperative intensity may be insufficiently stimulated if the functional responsibility for constraint fulfilment is attributed to only a single function. With regard to cooperative ability, separate responsibilities would not be sufficiently able to encourage cross-functional counterparts' inputs in different scenarios: When product design is given a manufacturability constraint, production representatives would likely not provide sufficient input and support for product design to fulfil the constraint, if they are not taken into co-responsibility. In another exemplary scenario, when production planning is given a manufacturability constraint, they would likely be unable to exert sufficient influence on design to achieve constraint fulfilment if the latter is not made co-responsible.

Fulfilment tracking hierarchy

"I'd hang the whole thing up at a higher hierarchy, because they should have the sum of all targets, the overall optimum in their view. And if only the operational level looks at it, then they'd only consider their own goal but not if it's synchronous to the other goals which the project has […]. They [management, author's note] have to decide, because they have the overall view and optimally know the sum of all designers, with one of them having his focus on the screwing, and another one on the material quantity, and the third one on weight and they can decide where the optimum is" (164:27).

This quote is representative for the majority of discussions during the exploration of the following dimension: the hierarchical level by which constraint fulfilment should be traced and evaluated. Most informants agreed on the importance of a certain hierarchical power being involved; managers were ascribed of being able to keep a better overarching perspective than the operational level. Department managers (U54) and group managers (U53), who are two, respectively one, level above the operational base at CarCo, were favoured in the discussion.

Other informants did not attach great importance to the hierarchical level of the fulfilment tracking committee. Instead, they emphasized the composition of this committee to be essential; representation of all interfaces accordingly needs to be ensured. "The main thing is how the project team is made up, and that's indeed a point. Of course, someone from product design has to be in there, and here it becomes important. It's not much of an help if a project manager is in there to moderate a bit, there really should be a production planner, a process designer and a product designer who really discuss on this level, and maybe also someone from procurement" (169:26).

Again, informants' suggestion of hierarchical power being necessary to trace constraint fulfilment can be interpreted as a reflection on the competition dimension: If tracking would be carried out by the operational level, critical discussion on the cross-functional optimum would hardly be encouraged.
In addition to this possible impact on competition, composition of the tracking committee seems to have an impact on cooperative intensity. If the committee comprises all relevant functional interface partners, cross-functional communication and exchange would naturally be facilitated.

Fulfilment tracking frequency

The frequency of tracing and discussing constraint fulfilment appeared to be a matter of controversial discussion among informants. While there seems to be a slight tendency towards a rather frequent tracking schedule, e.g. weekly (V58) or even more than weekly (V59), overall opinions did not converge to a consensus. Instead, the case study data base has many records of answers that postulate a certain dependency on situational factors. Most often, dependency on the NPD project phase was attributed by informants. "In the beginning more often, there you might have to discuss the topic quite intensively, in the beginning you might still question if often, if it's an achievable goal, what is the feedback from different design areas. And then you could let things run for a bit until it has advanced a bit in the series development, and then review it. So in the beginning, weekly in every case" (170:38).
Other respondents found the tracking frequency to be dependent on product design complexity and the resulting iteration loop duration. "Depending on how long iteration loops are. If it's a component which is construed within half an hour, then I could talk monthly about it. So I'd make it dependent on the time it needs to design" (182:42).

Suggestions for a low tracking frequency were provided on grounds of avoiding a "steering frenzy". Constraints should be trusted to be internalized soon after their introduction, such that frequent tracking becomes more and more obsolete: "You are not told every week, or more than every week, that it has to be functionally working either, or that it has to be cheap - at some point you should know this for yourself, hopefully. I think that once a month should be sufficient, as long as it's communicated and discussed" (161:20).

With regard to fulfilment tracking frequency's impact on coopetitive behaviour, there seems to be a relationship with cooperative ability. If situational dynamics entail dependence of cooperation on formal processes, as it is in the CarCo case, tracking frequency needs to be high in order for the constraint to be effective.
In addition to that, informants warned against creating a steering frenzy if tracking frequency is too high. Perceived inefficiency of formal relations, as being part of the formal aspects of cooperative intensity, may therefore be increased.

Introduction point in time during NPD

When exploring which NPD phase might be best suited to introduce the constraint to its respective recipient, there appeared to be consensus on early phases. Pointing at the initial phase (W61), which is the second phase out of five before SOP at CarCo, a respondent explained: “Quite early indeed. It’s always the point that, shutting the stable when the horse has bolted, when the concepts are finished already, then you don’t have any lever anymore. They tell us every to-do and discuss, but we don’t have a chance anymore, if the concept direction is set. Therefore, early” (163:45). A few informants even proposed the very early strategy phase (W60) as the right point in time, some mentioned the later product concept phase (W62) and a few respondents argued in favour of series development (W63) or even series production (W64). Fundamentally, however, the broad majority of CarCo informants voted in favour of the initial phase.

Most reasoning drew on a similar argumentative base. The later the constraint is introduced into the process, the less room for action enabling to fulfil it remains. “It’s important that they get it early enough, such that they still have scope for action. It shouldn’t be as it is now for us, that everything is already decided but you still have to achieve your goals” (159:42).
In particular, if the constraint is to encourage an innovative solution for fulfilment, early introduction becomes outright necessary: “In the strategy phase, I would be able to already figure out if I reach the target with the normal incremental improvements, for example just taking a larger screw […]. Or do I need something completely new which is not yet done, that I wouldn’t take a screw but would weld it. I would have to figure that out already early, because in the concept phase it could already be too late, then I could only recourse to topics which lie already in the drawer” (164:29).

However, a few interview participants feared that a very early introduction may result in an unrealistic, and thus demotivating, constraint value. “Working towards a concrete value of 17€ does not make much sense much earlier, because the product might still change so strongly in an early phase, that my work would be pointless. If I can break it down to 17€ by then, there may be a spurious accuracy in that given scenario, which may be gone in three weeks after 50 product changes have occurred. So rather in the concept phase, maybe towards target agreement” (168:22). Obviously, this contradicts the other notion of an early introduction enabling innovative solutions to fulfil the constraint.

Introducing the constraints in early NPD phases allows cross-functional discussion to take place without design pushing back cross-functional requirements, because their late introduction would cause additional efforts and require additional product validation. Therefore, the integration point in time is assumed to be an important lever on the competition dimension of cross-functional coopetition.

Introduction mode in existing enterprise

While the point in time during a project is one important aspect to consider, the introduction mode is certainly another one. Case study informants discussed whether a disruptive introduction, making a clear differentiation to existing channels of transferring manufacturability requirements into product design, was preferable over a gradual introduction, which successively integrates manufacturability constraints into NPD. The following quote summarizes this discussion, eventually coming to the conclusion that sheer size and complexity of CarCo's processes suggest taking a disruptive approach: "If you really want to create a dogma shift, you have to work disruptively sometimes. Then you really have to say, we'll do that in this project. And talk about lessons learned afterwards. But if you let it slowly flow into the existing process, then it would probably always being pushed away […]. So either you say, you make everything new for this project, this goes up and this goes down, and let's get started. Or you introduce it successively in small steps, so others have to give off more and more, and you get a bit more. But I think this would be more difficult […]. We're too big for that, the whole company is too complex for that, that you could just introduce something step by step" (156:48).

Among interview participants, there seemed to be a tendency towards such a disruptive introduction. Similar to the quote above, many participants argued based on entrenched processes and mindsets within CarCo, requiring to take a sudden approach in order to be able to overcome deep-rooted behaviour. As an example, a production planner talked about problems that may occur when introducing the constraint method gradually within the existing system. At the core of his quote is the learned expectation, that a target will be gradually tightened with the advancing NPD. If constraints are introduced without a palpable differentiation, it risks to be seen as just another target which cannot be trusted, as it might also be tightened in the course of the NPD, therefore requiring the same buffer-logic to achieve constraint fulfilment which is already applied to many of CarCo's targets. "It can only be a reference value, because otherwise you would have to have another value for every stage-gate […] If you would say 45 minutes for SOP, it would be 55 minutes at stage-gate one and maybe 50 minutes for stage-gate two" (171:37).

On the contrary, a number of informants argue that a gradual introduction mode would be preferable in order to be able to thoroughly test and evaluate the new method. "You could start a pilot project, and calculate it, maybe for a sub-project and try it and see if it works, and if you see advantages you can roll it out to the big picture" (163:47).

Most of the argumentation in favour of a disruptive introduction of the constraint method is based on self-sustaining structures which would resist a gradual change. In such structures, a disruptive introduction mode may be able to improve cooperative ability by removing or reducing deeply entrenched functional structures. Therefore, this dimension of organizational embedding may well impact cooperative ability.

7.8 Manufacturability constraints' impact on creativity

Until this point in the case study, the exploration of manufacturability constraints and its moderators was motivated by the overarching question of how to improve cross-functional integration by impacting coopetitive behaviour. For the research question to be examined in the following chapter, this overarching field is left to examine constraints' impact on creativity instead. This can be justified by the persisting academic dispute in constraint research about constraints improving or impeding creativity. Likewise, the broader context of NPD success, for which creativity plays a role just as cross-functional integration does, substantiates the following examination.

According to the qualitative methodology of the case study at hand, interview participants were asked open questions on creativity after having explored the introduction of constraints with them. Surprisingly, answers converged towards a few similar areas, such that five emerging second-order themes could be derived. They can be positioned along a spectrum stretching between positive and negative impacts on creativity. Illustration 50 displays the second-order themes allocated to their aggregate dimensions: positive impact on creativity, contingent impact on creativity and negative impact on creativity.

To provide an overarching impression of informants' opinion, second-order themes are displayed together with their mentioning frequency. It shows that a majority of interview participants attributed a positive impact on creativity (30 mentionings overall), with much fewer mentionings of a negative impact (4 mentionings). Those informants who said that it depended, be it on the NPD phase or the granted scope of action, make up a noteworthy share (14 mentionings) as well.
In the following, individual second-order themes will be explained in detail.

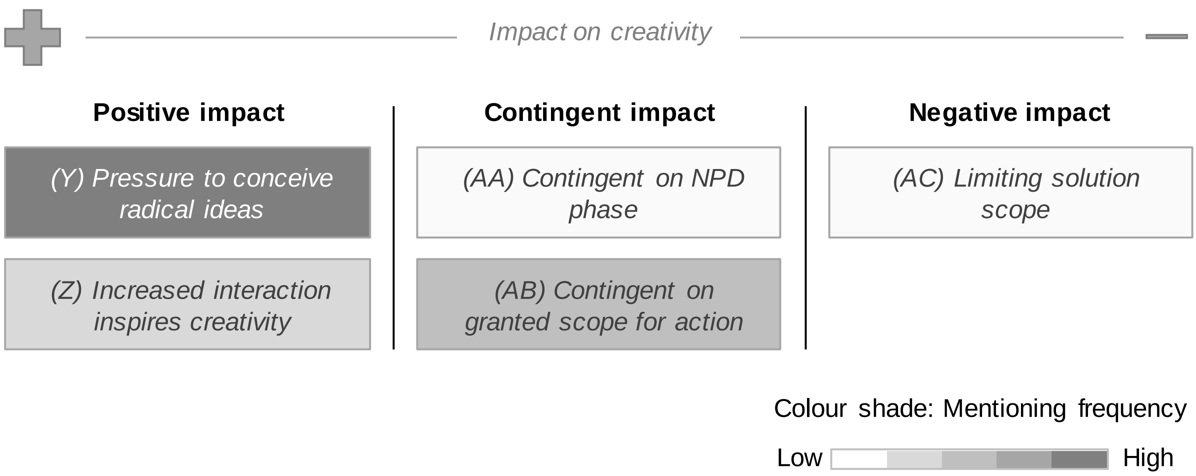

Illustration 50: Mentioning frequency of aggregate dimensions of impact on creativity

Pressure to conceive radical ideas

"I think more creative […]. Because necessity is the mother of invention" (157:46). The quote above is representative for many others within the most frequently pronounced second-order concept. Informants are convinced that pressure to fulfil the manufacturability constraint forces constraint recipients to go new ways and find innovative solutions. "He has to become more creative, because he has to accommodate an additional requirement which he didn't consider before, and this will force him to think outside the box" (167:40). Similarly, another informant provided a specific example in the manufacturability context: "I think it would expand it [creativity, author's note], so you would become more creative. Because otherwise, I'd say you put three screws in it, or maybe a bit different, but now I'd think ok, I know how long screws - they take a long time, what else could you do, maybe gluing or other things which I never had thought of. Thus, I believe there would be more creative approaches in any case" (161:21).

In order to be able to exert this creativity-stimulating pressure, the constraint seemingly needs to be ambitious: "You only start to really give some thought in such cases, if you receive targets which are not necessarily easy to solve" (164:31).

Increased interaction inspires creativity

Informants named another driving force of creativity which is excited by the introduction of constraints: inspiration for new ideas coming from an exchange with other individuals. Accordingly, constraints cause increased interaction, for example with cross-functional counterparts, which may help to create new ideas. "Foster it [creativity, author's note]. Because I have to go figure it out. Just going on doesn't quite work anymore. I have to find new ways, have to give some thought, trying it out like this, maybe some new materials… And I have to go talk to people, also talking with production, and that's not bad. Therefore, it would foster it" (179:45).

Certainly, the drive to look for other person's input and ideas is related to pressure exerted from constraints as discussed above. "If I'm at my wits' end, then I'd go and ask colleagues, or ask process design, what you could do differently" (164:21). The resulting effect, however, is another one, but also one with a positive outcome on creativity. In this case, pressure would encourage the constraint recipient to reach out to other people's input, providing her with new ideas for creative solutions to constraint fulfilment.

Contingent on NPD phase

Timeliness has been a repeated topic of different research aspects within this case study. For creativity, it seems to play an important role as well. As the following quote indicates, constraint introduction in early phases may well stimulate creativity, but not anymore in later phases. Even more so, introduction in late phases risks to bring about frustration when an ambitious constraint enforces going new ways, but the solution scope is restricted within narrow limits of an existing design. "I'd say neutral, because

you could say that it would encourage creativity, if you already have a specific goal, and within this scope it can indeed encourage creativity. But too much creativity could also be counterproductive, if you set the goals much later, and before that you were free as a bird and now you have to make it fit somewhere into this" (150:19).
In a similar manner, another informant described how constraints would encourage creative problem solving focusing on essential use considerations. He emphasized that an early introduction in NPD is essential to enable this stimulation. "I think that he'd become more creative […], because you'd be inclined more to think about alternative concepts. Because you'd realize early that the standard path doesn't work, and he doesn't figure that out only late, when it's too late already maybe, but ideally already early. And he'd sit down and think fundamentally, do I need to screw this at all, or do I need a lid at all. I'd start like that, ok if I'd have to screw on a lid, thinking quite revolutionary, do I actually need a lid? If I'd be a product designer, then this would be the next logical step. We build some kind of block, and it has to be waterproof and fit into the assembly space in the car. And I have the high voltage battery, and I have the underbody, so it would actually be logical to say that I take the underbody as a lid of the high voltage battery" (164:30).

Contingent on granted scope for action

Frequently, informants attributed dependency on grated scope for action to a potentially positive impact of constraints on creativity. According to them, constraints can only induce creativity if frame conditions allow for a certain degree of freedom in problem solving. "If it encourages or impedes creativity? In my view, it's encouraging if he has the freedom to use these things to the full limit. If they say to him, design it to 56, you'll get a tap on the head if it's 57, and if it's 55 I take away your bonus. Then it's impeding, then you'll have a system which restricts you even further" (166:41). Naturally, this freedom or scope for action is associated to the above category of contingency on NPD phase: If constraint introduction occurs in an early phase, more scope for action is given; in late phases solution space is too narrow to allow for creativity. While the above category, however, only refers to the timely dimension as a possible limitation of scope for action, informants go beyond this dimension in many of their statements. Corporate target setting or product-related system limitations may constitute creativity-impeding limitations of scope for action, as well.

In addition to that, informants mentioned that transparency on the scope for action is another required precondition for creativity to emerge. Some kind of trigger or starting point, making it clear to the constraint recipient that she is granted a large scope for action, is accordingly required to induce creativity. "It is such and such with creativity; at least I know this from my old department, you have to put forward a shift in thinking at least once to make something start. For example, if you say, how would a car without wheels look like […]. Such that the colleague would start to think, ok, how could this be done completely different?" (165:18).

Limiting solution scope

Besides informant opinions that attributed a positive or contingent impact of constraints on creativity, there were a few interview participants that clearly designated a negative impact on creativity. “For me, it would limit me as a production planner, if I get this constraint. Because it’s something else that I have to consider” (181:32).
Often, these informants put forward an argumentation which reproaches constraints to limit the solution space and therefore restrict creativity. “Rather less creative. For example, there was a workshop recently, and I intentionally decided not go there, because I wanted to give them the maximum possible solution space, and these and those possibilities are there, and decide only later which possibilities would be the best ones for production. Otherwise, they’d be already limited from the beginning” (171:41). Quite surprisingly, advocates for this negative impact of constraints on creativity are a minority when mentioning frequency within the case study data base is taken as a measure.

Overall, the introduction of the constraint increases creativity. The participants’ mentioning frequency towards this category is indicative hereof. Only if the NPD phase and the granted scope of action are chosen unsuitably will constraint introduction risk to reduce creativity for the majority of involved participants.

7.9 Summary and theoretical model

7.9.1 Summary of analysis

In the previous chapters, the impact of the introduction of manufacturability constraints on cross-functional coopetition was analysed with regard to different aspects. Starting off from the analysis of general dynamics caused by the constraint introduction, the moderating impact of constraint types and dimensions of organizational embedding was analysed, and finally the impact of constraints on creativity in general.

As a general summary of findings, it can be concluded that the introduction of manufacturability constraints has a positive impact on all three dimensions of cross-functional coopetition, and therefore cross-functional integration in general. With regard to cooperative intensity, it has the potential to increase interaction (A) even at non-adjacent interfaces, encourages to involve manufacturing in NPD (C) and sets focus to topics in a way that allows for prioritization of cross-functional discussions (D). Concerning cooperative ability, constraint introduction facilitates increased understanding and interest at the design-manufacturing interface (E) and fosters the internalization of manufacturability with design functions (F). In reference to cross-functional competition, manufacturability constraints encourage a cross-functional discussion on the overall optimum (H) and help to increase transparency on where the cross-functional optimum lies in the first place (I).

However, these positive impacts are dependent on several side conditions, whose absence may either reduce a positive impact or obstruct it in its entirety. In this sense, interaction is required for the constraint to be effective (B), immediate feedback on constraint fulfilment is important for both constraint consideration and optimization (G) and finally, there is a risk of over-emphasizing the constraint dimension at the cost of other design requirements (J).
Moreover, the introduction of manufacturability constraints likewise entails a potential negative impact. Based on additional efforts for product design, which are caused by the constraint introduction, the design process as a whole may be prolonged, with resulting negative consequences on time-to-market for any given NPD project (K).

Notably, for case study participants from CarCo, possible advantages from the introduction of constraints appear to outweigh potential negatives. Illustration 51 summarizes interview participants’ answers when asked for their overarching opinion on the introduction of manufacturability constraints, after they have explored different constraint introduction scenarios.

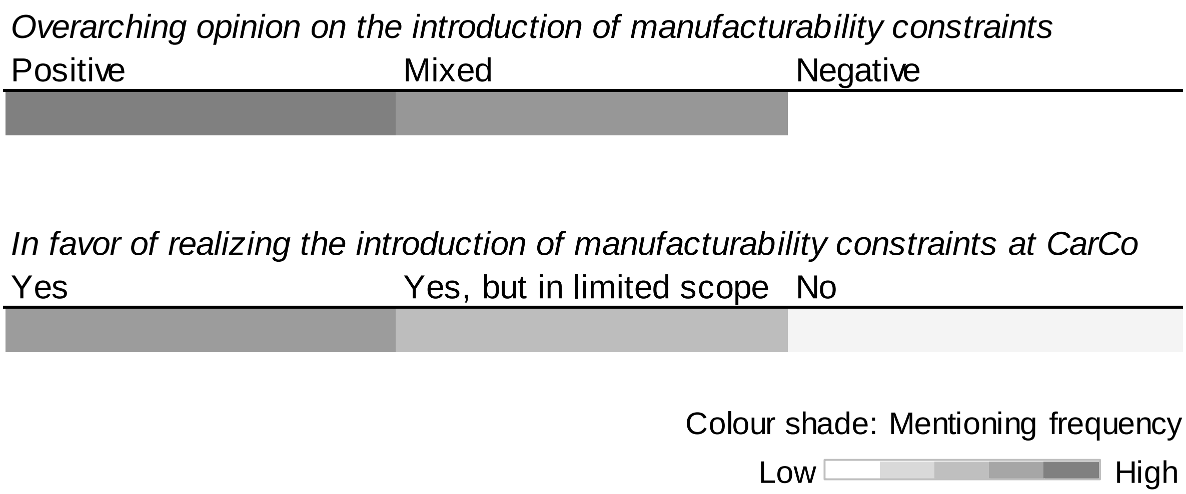

Illustration 51: Overarching participant feedback on constraint introduction

Besides side conditions identified from the analysis of constraint introduction in general, the analysis of the moderating impact of constraint type and organizational embedding yielded a multitude of other moderating factors.
With regard to the constraint type, this includes different aspects on the external contextual applicability such as tangibility (L) and comparability (M), as well as on the internal dimensioning of the constraint, such as allowing for actionability (N) and ensuring calculation accuracy (O). Constraint types were evaluated more positively by CarCo interview participants, if they fulfilled these respective dimensions. Among the three explored constraints, assembly time (minutes/unit), as the constraint type with a medium abstraction level from the product, received highest appeal. As a close follower, variable manufacturing costs (€/unit) were also highly estimated by interview

participants. Number of fasteners (number/unit), as the constraint type with the lowest abstraction level from the product, was rather unpopular in the CarCo exploration.
Concerning organizational embedding, the morphological analysis performed with interview participants yielded nine dimensions with two to five values, respectively. For the CarCo setting, a rather hard constraint rigidity (P) was considered most favourable, as well as an equivalent consideration of the constraint compared to other design requirements (Q). Monetary incentivization was rejected (R) in favour of mere fulfilment monitoring. With regard to recipient hierarchy level (S), the project management level, one or two levels above the operational level, was suggested. As the functional recipient (T), informants recommended product design, production representatives or the latter functions' shared responsibility. Considering fulfilment tracking, participants viewed department level hierarchy levels (U) and more than weekly tracking frequency (V) as most favourable. Constraints are to be introduced in early phases of NPD (W) right after strategic considerations have been concluded, and a disruptive introduction within an existing enterprise is to be favoured over a gradual approach (X).

Considering the analysis of manufacturability constraints' impact on creativity, participants' opinions converged on a positive impact based on pressure to conceive radical ideas (Y) and creativity-spurring inspiration through increased interaction (Z). Very few participants argued for a negative impact on creativity, with their argument focusing on a limited solution space (AC). In between, however, there was a significant number of respondents arguing for a contingent impact direction, with the impact depending on either the NPD phase (AA) or the granted scope for action (AB).

In summary, the introduction of manufacturability constraints seems to have a positive impact on both cross-functional coopetition and creativity. It may, however, have a negative impact on time-to-market due to increased design effort.
Furthermore, the positive impact is dependent on a multitude of different aspects that include the moderating impacts of constraint type and organizational embedding. Inherent relationships within this pool of moderating aspects will be illuminated in more detail in the following.

7.9.2 Theoretical model

When taking an overarching view across all moderating or contingency-inducing aspects that have been brought to light with regard to very different questions of the previous analyses, which includes (B), (G), (J), (L)-(O), (P)-(X), (AA) and (AB), there seem to be content-related overlaps and similarities. To name an example, the original second-order themes of comparability to other design requirements (M) and equivalence with regard to other design requirements (Q) stem from different backgrounds and describe the moderating impact of different objects, namely constraint type and organizational embedding. However, they point at the very same

purpose, namely comparability of the constraint dimension to other design requirements in order to optimize for the cross-functional optimum.
Building on such relationships, a structured analysis was performed of all moderating and contingency-inducing aspects that were identified as second-order themes during the analysis of manufacturability constraint introduction. As a result from the analysis, which is provided in detail in the following, eight overarching moderating factors were found. They all include a moderating impact based on the constraint type or the organizational embedding, in four instances even both of them, and likewise includes contingency factors derived from other aspects of constraint introduction.

Notably, it seems that neither constraint type nor organizational embedding have a direct moderating impact, as opposed to the author's initial hypothesis. Instead, there appear to be mediating factors involved, which comprise different constraint characteristics and which have a direct moderating impact on the examined relationship. These characteristics, the eight overarching moderators as described above, determine the constraint's overall quality. Therefore, their joint impact is denominated constraint quality in the following. The findings suggest that constraint type and organizational embedding, on the other hand, have a direct impact on constraint quality, either simultaneously or individually. With regard to the above example, the constraint quality characteristic *comparability* may be achieved by both, by choosing a quantifiable constraint type such as €/unit or by choosing an organizational embedding that ensures equivalent consideration of the constraint dimension with other design requirements, e.g. though simultaneous weighing up of all requirements in one steering committee. Therefore, the characteristics of constraint quality assume a mediating role for the impact of constraint type and organizational embedding on coopetitive behaviour or creativity.

Table 9 summarizes the structured analysis, naming samples from the CarCo case study for exemplary moderating impacts.

Structured derivation of constraint quality characteristics moderating the impact of manufacturability constraints				
Character-istics of constraint quality	**Moderated coopetition dimension / creativity**	**Under-lying second-order theme**	**Moderating impact of constraint type (case study examples)**	**Moderating impact of organizational embedding (case study examples)**
Inducing interaction	Cooperative intensity	(B), (T), (U)		• Constraint introduction accompanied by explanations • Shared functional responsibility as constraint recipient • Cross-functional composition of fulfilment tracking committee
Tangibility	Cooperative ability	(L)	• Uncomplicated constraint calculation • Meaningfulness of constraint for involved interfaces	
Actionability	Cooperative ability, creativity	(N), (W), (AA), (AB)	• Achievable constraint value • Solution flexibility how to fulfil constraint • No arbitrary determination of constraint value	• Constraint introduction in early NPD phase • Introduction with explicit mentioning of scope for action • Corporate target-setting allowing for flexibility on constraint fulfilment
Accuracy	Cooperative ability	(O), (S)	• Accurate calculation of constraint value • Absolute constraint value	• Hierarchically high constraint recipient to avoid distorting details
Disruptive introduction	Cooperative ability	(X)		• Disruptive introduction mode
Providing immediate feedback	Cooperative ability	(G)	• Uncomplicated constraint calculation	• Tool-supported constraint allowing for real-time calculation of constraint fulfilment
Compara-bility	Competition	(M), (Q)	• Quantifiable constraint • Comparable with other design requirements regarding contribution to overall optimum	• Equivalent evaluation of constraint with regard to other design requirements
Balancing constraint importance	Competition	(J), (P), (R), (S), (T)		• Incentivization balancing constraint consideration and over-emphasis • Constraint rigidity balan-cing constraint consid-eration, over-emphasis • Constraint recipient (function and hierarchy) accountable to pursue cross-functional optimum, e.g. project manager or shared functional responsibility

Table 9: Structured derivation of constraint quality characteristics

Accordingly, each characteristic and its roots in the analysis will be explained in the following.

Inducing interaction is based on a prerequisite for effective constraint introduction (B), requiring that constraints should serve as a trigger for discussion at the cross-functional interface and not simply be thrown over the wall without explanations. Two organizational embedding dimensions take the same line. With regard to the recipient function (T), many informants argued for shared functional responsibility as they are convinced that this forces functions to talk with each other, an essential requirement for integration. Considering fulfilment tracking hierarchy (U), informants repeatedly mentioned the importance of the composition of the tracking committee, which is ought to consist of all involved functions in order to make them interact with each other. Naturally, this characteristic impacts the coopetitive intensity dimension.

Tangibility is based on the second-order theme (L) and includes meaningfulness of the constraint type for involved interfaces and easy value derivation, such that the constraint value can be easily calculated and comprehended by all involved functions. It mainly concerns the cooperative ability dimension, as a lack of tangibility would discourage cross-functional counterparts' interest in the constraint and in the functional requirement it represents, impeding internalization and mutual understanding.

Actionability involves different underlying second-order themes that empower the constraint recipient with the flexibility and ability required to fulfil the constraint. In reference to theme (N), this includes achievability of the constraint value and the related avoidance of an arbitrary value determination. In addition, the constraint recipient needs to be provided with a certain flexibility on how to fulfil the constraint. If the solution is already predetermined by the constraint, such as in the case of the fastener constraint type, or scope for action is narrow for any other reason, actionability is not given. Second-order themes (W) and (AA) suggest the introduction of the constraint during an early NPD phase, as in later phases scope for action becomes more and more narrow. (AB) refers to other factors that could possibly limit scope for action, such as governance, product-related or system-related limitations. Actionability moderates the impact on cooperative ability, as a lack thereof impedes the motivation to fulfil the constraint, therefore encumbering internalization and understanding of the constraint. Moreover, it impacts creativity, as scope for action and early introduction have been identified as contingency factors for creativity.

Accuracy builds largely on (O), which includes the reliably accurate calculation of the constraint value and the suggestion to take an absolute value in order to avoid potential non-transparency in using transition bridges for relative values, where information asymmetry could lead to moral hazard. Informants' discussion on the organizational embedding dimension of the recipient hierarchy level (S) is related to the latter:

Respondents argued that the hierarchical level should be rather high, because only operational levels would be aware of all details to a sufficient degree such that information asymmetry could be used to their advantage at the cost of the constraint accuracy. Since an accurate value enhances cross-functional understanding and a lack thereof potentially destroys trust at the interface, accuracy concerns the cooperative ability dimension.

Disruptive introduction stems from the introduction mode in the existing enterprise (X), which many case study informants recommended to be disruptive to be able to break through entrenched functional structures. In a gradual introduction, those functional structures would otherwise constantly undermine constraint consideration. The disruptive introduction characteristic therefore concerns the cooperative ability dimension of cross-functional coopetition.

Providing immediate feedback builds on second-order theme (G), which indicates that immediate feedback on the constraint fulfilment after a design modification is necessary for both constraint consideration and constraint optimization. Again, uncomplicated constraint calculation would facilitate providing immediate feedback. Alternatively, a tool-supported constraint embedding, as it was explored in the CarCo case study, would enable immediate feedback. As this characteristic helps to generate a better understanding of consequences on the respective cross-functional counterpart, immediate feedback influences the cooperative ability dimension.

Comparability stems from the second-order themes (M) and (Q). Both themes advocate equivalent comparisons of the constraint dimension to other design requirements in order to optimize for the cross-functional optimum. This can either be achieved by a quantifiable nature of the constraint type or any other form that allows to assess a constraint's contribution to the overall optimum. Alternatively, mechanisms of organizational embedding, e.g. governance- or system-related features, could enforce direct comparisons of the constraint dimension with other design requirements. As it facilitates open competition between different functional requirements, comparability relates to the competition dimension of coopetitive behaviour.

Balancing constraint importance includes several second-order themes which require to seek a balance between the constraint not being considered and the constraint being over-emphasized at the cost of other design requirements (J). Different dimensions of organizational embedding allow to introduce such a balance, e.g. by fostering motivation for constraint consideration in a subtle way that avoids over-emphasis, such as through constraint rigidity (P) and incentivization (R). Choosing an appropriate recipient hierarchy level (S) and recipient function (T), which bear accountability for the overall optimum, allows to achieve balance of constraint importance, too. Because balancing constraint importance allows to critically pursue the cross-functional optimum, it contributes to the competition dimension.

Illustration 52 depicts all characteristics of constraint quality and their respective impact on coopetition dimensions and creativity. It graphically shows how each characteristic mediates the impact of constraint type, organizational embedding or their joint impact.

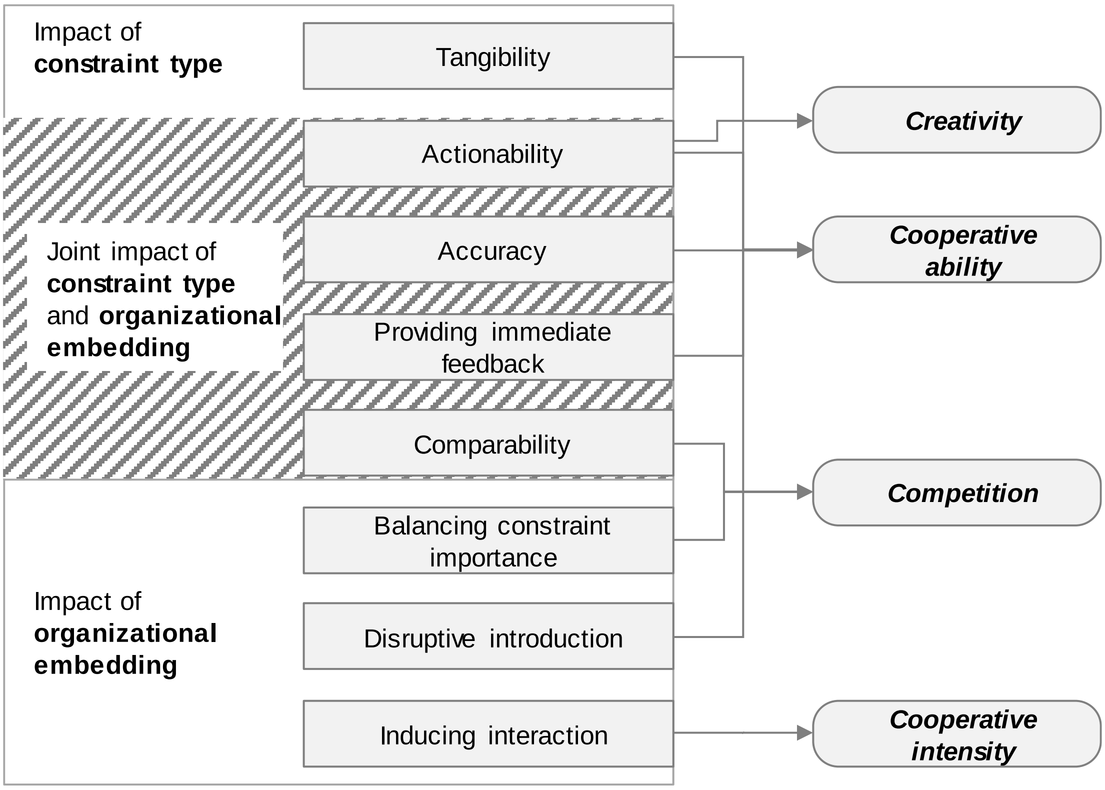

Illustration 52: Impact relationships of constraint quality characteristics

In a simplified illustration of the identified relationships, as depicted in illustration 53, the findings are summarized. The assumed moderating impact of constraint type and organizational embedding does not directly influence the relationship between constraint introduction and coopetitive behaviour. There is an overarching moderator, denominated constraint quality, which moderates the impact of constraint introduction on coopetitive behaviour. Constraint type and organizational embedding, in turn, have an impact on constraint quality. Notably, the impact of constraint introduction on creativity seems likewise impacted by constraint quality. Therefore, though being unable to empirically underpin this hypothesis, the author assumes that constraint quality impacts the relationship of constraint introduction on time-to-market alike.

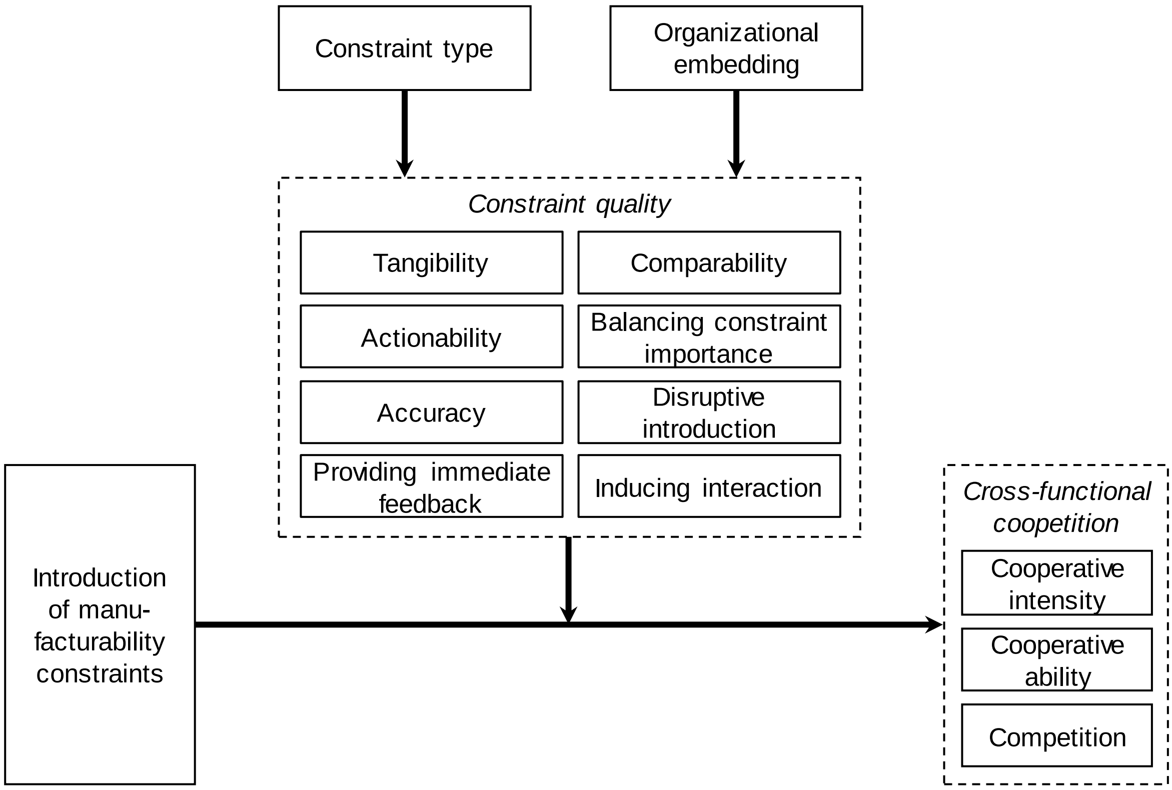

Illustration 53: The moderating impact of constraint quality

In search of an overarching theoretical model, this study's findings provide the author with reason to assume that the introduction of manufacturability constraints has a positive impact on cross-functional integration at the design-manufacturing interface as well as on creativity, with a potential negative impact on time-to-market. These impact relationships are moderated by constraint quality, which itself is determined by constraint type and organizational embedding. Constraint quality can only be determined in accordance with a specific setting. For example, the characteristic tangibility is dependent on industry- and product-related prior experience of the involved participants.

The author is not able to take statements on neither strength nor complementarity nor substitutability of this moderating impact. There is a chance, that each of the individual characteristics of constraint quality represents a knock-out criterion, meaning that if one characteristic is not given, the positive impact of constraint introduction on cross-functional integration disappears. Alternatively, and more likely from what the study's findings suggest, constraint quality is made up by a weighted mix of the inherent characteristics and has a moderating impact that makes the relationship stronger or less strong, while not eliminating it at a whole.

The impact direction of the different constraint quality characteristics, on the other hand, can be solidly stated based on this study's empirical findings. All eight characteristics follow a trade-off in their impact direction: If the characteristic is fulfilled in any given constraint design, their moderating impact is positive. If the characteristic is not fulfilled, the moderating impact is negative. Illustration 54 depicts these trade-offs in the impact direction of every identified characteristic.

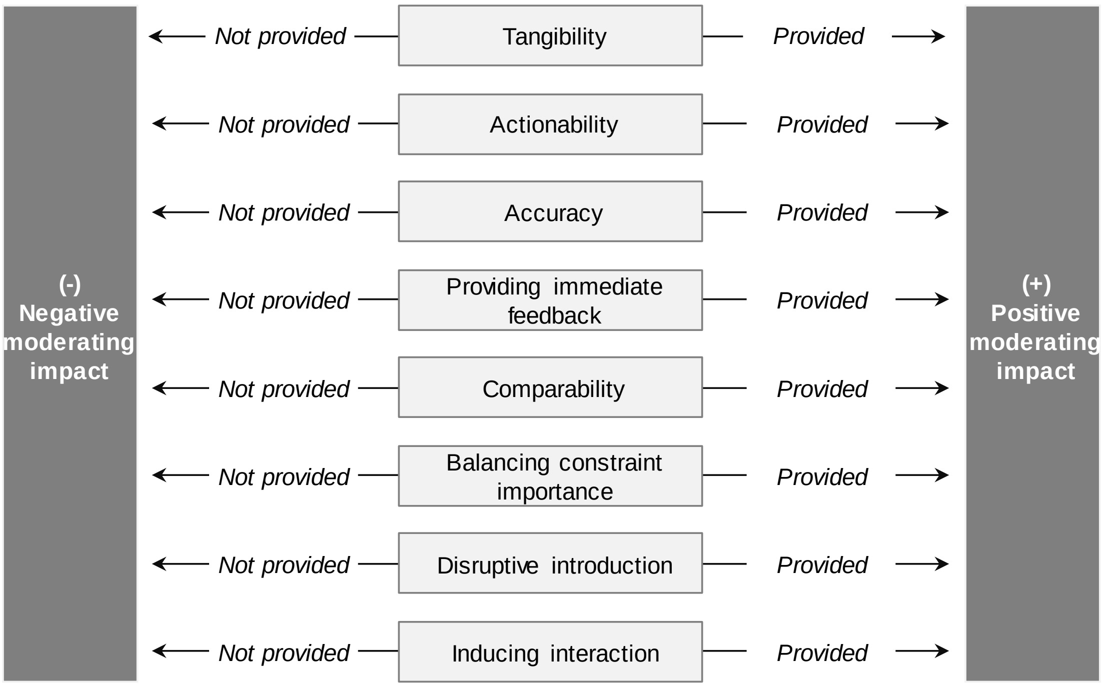

Illustration 54: Impact direction of constraint quality

As an example, if a certain constraint is tangible, actionable, accurate, comparable, balances constraint importance, provides immediate feedback on its fulfilment, induces interaction and is introduced disruptively, the moderating impact of the constraint will certainly be positive.

In summary, the author is confident to assume that the introduction of manufacturability constraints, if characteristics of constraint quality are satisfied by choosing the appropriate constraint type and/or organizational embedding, will have a positive impact on cross-functional integration at the design-manufacturing interface, as well as on creativity, while potentially prolonging time-to-market. The resulting theoretical model with all identified relationships is portrayed in illustration 55.

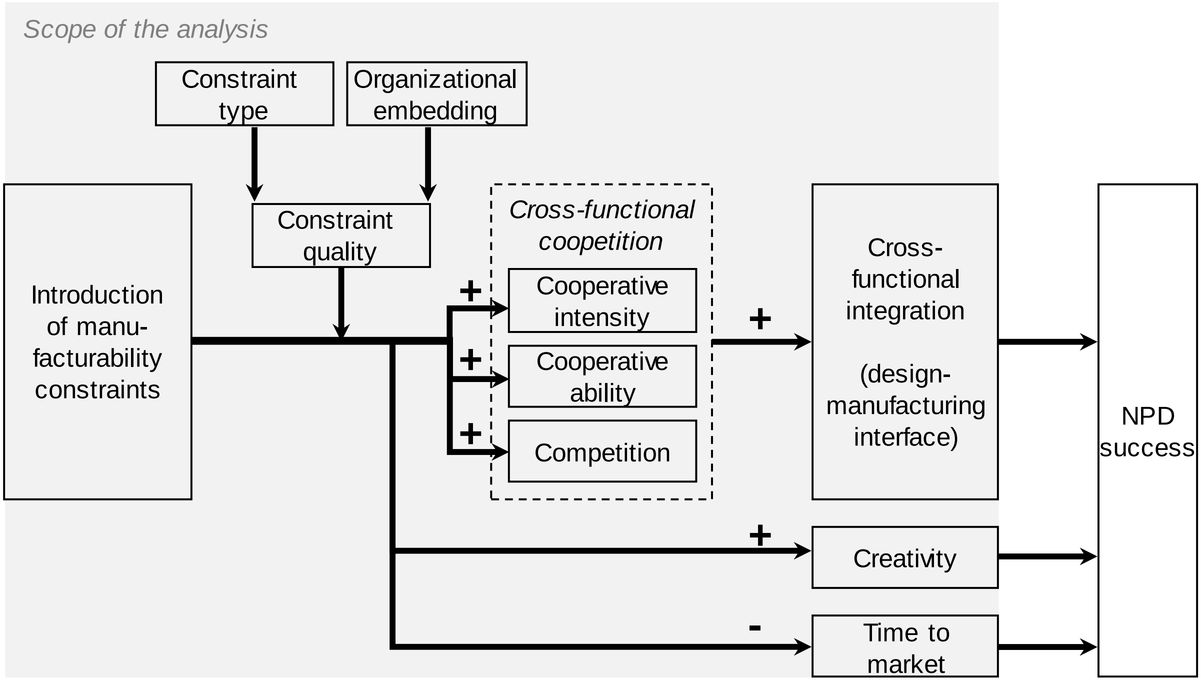

Illustration 55: Theoretical model of the impact of manufacturability constraint introduction

8 Conclusions

8.1 Review of research questions and findings

The following chapter will highlight important findings that have been made for the five research questions that guided the empirical study at hand.

1. **How does cross-functional coopetition impact cross-functional integration at the design-manufacturing interface of NPD?**

Based on a profound analysis of all dimensions of coopetitive behaviour in form of a case study at a German large-scale industrial NPD project, the author is able to draw conclusions on cross-functional integration which consider inherent socio-organizational and contextual aspects. In this regard, the employed coopetitive perspective enabled capturing cross-functional integration holistically, covering all aspects that existing theoretical conceptions suggest. Taking Kahn's (1996) two-pillar model as a reference, the following can be concluded: Cross-functional cooperative intensity and cross-functional cooperative ability translate into Kahn's interaction and collaboration pillars. Cross-functional competition is able to gauge the effectiveness of cross-functional integration, likewise encompassed in Kahn's conceptions. It goes beyond a mere behavioural measurement of whether functions talk to each other and share resources and information, asking if the observed interaction effectively finds expression in a product that accounts for all functional requirements, be it customer usability, manufacturability or design requirements. While other measurements that operationalize cross-functional integration for empirical research have been found to

be limited to behavioural aspects, cross-functional coopetition covers attitudinal aspects and effectivity in addition.
Indeed, the deployment of the coopetitive perspective on the case study at hand revealed that effective integration requires more than a transactional exchange of information and resources. Socio-organizational and contextual aspects shape integration in the NPD context to a significant extent; analysing them from a coopetitive angle allows to derive a structured categorization and impact prediction as presented in the theoretical contribution of this thesis.

In conclusion, this study's results suggest that cross-functional coopetition is a strong predictor of cross-functional integration. In reference to the research question, this leads to the conclusion that cross-functional coopetition has a direct and positive impact on cross-functional integration at the design-manufacturing interface of NPD.

2. **How does the introduction of manufacturability constraints impact coopetitive behaviour at the manufacturing-design interface?**

From the empirical analysis, it can be concluded that the introduction of manufacturability constraints has a positive impact on all three dimensions of cross-functional coopetition. Concerning cooperative intensity, it increases interaction even at non-adjacent interfaces and encourages manufacturing's involvement in the design process. Second, it arouses interest for the cross-functional counterpart and enhances understanding and even internalization of their requirements, thus increasing cooperative ability. On the competition dimension, it increases transparency on the cross-functional optimum and encourages critical cross-functional reasoning and discussion on it, hence fostering constructive competition at the design-manufacturing interface. The findings suggest that the positive impact on coopetitive behaviour is dependent on several conditional aspects. These include communication accompanying constraint introduction, immediate feedback on constraint fulfilment and a risk of over-emphasizing the constraint dimension at the cost of other design requirements.
In conclusion, the introduction of manufacturability constraints has a positive impact on coopetitive behaviour at the manufacturing-design interface as long as identified preconditions are met.

3. **What is the moderating impact of the constraint type on this relationship?**

Differences with regard to the constraint type have significant influence on the relationship of manufacturability constraints on coopetitive behaviour at the manufacturing-design interface. My analysis shows that if the constraint type fulfils certain characteristics on both the external applicability and the internal dimensioning, the relationship is moderated positively. These characteristics include

presuppositionless tangibility for involved interfaces, comparability to other design requirements, allowing for actionability in terms of achievability and solution flexibility and lastly, accuracy of constraint calculation. Among the three explored constraint types, the constraint with a medium abstraction level performed best in fulfilling these characteristics.
In an overarching analysis of all identified moderating impacts and preconditions, it was found that the constraint type does not have a direct moderating impact on the relationship between constraints and coopetitive behaviour. Instead, the constraint type impacts different characteristics that can be summarized as constraint quality. The latter, in turn, is found to have a moderating impact on the relationship of manufacturability constraints on coopetitive behaviour at the manufacturing-design interface.

4. **What is the moderating impact of the organizational embedding on this relationship?**

A morphological analysis performed with interview participants generated nine dimensions with two to five values, respectively, that were found to have an impact on the relationship between manufacturability constraints and coopetition. Dimensions comprise constraint rigidity, priority with regard to existing design requirements, incentivization, recipient hierarchy level and function, fulfilment tracking hierarchy and frequency, introduction point in time during NPD and introduction mode in the existing enterprise. For different values of the respective dimensions, the impact of the introduction of constraints changes in direction and can have a negative or positive influence on coopetitive behaviour.
Organizational embedding was found to have no direct moderating impact, though. Alike the constraint type, organizational embedding shapes characteristics of constraint quality, which itself has a moderating impact on the relationship of manufacturability constraints on coopetitive behaviour at the manufacturing-design interface.

5. **How does the introduction of manufacturability constraints impact creativity?**

Creativity was found to be positively impacted by the introduction of manufacturability constraints based on both pressure to conceive radical ideas and creativity-spurring interaction. According to a number of informants, the positive effect may be dependent on contingency factors including the NPD phase of constraint introduction and the granted scope of action for the constraint recipient. Both factors are part of the characteristics that are aggregated in constraint quality. Therefore, the impact on the introduction of manufacturability constraints is positive, but moderated by constraint quality.

8.2 Contributions to literature

8.2.1. Contributions to cross-functional integration in NPD

In-depth understanding of the dynamics of cross-functional integration in NPD
In existent research, the belief in a positive impact of cross-functional integration on NPD success persists without fundamental doubts. However, there remains a lack of clarity on surrounding aspects and contingency factors. Empirical efforts on the relationship between various measures of NPD success and various facets of cross-functional integration yield widely ambiguous results. Based on this recognition, the author set off to gain a profound understanding of the dynamics that shape cross-functional integration in a NPD context. Qualitative research, as opposed to quantitative efforts which dominate the research field, enabled getting a grasp on less tangible items and accounting for contextual, social and organizational factors, all widely acknowledged in their importance by academia but seldom incorporated in empirical studies so far.
The qualitative analysis painted a detailed picture of socio-organizational and situational dynamics that shape cross-functional integration in a case, which can be considered typical for large-scale industrial innovative environments. Such a profound and wide-ranging study with nominally unlimited items of observation is unprecedented in the research field of cross-functional integration in a NPD context and is able to create a new basis of understanding for these matters. The study is able to show that social and contextual dynamics have tremendous impact on patterns of cross-functional integration. Effective integration, with a positive outcome from a cross-functional perspective, requires much more than a transactional exchange of information and resources, to which existent survey items often are limited. Indeed, the CarCo case shows that a transactional exchange can indeed occur without effective integration resulting from it. Given the significance of social and contextual dynamics that have been identified, the author hopes to spark a shift in thinking such that future empirical studies provide room and effort to conceive these dynamics on their survey questionnaires.

Beyond proving their significance, the study at hand allows for a structured impact analysis of these dynamics. When previous research may have dismissed social or contextual particularities as part of a wider error term, the model of cross-functional interface dynamics which emerges from this study allows to systematically attribute likely dynamics to certain setting preconditions and predict their impact direction on cross-functional integration in NPD. The findings suggest that function-specific dynamics will be observable only for a certain functional pairing at the interface, but for a broad range of contexts and environments. Contextual dynamics, on the other hand, are assumed to be valid for all functional pairings but limited to a certain context. The third category, social dynamics, will be observable in all contexts and at all interfaces at which human beings participate. The study at hand contributes to existing literature not only by identifying function-specific dynamics for the design-manufacturing interface, contextual dynamics for innovative and large-scale industrial settings, and a set of social dynamics. It also provides a structure and blueprint for future research efforts to complement dynamics for other contexts and other functional pairings.

Third, the study at hand answers researchers' call for empirical efforts on the design-manufacturing interface, which has often been neglected in existing research efforts. The findings contribute an in-depth analysis of underlying mechanisms at the interface that is believed to be able to complement academia's understanding of different functional interfaces. Indeed, the findings show that the design-manufacturing interface has its own particularities, with dynamics and barriers to integration differing from those of other interfaces.

Theory on a new method to enhance cross-functional integration

This study contributes theory on a new method to enhance cross-functional integration in a NPD context, building on the introduction of constraints that embody certain functional requirements. The method is grounded in an empirical environment and therefore is likely to receive better empirical acceptance than existing methods, which are reproached with a high theoretical burden and insufficient recognition of empirical requirements. Exploration within different empirical scenarios has shown a positive impact on cross-functional integration and proven wide acceptance in a corporate setting. Moreover, the method produces a beneficial effect on creativity in design problem solving.

In addition to the empirically explored approach, a theoretical backbone is contributed that derives cause-effect relationships from observed underlying mechanisms. Potential negative effects on time-to-market and moderating impacts have been analysed and depicted in an overarching model. With regard to moderating impacts, a set of characteristics of constraint quality has been derived from the empirical grounding. The study's findings suggest values thereof that are able to positively impact the relationship; constraint type and organizational embedding have been explored as factors that, in turn, impact constraint quality.

8.2.2 Contributions to coopetition research

In the course of this study, a coopetitive perspective was taken to analyse behaviour at the design-manufacturing interface and to draw conclusions on cross-functional integration. In substantiating connections between cross-functional integration and cross-functional coopetition, this study contributes the first empirically founded analysis of this relationship. The findings suggest that cross-functional coopetition is indeed a good predictor for cross-functional integration. Even more so, it permits to capture cross-functional integration in the comprehensive way that theoretical fundamentals are calling for, but that existing models of cross-functional integration

are unable to cover. To be more concrete, cross-functional integration allows to measure attitudinal aspects of integration through its cooperative ability dimension and provides an indicator of the effectivity of integration efforts through the competition dimension. By contrast, existing empirical measurements building on constructs of Kahn (1996) or Olson et al. (2001) assume a narrower perspective and focus on easily measurable behavioural aspects of integration. The case study at hand places an interesting counterpoint to this in showing that behavioural integration may well be observed without effective integration emerging from it, in a sense that would create NPD outcomes that are optimized from a cross-functional perspective.
The author believes this recognition to contribute to existing literature in proving a better alternative to measure cross-functional integration by taking a coopetitive perspective. This may help to elucidate some of the ambiguous results that empirical studies, building on a poor measure of cross-functional integration, have generated.

Second, this study contributes to coopetition theory by bringing forward empirical research on coopetitive behaviour on micro level I, which has been scarce overall and non-existent with regard to qualitative research. The profound qualitative analysis of the study at hand helps to establish a solid base for the nascent and thriving research field striving to illuminate essential mechanics and antecedents, which support or impede the emergence of cross-functional coopetition.
Additionally, this thesis represents a contribution to empirical research on micro level I coopetition in a NPD context, which has been very limited albeit being recognized as a promising research field.

8.2.3 Contributions to research on constraints in innovation

Despite its proverbial existence, the role of constraints in an innovation context remains unclear for academia. Different research efforts come to contradicting results on whether innovation fosters or hampers innovation, while missing out on going beyond a superficial level of analysis. The study at hand contributes to the theoretical body on constraints in an innovation context by presenting the first in-depth qualitative analysis of this relationship. The findings confirm Hoegl et al.'s (2008) presumption that constraints impact different antecedents of NPD success, which helps to explain ambiguity in the wide relationship between constraints and innovation: While cross-functional integration and creativity seem positively impacted, time-to-market may be negatively influenced. Furthermore, the study is able to identify and categorize boundary conditions as well as organizational and contextual moderating impacts, which further influence the relationship between constraints and innovation. Therefore, the study confirms that there is no simple answer to whether constraints foster or hamper innovation, but it explains underlying mechanisms that lead to this ambiguity and it provides a structured analysis under which conditions it has a positive or a negative impact. Identified characteristics of the moderating impact of constraint quality and explored effects of constraint type and organizational embedding provide a theoretical basis to further structure the relationship between innovation and constraints.

In addition, the author believes to contribute to constraint literature by exploring the deliberate use of constraints, and indeed yielding a positive result. So far, research has focused on examining constraints as a given frame condition and did not make use of constraints' advantageous side effects in an organizational application. By presenting a possibility how such an application can be successful through this study, the author hopes to encourage other purposeful usages of constraints to be developed by future researchers.

Empirical research on constraints in innovation concentrates to large parts on resource constraints. By adding an empirical effort on product constraints, this study complements existing literature.
In addition to that, the thesis includes a grounded, comparative analysis of different product constraints which is unprecedented in existing research. The findings suggest that it is less the abstraction level from the product, but more a set of characteristics defined in the constraint quality that decides if a certain constraint type has a positive impact or not. These findings may be able to contribute to the success of future research efforts in the field of constraints in innovation. Furthermore, they potentially represent a basis for the continuation of a structured comparative classification of different constraint types.

Finally, the study at hand makes a case for constraint research on an intra-organizational level of analysis with an incumbent firm. While most research efforts in this field focus on start-up or bottom-of-the-pyramid settings, existing corporations remain important breeding grounds for innovation and thus deserve increased attention. The thesis at hand answers this call, affirming that indeed there are interesting applications for constraints in incumbent settings.

8.3 Limitations

Research results and proposed contributions to theory should be considered in light of the study's limitations, which can be allocated to three fields. First, dependence on the researcher's judgement, second, generalizability of results and third, explanatory power of derived theory.

Despite a rigid methodological approach that takes account of established quality criteria, any qualitative research effort remains dependent on the individual researcher's judgement and interpretation to a certain extent. Explanations derived from the original data may be biased by the researcher's own experiences or personal perspective. As the researcher in the study at hand took a participant-as-observer role within production management at CarCo, particular prudence had to be applied to

ensure objectivity of results. For data that was collected during participant observation, a risk of a perception bias that enforces empathy for the problems and requirements of production management remains.
Besides, the study's findings represent the majority of involved participants, not all of them. For all questions, there were respondents whose opinion differed or even opposed presented results.
Furthermore, explanatory power with regard to involved abstract concepts in this study, predominantly coopetition, may be reduced by their operationalization. Participants were not presented the abstract concept of coopetition, but with operationalized terms to suit participants' empirical contexts. For example, competition, as one constituent of coopetition, was operationalized as "friction", "conflict" or "rivalry for budget or management attention".

For different parts of the analysis, alternative explanations can be stated that provide conclusions which are different to the ones drawn in the course of the study. With regard to the model of interface dynamics, derived contextual, social and function-specific dynamics could also be explained by particularities of the people involved at the observed interfaces. In consideration of the introduction of manufacturability constraints, the observed positive impact could also have been induced by the tools that have been programmed to support constraint exploration in a realistic scenario. Although the researchers asked for feedback on the constraint introduction and tools in separate questions and applied different codes, informants could possibly have projected their positive perception of the tools on the constraint introduction. With regard to the derivation of quality constraints as a moderating impact, there could be a latent variable, representing an alternative explanation. Albeit empirical grounding of the identified characteristics makes their obsolescence unlikely, there could be hidden variables besides the characteristics, which remained unidentified in the study at hand.

Based on their methodological nature, case studies are unable to postulate definitive generalizability of their results to other cases. Empirical grounding entails invaluable advantages as a research method with regard to richness and applicability of data and theoretical insights. On the other hand, however, it naturally represents a challenge for the generalizability of results. Even though CarCo can arguably be considered as a typical case for an innovative project in a large-scale industrial setting, generalizability to other contexts, for example cross-functional integration in a start-up, or other functional pairings, may be limited. Certainly, there also is a risk that derived theory reflects particularities of CarCo as a single company, with limited generalizability on other firms, even if they are subject to similar contextual factors.
Potentially, in other industrial contexts or other cultural settings, dynamics may be different and therefore results limited with regard to their generalizability.
Besides, data collection and resulting empirical grounding of the case study at hand was limited to the observation of certain NPD phases, covering the beginning of the

initial phase, concept phase and the beginning of series development. A very early phase or a very late phase in NPD could be subject to dynamics different to the ones covered in this study's theoretical contributions.

With regard to the explanatory power of derived theory models, possible limitations may be of relevance. The model of interface dynamics categorizes and describes entire dynamics patterns and refrains from placing model items connected by simple cause-effect relationships. Although such relationships would take the model to a simplified, easier-to-interpret scheme, it would, however, not be able to live up to contingencies and dependencies found in the empirical grounding. For this reason, the model's full explanatory power emerges only in relation to a certain setting, within which it can be interpreted and for which it can provide projections on the dynamics impacting cross-functional integration.

Furthermore, the model does not provide a full projection on how integration at a certain interface is likely to be; instead, it permits statements on social, contextual and function-specific dynamics that shape cross-functional integration. Naturally, cross-functional integration depends also on involved personae, products and processes – which differ from individual organization to organization.

The theory on the introduction of constraints has been derived based on the exploration performed with CarCo interview participants in different scenarios. Although the exploration environment was assimilated to real conditions that prevail at CarCo, this approach can only approximate a real introduction of constraints. As a potential limitation coming out of this, interview participants may be negatively biased if they were unable to dissolve from the status quo within NPD, or may be positively biased if they overlooked negative consequences because the scenario didn't seem realistic to them.

Besides, the author did not include time-to-market as an object for analysis from the beginning of the study, therefore lacking the appropriate theoretical backing during data collection. Statements on time-to-market derived from this base should therefore be judged with particular caution.

8.4 Propositions for further research

Different theoretical contributions of the study at hand open up promising avenues for future research, which will be described in the following.

The model of cross-functional interface dynamics at the design-manufacturing interface, which was derived from the in-depth analysis of integration mechanisms in the case study at hand, represents an unprecedented effort to structure social, contextual and function-specific dynamics that impact integration at any given interface. Certainly, it would be an interesting path for future researchers to find generic dynamics for other functional pairings or other environmental contexts. For example, grounded qualitative research would be able to discover dynamics specific to a start-up context or the marketing-design interface. Similarly, a qualitative effort in another cultural background would allow to confirm or disprove the general validity of social dynamics across different cultures.

Besides such an enlargement or continuation of the model of interface dynamics, individual dynamics identified from the case study at hand offer promising starting points for further research.

To begin with, the interplay of time lag, information asymmetry and responsibility considerations towards a game of power and enforcement in the "avocado game", which has been identified to take place at the design-manufacturing interface of NPD, might be an interesting explanation pattern for other related phenomena. Modelling organizational processes, decision or negotiation procedures as a corresponding social game has the potential to generate new explanation patterns.

Second, the finding that innovation complicates integration carries potential for a new research impulse on the heavily debated inverse question, namely how cross-functional integration impacts innovation. As in the case study at hand, this counteraction may influence the effect of interface integration on NPD success in other cases alike. Integrating this recognition into future quantitative or qualitative research efforts on the topic could improve their explanatory power.

The dynamic suggesting that integration is "lost in complexity" could represent an application field of complexity research. It embodies a situation where complexity that has deliberately been created by an organization, though well-intentioned, distorts organizational targets, in the case at hand cross-functional integration. Explaining and solving this or similar organizational dilemmas could be an interesting path for future research.

Similarly, the identified dynamic of formal integration as a "house of cards" may be an interesting field of engagement for organizational research and innovation research: How can corporate structures of incumbents be maintained resilient and flexible enough to support innovation?

In interface research, the importance of adjacent interfaces has remained unacknowledged so far. This study suggests that indeed, adjacent interfaces are major determinants of integration. Potentially, these bridging functions, that exist in empirical reality but so far have been neglected by research, could bear importance for other matters within organization research as well.

Finally, further research on the identified mechanism on wall building between organizational functions would be useful for all empirical efforts to increase cross-functional integration. If research would be capable of explaining the forces that build up these walls, it would be in a better position to make recommendations on how the build-up can be prevented in the first place, instead of providing theory on how to remove them.

The theory that emerged on the introduction of constraints and its impact on NPD success raises a few intriguing avenues for further research. Based on this study's qualitative research findings, the author is able to propose several relationships that would be interesting to validate by means of a quantitative research effort.

To begin with, the findings strongly suggest a close relationship between micro level I coopetition and cross-functional integration. This is valid to such an extent, that the author suggests to take coopetitive behaviour as a measure for integration at cross-functional interfaces. A survey study, building on established scales for cross-functional coopetition and extensive measurements for cross-functional integration which include attitudinal behaviour and effectivity of the integration effort, could usefully examine this relationship. Specifically, it is proposed:

Proposition 1a (P1a): The stronger cooperative intensity is at a cross-functional interface in a NPD project, the stronger will be cross-functional integration at the same interface and the closer will the NPD outcome be to a cross-functional optimum.
Proposition 1b (P1b): The stronger cooperative ability is at a cross-functional interface in a NPD project, the stronger will be cross-functional integration at the same interface and the closer will the NPD outcome be to a cross-functional optimum.
Proposition 1c (P1c): The stronger competition is between two interfaces in a NPD project, the stronger will be cross-functional integration at the same interface and the closer will the NPD outcome be to a cross-functional optimum.

Exploring the introduction of constraints and assessing their impact on cross-functional integration and other antecedents of NPD success, such as creativity and time-to-market, led the author to derive a number of theoretical propositions. These constitute new theory, which emerged grounded in an empirical setting. In order to substantiate initial theoretical propositions, a laboratory study could be helpful, as it would enable a neat comparison of outcomes achieved with and without the introduction of constraints, which certainly should be a next step for the initial theory to receive acceptance and to be refined for empirical application. While empirical grounding that explicitly accommodates contextual aspects was essential to establish the theory and understand its mechanics, the author believes the theory to be functioning laboratory conditions alike.
While it would be intriguing to test different functional constraints in such a kind of study, the author recommends to test manufacturability constraints, as the established theoretical understanding of function-specific dynamics will facilitate interpretation.

Proposition 2a (P2a): The introduction of a manufacturability constraint during NPD at the design-manufacturing interface increases cooperative intensity at this interface.
Proposition 2b (P2b): The introduction of a manufacturability constraint during NPD at the design-manufacturing interface increases cooperative ability at this interface.
Proposition 2c (P2c): The introduction of a manufacturability constraint during NPD at the design-manufacturing interface increases cross-functional competition at this interface.

Similarly, testing propositions from this study on other antecedents of NPD success would be insightful in such a laboratory study.

Proposition 3 (P3): The introduction of a manufacturability constraint during NPD at the design-manufacturing interface enhances creative design problem solving.
Proposition 4 (P4): The introduction of a manufacturability constraint during NPD at the design-manufacturing interface prolongs the NPD process.

In order to facilitate future testing of the propositions derived from the theoretical findings, a graphical representation thereof is presented in illustration 56.

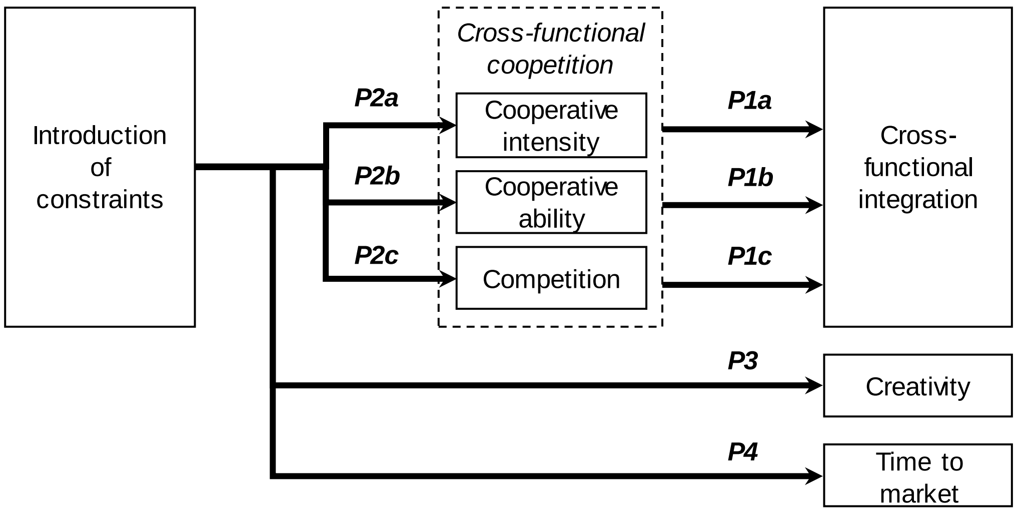

Illustration 56: A framework for testing propositions on constraints' impact on NPD antecedents

The study at hand considers a moderating impact of constraint quality on the relationship between constraint introduction and both cross-functional coopetition and creativity. Constraint type and organizational embedding were found to impact constraint quality, but it is well possible that other factors have an impact alike. Further qualitative research would help to bring light into this issue, but it would require another exploratory setting with informants. As an alternative, an exploratory factor analysis, based on an extensive survey that inquires factors potentially impacting constraint quality, would likely be insightful. It could be executed with participants of a sufficiently dimensioned laboratory study as explained above. Subsequently, structured equation modelling would help to substantiate, or disprove, the moderating impact of constraint quality on the relationship between constraints and cross-functional coopetition.

Furthermore, it will be interesting to identify constraints that satisfy the identified characteristics of constraint quality. Going beyond the three tested constraints in this study, there may be quantitative indicators that satisfy all identified characteristics to a high degree and thus would likely serve as effective constraints. While constraint quality will always remain specific to the industry- and product-related case, it is likely that some constraints work well for many of these cases. It would be interesting to identify a variety of constraints, for which constraint quality in certain contexts is likely good, and from which practitioners could choose from. A laboratory study, which tests a series of constraints that have been selected based on their constraint quality, may be helpful for this purpose.

This study's results show that a deliberate use of constraints to impact antecedents of NPD success could be successful. The author hopes that this result is able to encourage similar endeavours. With this study making the case to enhance manufacturability requirements in product design, the author believes that other functional requirements from stakeholders downstream the NPD process could strengthen their voice in product design by using constraints in an equal manner. For instance, environmental considerations such as sustainability of used materials or energy consumption would be an intriguing and relevant case. Customer usability concerns, often neglected by technology-affine design engineers, could be another interesting case. Qualitative research that accompanies a real introduction of such constraints into the design process of an organization would be useful in this respect.
Furthermore, any deliberate use of constraints to enhance NPD success seems promising based on the results of the study at hand; not only through an increase of interface integration, but also through an increase of creativity or even other, still unknown related antecedents. Further empirical or theoretical efforts that develop this thesis' initial theoretical basis to substantiate a purposeful use of constraints in an innovation context would constitute interesting avenues for further research.

Appendix A: Detailed tables of empirical research on effects and contingencies of cross-functional integration in NPD

Relationship between cross-functional integration and NPD success							
	Scope	**Methodology/ sample**	**Functional units**	**Measurement NPD success**	**Measurement CFI**	**Moderators/ Mediators**	**Results**
Olson et al., 1995	Organizational moderators for the impact of cross-functional interaction on NPD success	Survey data from 45 cross-industry projects	R&D, Marketing, Manufacturing	• New product effectiveness (e.g. new product quality, time to reach break-even) • New product efficiency (time required and budget adhered to) • Psychosocial satisfaction with the outcome	• Functional interdepend-ence, resource flows, participant satisfaction, task difficulty, functional goal attainment	• Product innovativeness • Formalness of coordination mechanisms (e.g. bureaucracy or centralization)	• Impact of cross-functional integration on NPD success is highly dependent on product innovativeness and coordination mechanisms • Generally, a fit between all elements is important, e.g. more bureaucratic structures are more successful for non-innovative products
Kahn, 1996; Kahn and Mentzer, 1998	Investigation whether collaboration or interaction increase company performance	Survey data from 514 US American Electronic industry managers	R&D, Marketing, Manufacturing	5 performance measures on scales, one of them product development performance	• Interaction (9 items on meetings and documented information exchange) • Collaboration (6 items on e.g. mutual understanding, same vision)		• Collaboration has a strong positive impact on development performance, while interaction alone is not sufficient
Song et al., 1997	Antecedents of consequences of cross-functional integration in NPD projects	Survey data from 598 managers from Mexican high-tech companies	R&D, Marketing, Manufacturing	4 items (Product quality, NPD cycle time, NPD objectives met, NPD program success)	3 items (Communication, task orientation, interpersonal relations)		• Significant positive impact of cross-functional integration on NPD performance • Internal antecedents impact the degree of cross-functional integration, external antecedents don't • Results were similar for all three functions

Song and Parry, 1997	Identification of NPD success determinants, with cross-functional integration being of the examined determinants	Survey data on 788 NPD projects from cross-industry Japanese firms	R&D, Marketing, Manufacturing	4 items on relative success of the new product (general, sales volume, 2x profitability)	3 items on “good integration” pair-wise of R&D, manufacturing, marketing		• Within various examined determinants, cross-functional integration is one of the most important success factors • Cross-functional integration impacts NPD success by having a profound impact on technical and marketing proficiency and the relative product advantage
Langerak et al., 1997	Impact of cross-company and cross-functional integration on NPD success in different competitive environments	Survey data from 103 Belgium and Dutch companies	R&D, Marketing, Manufacturing	Several performance measures (e.g. development period, payback period, share of new product in sales)	Relative time spent by each function in each phase	• NPD phases (pre-development, assessment, product development, commercialization) • Turbulence of external environment	• Optimal degree of collaboration depends on the competitive environment
Sherman et al., 2000	Impact of five forms of cross-functional integration on product development cycle time	Survey data from 65 business units/companies in the US and Scandinavia	Several bilateral pairings, R&D manufacturing integration one of them	• Product development cycle time (1 item)	• 5 items on R&D/manufacturing integration (e.g. close collaboration, attention to manufactura-bility during design)		• Positive impact of R&D/manufacturing integration on cycle time, but other forms of integration with stronger impact
Lovelace et al., 2001	Role of conflict communication for cross-functional NPD teams’ efficiency and innovativeness	Survey data from 43 US American NPD teams	Unspecified	• Innovative-ness of team outcome • Efficiency of team outcome (budget and time adherence)	Functional diversity of teams (entropy-based diversity)		• Cross-functional diversity is not the decisive factor for neither product innovativeness nor NPD efficiency • Instead, the communication management of task disagreement

Frishammar and Ake Horte, 2005	Impact of external information (with cross-functional integration being of them) on innovation performance	Survey data from 206 Swedish companies	Unspecified	• 3 items on innovation performance	• Personal interaction (4 items • Impersonal interaction (5 items) • Collaboration (6 items)		• Collaboration with positive impact on innovation performance • Both personal and impersonal interaction without impact on innovation performance

Table 10: Empirical research on cross-functional integration in NPD - development of research field

Comprehensive exploration of moderators and mediators

	Scope	Methodology/ sample	Functional units	Measurement NPD success	Measurement CFI	Moderators/ Mediators	Results
Song et al., 1998	Impact of cross-functional joint involvement across product development stages	Survey data from 236 US American cross-industry managers	R&D, Marketing, Manufacturing	• Product effectiveness (6 items, e.g. relative product quality and price) • Product efficiency (1 item: relative timeliness of NPD introduction)	4-8 different items for joint involvement measured for each NPD phase	5 NPD phases: market opportunity analysis, planning, development, pretesting, and launch	• Strong dependence of impact of integration on NPD success on NPD phase and interface • For certain functional pairings in certain stages, cross-functional integration can even be detrimental, e.g. involvement of all three functions in market opportunity analysis • Specific function- and stage-specific patterns evolve, where integration is supporting or impeding NPD success
Kahn, 2001	Impact of interdepart-mental integration and market orientation on product development performance	Survey data from 156 US American Textile managers	R&D, Marketing, Manufacturing	• Product development performance (pre-launch) • Product management performance (post-launch)	• Interdepartme ntal Interaction • Interdepartme ntal Collaboration • Interfunctiona l Coordination	NPD phase	• Both marketing and manufacturing managers see positive impact of interdepartmental integration on NPD • R&D managers do not reflect any relationship

Olson et al., 2001	Impact of cross-functional integration on NPD project performance	Survey data and supplemental interviews from 34 U.S. American cross-industry NPD project teams	R&D, Marketing, Manufacturing	• 5 items on NPD Project performance	• 3 items (communication, information exchange, transferred work)	• Early and late NPD stages • Project innovativeness measured by prior product experience	• Higher NPD performance for integration of R&D/marketing and R&D/manufacturing in early stages • Higher NPD performance for integration of manufacturing/marketing and R&D/manufacturing in late stages only for innovative products • Integration of manufacturing/marketing in early stages positive for non-innovative products and negative for innovative products
Vandevelde and van Dierdonck, 2003	Identification of success factors at the design-manufacturing interface for production start-up phase	Survey data from 53 Belgian companies	R&D, Manufacturing	Smoothness of the production start-up	• Formalization of the process • Empathy from design to manufacturing • Communication • Design involvement in production start-up	• Complexity of the product • Newness of the product	• Empathy from design to manufacturing ensures a smooth production start-up • Formalization of the process ensures smooth production start-up
Troy et al., 2008	Impact of cross-functional integration on NPD success considering diverse moderating factors	Meta-analysis of 146 correlations 25 quantitative studies	Diverse, no specification given	Diverse, no specification given	Diverse, no specification given	• 7 management-controlled moderators (e.g. Integration at team vs. organization level, integration as cooperative climate vs. information sharing only) • 2 researcher-controlled	• Relations are indeed highly complex • Positive impact of integration on NPD can be stated, but strongly dependent on the moderators

						moderators (e.g. objective or subjective success measures) • 3 contextual moderators (e.g. services or goods, non-western or western)	
Brettel et al., 2011	Impact of cross-functional integration on NPD efficiency and effectiveness	Survey data from 118 German cross-industry companies	R&D, Marketing, Manufacturing	• NPD Effectiveness • NPD Efficiency	• 5 items on goal alignment, resource sharing, formal and informal interaction, information exchange	• Project phase (development & commercialization phase) • Innovativeness of product (incremental & radical innovation)	• Relations between various aspects of cross-functional integration and NPD performance measures are highly complex • R&D/Marketing: positive for efficiency, but not effectiveness. Impact of integration dependent on phase and innovativeness. • R&D/Manufacturing: Positive for efficiency in development phase • Marketing/Manufacturing: No relation for radical innovations, positive for effectiveness in commercialization phase

Table 11: Empirical research on cross-functional integration in NPD - comprehensive research ambitions

	Relationship specification						
	Scope	**Methodology/ sample**	**Functional units**	**Measurement NPD success**	**Measurement CFI**	**Moderators/ Mediators**	**Results**
Nakata et al., 2006	Role of cross-functional integration, customer	Survey data from 259 cross-industry NPD	R&D, Marketing, Manufacturing	• 5 items (e.g. relative sales volume,	3 items on good integration and communication for pairwise	Mediating role of new product advantage	• Cross-functional integration with positive impact on new product advantage

	orientation and new product team proficiency on new product advantage, and the latter's impact on NPD success	projects from Korea and Japan		relative profitability)	between manufacturing, marketing and R&D		• New product advantage with positive impact on NPD success
Luca and Atuahene-Gima, 2007	Examination of the impact of cross-functional collaboration and market knowledge dimensions on NPD success	Survey data from 363 Chinese managers	Unspecified, survey asks generally for "integration with other departments"	5 items (e.g. relative profitability, relative share of sales)	3 items on cooperation from different departments	Mediating role of knowledge integration mechanisms	• No direct impact of cross-functional collaboration on NPD success • Positive impact of cross-functional collaboration only via knowledge integration mechanisms
Engelen et al., 2012	Examination of cultural contingency factors of the impact of cross-functional integration on NPD success	Survey data from 619 companies in 6 different countries	Unspecified, survey asks generally for "integration with other departments"	• 4 items on new product (2x relative sales, profitability, market share)	• 4 items on collaboration (e.g. collective goals, teamwork) • 3 items on interaction (e.g. engagement in circulated reports, memo-randums)	Moderating effect of national and corporate culture	• Both cross-functional collaboration and interaction with positive impact on NPD success • Impact is stronger for collectivist cultures, and stronger for strong company cultures
Graner and Mißler-Behr, 2014	The application of methods in NPD and its impact on cross-functional integration and NPD success	Survey data from 400 cross-industry NPD projects from Germany, Switzerland, Austria	Unspecified, survey asks generally for "integration with other departments"	6 items (e.g. relative profitability, ROI)	4 items on cooperation from different departments	Mediating role of NPD method application	• Cross-functional collaboration leads to better NPD performance • Application of NPD methods leads to higher integration and hence to better NPD performance
Tsai and Hsu, 2014	Development of a mediated moderation model for the role of	Survey data from 182 Taiwanese companies	R&D, Marketing, Manufacturing	• 10 items (e.g. relative sales, relative time-to-market)	12 items (e.g. information sharing, willingness to cooperate)	Moderating role of competitive intensity	• Positive impact of cross-functional integration on NPD success under low competitive intensity, but no impact under high competitive intensity

	competitive intensity on the relationships knowledge integration mechanisms, cross-functional integration and NPD performance						
Nafisi et al., 2016	Involvement of Manufacturing (operators & engineers) in NPD	Exploratory single case study in heavy automotive industry (qualitative, 8 interviews)	R&D, Manufacturing	n.a.	qualitative	n.a.	Manufacturing engineers are more often involved than operators, latter confirms other studies that it is very difficult to involve manufacturing in NPD
Cho et al., 2017	Examination of a potential moderating role of international orientation within the impact of cross-functional integration on NPD success	Survey data from 189 Korean (Vandevelde and van Dierdonck, 2003)companies	Unspecified	• 3 items on new product outcome (time-to-market, number of new products, product quality) • 3 items on new product performance (customer acceptance, sales growth, profitability)	3 items (not specified)	Moderating effect of international orientation	• Cross-functional integration with positive impact on NPD success • International orientation not a moderator of the latter relationship, but a factor with direct positive impact on NPD itself

Table 12: Empirical research on cross-functional integration in NPD - relationship specification

Appendix B: Representative data for second-order themes

Second-order Themes	Representative Data
Representative Supporting Data for Second-Order Themes Cooperative Intensity	
(a) High communication intensity at adjacent interfaces	***(a1) Communication intensity at bilateral interfaces*** Product designer: "I have more interfaces with the process designers than with the production planners" (128:4) Production planner: "I think the alignment between product design and process design is very good" (160:2) Member of production management: "There's not much I have to do with product designers in my daily life" (127:1) Product designer: "With the manufacturer, I have nothing to do" (130:25) Product designer: "We have indeed nothing to do with manufacturing, we come up with something ourselves regarding all the screws and so on" (161:12) ***(a2) Strong informal relations at bilateral interfaces*** Production planner: "Between process design and product design, the connection is closer. When I was in process design, we often watched football together or went to the product designers' barbecues" (82:66) Production management: "My relations are 70% to manufacturing, 25% to production planning, 5% to product design, roughly" (127:17) Manufacturer [on the typical process designer, author's note]: "He sees the product designer all the time, he's much closer to them than to us. Only when the hardware arrives, the process designer really gets to know the manufacturer" (147:24) ***(a3) Manufacturing involvement only via interface cascade*** "That's what I meant with the cascade product design – process design - production planning – manufacturing. Production planning and process planning are really close. But process planning to manufacturing, there is a step in between" (82:69) "So the manufacturing people never sit together with the product designers?" "No, they wouldn't do this" "Manufacturing to product design, that's a wide span" (160:8) "Manufacturing is rather detached here, product design has closer contacts to the production planners" (167:5) "There is always the planner in between product design and manufacturing" (177:4)
(b) Importance of informal relations	***(b1) Individual effectiveness dependent on informal relations*** "I told you, that's all heavily dependent on individual persons. […] It all hinges strongly on individuals, if such a cooperation works or doesn't work" (20:1) "Often, this [the integration, author's note] depends on just one single person. That was the same with the injection engine development: there, they had one old liaison engineer, with him everything worked out perfectly" (145:28) "CarCo is simply built as a networking association, everything works via people" (160:10) ***(b2) Informal relations as success factor for integrated NPD*** "Most things, much, work on informal levels. This means that cooperation takes place on an informal level, much hinges on persons, how well you get along with each other" (82:70) "The principle of one hand washes the other is valid." (147:57) [on the question how convincing cross-functional counterparts works best, author's note]: "The first thing is always to have a coffee together. Try to build a relationship with them, independent of their department symbol." (130:11) "It's a very personal thing if something works or doesn't. […] I'd say that all of my actions are based on exchanging with people and understanding their individual situation" (127:15)
(c) Perceived inefficiency of formal relations	***(c7) Bureaucracy and formal alignment hinder integration*** "We have a problem with bureaucracy at CarCo, you have to do 100.000 feedback loops"(159:6) "The problem is how to get to a binding, simple, quick statement, because everyone is super-cautious in the sense of once bitten, twice shy. It first has to be aligned three

	times, then the calculation has to be re-adjusted, then certified and only then the number can be passed on" (148:7) ***(c8) Homemade structural complexity*** "That's really because so many people work here – if you just look at [names a CarCo product, author's note], that's not any more complex than simple plugs […]. But somehow, here – this is possible in a much leaner way, it would really be possible in a much leaner way. It would already help if the product designer just talks with the process designer, as an example, face to face. I don't know, because that's really extreme here." (181:7) "What is not value-adding for us, I say at CarCo but that's certainly the same for other OEMs, is the frequency of alignment committees. The contents that are conveyed there are often congruent, so you say the same thing 50 times." (82:24) "Without having understood the entire committee landscape to any extent, what we have as committee, and preparing committee, and another preparing committee […] Until the run through the committees is finished, half a year is over. I think there's too much time frittered away here." (178:31) ***(c9) Little trust in own formal committees*** [Talking about the project leadership committee, author's note]: "They don't know the real topics, maybe know the status, green, yellow or red, which you perhaps could as well just roll the dice, which would perhaps be closer to reality than what is reported. In my opinion, there's much politics in all of that." (181:15) "Our steering committees are a bit too weak, they don't succeed in what they're supposed to do, namely to make decisions that are valid. And on the other hand […], we notice every now and then that decisions, when they are finally taken, are just not accepted." 127:7) "So for example, next to the [says name of a certain committee, author's note] there is the [says name of another committee, author's note], in principal this is just the unrecorded part of the other committee, rather a discussion committee." (148:9)
(d) Late involvement of manufacturing	***(d10) Late involvement of manufacturing and representatives*** "It's crazy what we do, we have our time line and manufacturing representatives get on around 38 months before SOP - although the entire phase takes 72 months. So, the ship to take impact has already departed, and only then we get on with the entire team." (158:43) "I think before target agreement, the manufacturer is way too far away" (160:1) "No one's gonna do that for you. We've never seen this, that the plant manager holds a product line manager to account, telling him to reduce manufacturing costs. He gets into NPD much too late for that." (176:4) "In total, we as product designers attach not enough importance on the question if that's working out for manufacturing. For which reason whatsoever, that's too less taken care of. Or too late, namely when the product is done." (149:45) ***(d11) Manufacturability inputs rejected due to late raising*** "Those manufacturing topics, fair enough, they are all legitimate, but they come up with that only now, now that the concept is done. They would have had to integrate themselves much earlier." (235:1) "Everything that you still find after target agreement is a waste of time." (176:7) "Actually it's always like that, that the process side very seldomly dominates with regard to costs. […] Only in the early phase, you are granted an advantage sometimes, when it's actually cost-neutral." (171:21) "The problem is not new, there are production requirements and there are design requirements and that these two don't always match up is clear. Nevertheless, the point in time where I could still change something and have an impact – and not when I come after target agreement […]. If you would have said this before, we could maybe have still done something and it wouldn't have cost anything. And that's one of the points, and that's actually just symptomatic for many other things." (148:43) "I think that for many cases, manufacturing input would help […]. But in the decisive moments, where they could have delivered input, they were not informed on the current development stage and therefore, actually were not able to assess that." (143:6) ***(d12) Manufacturing involvement either too late or too early*** [Talking about the right point of time to integrate manufacturing in NPD] "It's extremely difficult to get on a running development project with the actual team [as manufacturers, author's note]. You have an extremely low hit rate that something is discussed at this very moment which is relevant for product design at this very moment. You are either too late, so product design has already come past this topic,

	or too early, so product design has not yet dealt with the topic. And that's never going to work, you cannot assume that product designers will remember this if you bring it up someday at a workshop. " (176:9)
(e) Compartmentalized nexus of contacts and channels	***(e13) Confusion on cross-functional channels and contacts hinders integration*** ""From my view, honestly, it's overcontrolled, the whole thing. Sure, I have many interfaces, and I can all put them down on such a process chart and I can say you go here and he comes there and then it goes again to another one and parallel to this one and this one will send it to IT and so on." (164:14) "There are so many things that it becomes confusingly chaotic or obsolete. There is a lack of prioritization and some insist on details. You should organize all this in a much less complex way." (146:18) "To begin with, it's not too easy to find the right product designer, I had to search for a while at first. The allocation of who does what is not totally clear or transparent." (153:4) [Manufacturer, author's note]: "We should definitely bring the knowledge we collected to the new product generation. But we are having problems to do that, because we do not have the right people to bring this together […], such that a person could make a direct contact with them." (154:28) ***(e14) Ideas for manufacturability improvements get lost in the process of addressing them*** "We do a lot of things together, how can we simplify the product, how can we reduce processes, we have incredibly many ideas, but at the end there's not much realized." (162:2) "Actually, everything is there, but you have to ask yourself why the one thing or the other is not neatly handed over to the other function." (177:14) "As is so often the case, lessons learned disappear on some kind of server or in some kind of drawer, and at the end of the day it doesn't reach the person that it should reach. Or the requirements are always reset, and that's a rotten Sisyphus process." (173:13)
(f) Discussion topics focused on series issues and coordination	***(f15) Discussion topics focused on series problems*** [Answer of a manufacturer if they have something to do with product design, author's note]: "Actually not much, well if there's a modification in the series product." (147:5) [On the question, for which topics manufacturing and product design are in contact, author's note]: "Mostly on modifications, modification management, quality topics, concept topics." (178:5) [on the question where there are discussion topics between manufacturing and product design, author's note]: "In the series at first, always if there are quality problems" (145:27) ***(f16) Focus on information and coordination*** "Rather alignment topics, coordination, steering them" (124:18) "At the moment I wouldn't say that there's much of a concept exchange, and here one idea and there another, it's rather – the main thing is to make sure it works somehow." (82:37) "The only platform that we have where I'd say we are in a discussion mode is the quality steering circle." (173:28) ***(f17) Unpleasant topics in upstream communication*** "We have the rather unpleasant job of - I usually say it like that: you have a carnival party, and we are the cleaning wagon, party is over, and then we clean up the garbage and then we have to say to the people [to product design, author's note], by the way, you've forgotten something there." (130:5) "It was actually only about escalation topics, there was never something like I have a content question. […] That means that you've always talked about problems. It's always, we are either not allowed to or not able to." (130:24)
(g) Communication tone patterns	***(g18) Discussion tone: Passive in the early phase*** "That's depending on the phase, so in an early phase it drags on, it's only heating up when you slowly approach calls for tender [during series development phase, author's note], and when you're at SOP it becomes heated" (82:47) "Certainly, compared to the product designers, who organize these meetings here, we're more passive, rather listening and receiving." (82:14) "Solution-focused and factual, definitely factual. It's less of a buddy relationship" (141:20) ***(g19) Discussion tone: Walls between manufacturer and NPD participants***

"It's a general principle that manufacturing screams that product design is to blame. That's a standard approach. […] We have a problem and it's product design's fault." (167:25)

[Manufacturer, author's note]: "Those in the plant, they are the stupid ones. The production planners from the headquarters, they look at you from above, look at you as a manufacturer, just asking dumb questions. That is quite a certain arrogance. For example, if I ask the product designer something, he wouldn't say simply that's not possible because of this and that. Instead, they start discussing, and then he just says no. That is quite a certain arrogance." (159:17)

"From the point of view of product design, you always had the feeling that manufacturing is always and only demanding, which was unfair sometimes. A famous example, and that is what you see again now, is that manufacturing would really send people to discussion groups to solve problems. That has already been the case in many instances, that the demand came from manufacturing, but their people didn't grab a seat at the table." (167:24)

"So there was this guy from the XY department […], he needed a special part from plant [names a plant location, author's note]. So he called there, saying I'm the new [says his role, author's note], but they said no, you can't get that. Then they talked on the phone three times in a row, but it didn't work out. So then, he sat into his car, had two cases of beer in his trunk, also bringing a snack with him. So he got to know all of the boys in the plant, getting them drinks and snacks. Since then, he knows all of them in person, and he gets everything, really everything." (178:25)

Table 13: Representative supporting data: research question 1 - cooperative intensity

Representative Supporting Data for Second-Order Themes Cooperative Ability	
Second-order Themes	**Representative Data**
(h) Different mindsets of design and manufacturing	***(h20) Awareness of cultural differences between functions*** "If you master the cultural aspects here, then you'll get by fine" (82:95) "The cultures are totally different. During the first half year, I noticed it extremely, how different the production department is, the KPI orientation, let alone this strict hierarchy – that's quite a bit more easy-going in product design, or you could as well say chaotic." (130:29) "Cooperation between different types of production planners is already difficult here, even there the culture is very different." (142:25) [On the question how he sees the cultures between product design and production]: "Worlds lie in between, but it's difficult to put into words." (183:5) ***(h21) Diametrical mindsets of design and manufacturing*** "In the case of manufacturing, it's quite a bit different, as I said, they are much more hands on, they're wired differently. It's more about finding a personal access to someone, to a foreman or a worker at the assembly line, you have to act a bit more pragmatic." (127:27) "The product designers love to discuss freestyle, they don't like to be tied down." (125:35) [On manufacturing]: "Abstracting things, and imagining how something might look like just roughly, picturing something hypothetically, they are not able to do that." (124:7) [On manufacturing]: "They are very much concerned about tradition. They say, we have been producing combustion engines for ages, what's all this electro mobility stuff supposed to be here"? (124:3)
(i) Manufacturing wants reliable specifications	***(i22) Availability of precise specifications and hardware*** [A member of production management on the cooperation with manufacturers]: "When I ask them questions, how such a system should be designed, for example, they cannot just answer easily. Instead, I have to provide an application, a demo, to show them how this looks like, how this could look like. And then, when they have some kind of imagination, then they can tell me their change requests. But abstracting and imagining how this could look like roughly, hypothetically depicting that, they're not able to do that." (124:7) "In the early phase everything works only on a virtual basis. Manufacturing, however, they are rather relying on hardware, they have incredible difficulties with CAD models." (141:3) "Where we had many discussions in the last time, is that there has to be a very very exact specification. For example, for the electric engineering planners, they all have a new interface defined, but this interface is not yet defined by 100% by IT, and then the

	electric engineering planners simply say to us no, as long as this is not fix by 100% I won't do it. […] They only tender something if it's defined and specified by 100%." (143:30) ***(i23) No advocacy of production topics without detail knowledge*** "Sure, CAD data means something to me. But to really make a methods-time-measurement analysis in all of its accuracy, you at least need a finished and construed product, or some version of it. And to get in even earlier, you'd need at least some kind of database." (176:1) "That needs to be provided in detail, it has to match up one by one, because just a bit of another approach would lead to different, very different assembly times." (159:33) "I'd assemble [the product, author's note] for my own at first, or would have it assembled with myself observing it, and analyse it thoroughly […]. Only if I have this overview, I can work out how my production line should look like." (158:38)
(j) Social differentiation of manufacturing	***(j24) Clothing and language as means of differentiation*** [On best practices of working together with manufacturers]: "I can't go down there wearing my suit, I'll wear a pullover and the shopfloor shirt." (124:44) "I'd never go into production for example, with a suit and tie and stuff like that, then you'd directly be labelled as a headquarters snot." (178:26) "If you're at the production plant, if you talk dialect then they'll be your best friends […]." (124:16) "At headquarters, it's not that important, but in the plant you'll definitely have a better starting ground if you talk dialect, compared to someone who speaks proper German or something else." (124:16) ***(j25) Manufacturer walling off towards indirect functions*** "The product designer always says against the manufacturer I can't do it, it's not possible, my robot can't do it […]. That's how clear front lines have built up. These are front lines that exist." (158:33) "Two years ago, we as the two current doctoral candidates, a future doctoral candidate and a graduated doctoral candidate, drove to the production plant, and we were greeted by "we're all healthy here, we don't need any doctors here." (174:1) "Without a manufacturing department symbol, I'm not taken seriously here." (192:1) "Sometimes I find that frustrating. I had an example, where they just didn't want to show me the production process for weeks, although that was just 50 meters next to them. If you're not on the shopfloor yourself, they obstruct everything." (142:26) "I'd send all the young engineers onto the shopfloor to let them learn painfully. That they can see, what a fight this is every day anew." (147:9) ***(j26) Perceived distance of manufacturing*** "[Integrating, author's note] manufacturing is difficult, because manufacturing is always far away." (82:30) "The manufacturer topic is a bit detached." (167:4) "For a product designer or a production planner it is indeed difficult, or well, there are some that have difficulties to go to the production site." (177:32) "My interns, so far I only took them to process designers […]. Those guys are easy and that wasn't a problem at all. If we'd go to a manufacturer, I'd sensitize them a bit more." (129:12) [Manufacturing manager]: "I was a production planner for 13 years, but now I changed to the dark side of the force." (147:1)
(k) Upstream functions over-valued, downstream under-valued	***(k27) Limited cross-functional insights*** "I have absolutely no clue at all, what exactly they do in product design. Seriously, I neither have any clue how things work internally for them." (156:4) [On the question, how much insight a product designer has into production planning]: "Very little." "And the other way round?" "Exactly the same." (151:33) "I'm convinced that many product designers lack a comprehension of the processes in the plant. […] And obviously also the other way, the ones from the production department, they often lack a comprehension of the complexity." (141:19) "Usually, people stay in their department and separate themselves quite strongly from each other. Mostly, you know little about your counterparts from the other department, or about what they do." (127:37) ***(k28) Unawareness of downstream consequences*** "It just doesn't interest them, and sometimes they don't even know how their products are produced." (168:3) "I find it frightening, how many young colleagues [in product design, author's note] only come to the production plant for the first time after 1,5 years, finding out full of astonishment that the production line works like that and that." (167:29)

“It’s also a lack of understanding of the production planner, sometimes he just doesn’t know that there’s a customer out there that he has to satisfy, namely the manufacturer. That happens to other functions that are downstream the process, as well.” (131:16)

“We [in product design, author’s note] have a very limited view on what the consequences [on production, author's note] are of what we commit here.” (30:3)

“The product designers […], they have no idea how things go around here, and what the difficulties are. They have zero insight.” (147:55)

(k29) Perceived supremacy of indirect functions

“It took a while until I was respected at the design department with a production department symbol. They think, the production department builds the cars, but apart from that they don’t know anything at all.” (134:4)

“I hear this often from the people from manufacturing. They say, finally, someone from above comes down here and hears our problems.” (124:25)

“Sometimes it even gets personal, then I’m totally fed up with going into discussions in the product design teams. There, I’m tired of coming up with ideas and going into the design team meeting, because then you have stuff coming up to you such as, I’m quoting here, the product design team manager saying that only useless ideas come from assembly.” (142:11)

[Manufacturer]: “Sure, it’s not as attractive for the young engineers down here [on the shopfloor, authors’ note], for the good ones that you want to have for the company.” (147:12)

“Of course it’s much sexier to talk about products and functionalities, how fast is the engine, what is the torque, how smooth it is to steer, than about, well, how can I assemble this the quickest or the cheapest way.” (151:5)

(k30) Aura of artistry around development functions

“There is a topic of setting an example. There are always some [product designers, author’s note], who want to leave something behind, with some kind of technical solution or development or whatsoever. There are many that are a bit too artsy-fartsy there.” (178:40)

“Why do we always have to reinvent the wheel? We do that much too often. But probably it’s also due to the product designer’s pride.” (147:47)

[Product designer on the construction process]: “It’s a bit of a handicraft lesson here. Admittedly, we require from suppliers that they design neatly, but with us, it’s really chaotic and difficult to look through.” (16:1)

(l) Manufacturability requirements difficult to place

(l31) Manufacturability difficult to define

“We have a problem at CarCo to define or formulate manufacturability requirements in the first place. Everyone sees their own thing, everyone who is involved in some way sees the topic of producibility or manufacturability differently.” (141:13)

“For many requirements that we pose, we are partially unable to articulate what we really want […]. If you break it down into great depths, stating what it is that bothers me, then most of the time you’ll find something where you can formulate the solution way such that product design still has its freedom, and such that on the other hand, production requirements are also taken account for.” (148:21)

“Anyways, it doesn’t work the way it is today. It just doesn’t work. For example, there is nothing on manufacturability in the stage-gate criteria. Nothing at all. There is something like “production concept aligned”, but there’s nothing defined beyond that. And then you can also just drop it.” (141:42)

(l32) Manufacturing-ready design as production’s obligation

“Manufacturability is seen as a subordinate topic for most product designers. They see it also like, oh our manufacturing will do that, they’ll take care of it. But that it likewise belongs to their tasks, to design the product such that it is manufacturing-optimal, maybe it’s due to their academic education, that this is subordinate.” (151:4)

“As a manufacturer, you have to be simply penetrant [to bring in manufacturability suggestions into product design, author’s note], but sometimes it feels like tilting at windmills.” (159:4)

“But I think product design would say [on assembly time, author’s note], that’s a problem of the production department, it’s not my problem. My problem is to do a neat construction.” (179:27)

“A product designer would never say on his own initiative, that he puts an extra effort into just making it easier to assemble for manufacturing. For them, it is a production department objective, the manufacturability. This simply doesn’t interest anyone from product design, if you assemble it in ten minutes or one hour. For them, this is a production task.” (179:48)

(l33) Downstream requirements not binding

[Product designer]: “Process requirements? We don’t really pay attention to them, and we wouldn’t write those down in the specification sheet, because they’re not real requirements.” (104:1)

“I don’t know if our requirements - if they’re really seen as binding by product design. Indeed, we did bring in some requirements, and the requirement manager affirmed that they have been submitted to product design. […] But certainly, the product designers didn’t really look through them, because otherwise it wouldn’t have come this far.” (181:17)

[Production planner on the lessons learned that they pass on to product design]: “It’s not binding for them. It’s more like a list.” (142:4)

(l34) NPD process as unidirectional sequence

“Actually, they should come from the customer and say hey I can sell this car for 68.000€ and break it down from there, but at CarCo, nobody’s able to do that. CarCo processes are designed for the case where you know how the product works. They are not designed for disruptive things.” (45:3)

“The rule is that product design predefines everything, and manufacturing is left with the realization and production. For the other way round – well, we try to have an impact regarding product design, but it’s much more difficult.” (155:21)

“As a production planner, I’d always try to see how far I can come with the manufacturer [in solving a problem, author’s note], before I’d go to product design. Because mostly, that’s what we’ve said already, the product is the master clock. The product is seen as fixed, and we have to plan the production system around it. Only if this dogma would be resolved at some point [laughing], then we could start to say […] that manufacturing costs would be reduced from the beginning.” (156:38)

(m) Low advocacy for manufac-turability

(m35) Manufacturability as frequently deprioritized topic

“The product designer has always 1000 other problems, for him this one [manufacturability, author’s note] is the last one of all.” (176:10)

“It is simply, regarding manufacturability, here the problem is that product design, they want to develop and have fun, and here, want to be creative, but manufacturability falls off the table. And partially, you’re becoming overtaken at this point.” (179:13)

“We [from production, author’s note] always have the second stand or the second position. If the product designer says, I don’t retrieve the performance at the moment, with this tin package and with three wires in the groove, saying I need four wires […], then we’ll always say ok yes, then we’ll try to work it out that we manage to do that somehow from a manufacturing side.” (169:31)

(m36) Manufacturer without incentive to intervene in NPD

“Sure, the manufacturer is wired differently, he rather says why should I care about what comes in 5 years, if my line stands still today” (145:32)

“As a manufacturer, to put it simply, I don’t have any interest at all to get on board in NPD earlier, I don’t want to develop the products for the product designer.” (131:15)

“That’s exactly what I mean, you have some kind of construction thrown over, and in hindsight the product designer goes to manufacturing, and the latter says typically it’s alright [imitating typical dialect and proverbial stiffness of production plant region], but in fact it’s is not alright.” (149:20)

“How do you want to create an incentive for the manufacturer [to become involved in the NPD, author’s note]? He’s preoccupied with his series topics, and is utilized to capacity in his series topics.” (150:20)

(m37) Low manufacturing costs have no advocate

“We’ve never seen this, that the plant manager holds a product line manager to account, telling him to reduce manufacturing costs. He gets into NPD much too late for that. At a maximum, during launch phase, he takes care of assembly defect risks, maintainability, things like that. But if manufacturing costs are really too low or too high, doesn’t help the plant at all, as long as he receives the money for it, he just doesn’t have any interest. And neither does the production planner. There is no one, who would actively call for that.” (176:4)

[Production controlling]: “The topic of bringing down manufacturing costs as low as possible, I’d say it’s important but maybe not first priority, but rather second priority. In my view, the first priority is to put the manufacturing costs, which we state externally and which we receive in target agreement in the end, to put them on a level which allows us to pay our workers and build our production system.” (155:12)

“If I ask who has the benefit, then everyone is happy to have higher manufacturing costs. And most of all the plant, then they have more budget to play around with.” (176:13)

(m38) Time lag in NPD distorts responsibilities

“The production planner, after they’ve planned the production line, should actually come to the plant as manufacturer. Because then he has to pay for the whole shit he planned.

Because at the moment, the planner is already in a new project when SOP comes." (159:15)

"If we [process design, author's note] really screw something up, then the manufacturer are of course typically the one who suffers. At that point, it indeed is like that, that we're out of responsibility already." (82:74)

"Manufacturing is only hurt when in series production, there is a problem, he can't deliver parts or his supplier can't deliver parts. But what is in 2019 with the new product generation, he has no pain at all regarding this in his current business. " (125:6)

"Dear product design, you've developed bullshit, and we can't manufacture this now and we are responsible, although it absolutely is not our fault." (126:30)

(n) Innovativeness inhibits cooperative ability

(n39) Lack of cross-functional experience and contributions

"For evolutionary approaches, the integration works fairly well, because you can refer to lessons learned. For radical products, this doesn't work anymore." (30:4)

"That's an important point for good work in the product design team on the part of manufacturing: Having someone who just sits in there and passes on information, this doesn't work. You need good people from the production side in the product design teams, who gets across credibly that they have the experience." (151:20)

"At the time, in the vehicle plant, you had people with a huge experience, and even if it's not seen positive at CarCo if you stay at one position for so long. But it was good, to have someone with experience. You don't fool colleagues that have been around for 15 or 20 years." (153:11)

"That's a general problem here, many fresh people are in production planning, they start there directly. And then you just don't know it any better." (159:13)

"That's the difference to the product designers from the combustion powertrain, who are in business for a long time, they have a better understanding of the other functions, of the process partner. In our project, the product designer just doesn't know what he damages when he's 5 weeks delayed, that he causes such an immense delay for us downstream. He doesn't mean no harm, he just has no idea what he causes." (149:7)

"Where it gets difficult, is to set up a new product, just as it is for us with new battery electric vehicles or the plug-in hybrids. You have the problem that you just don't know yet, what the requirements are […]. We don't know what the BEV customer wants, does he really want to race across the highway with 200 km/h, or does he wants to drive with 100 km/h as long as possible, and so on. That makes it difficult to prioritize requirements." (160:11)

(n40) Formal NPD process unsuited for innovative products

[On the question what the main problem in NPD is, author's note]: "The requirements, be it product or volume, change quicker than the process would allow it to." (171:2)

"Normally, they have a predecessor product where they can derive cost targets. This works fine, until you have a disruptive product, then it goes into the void. Then they say to us, well, what's the planned assembly time, just put 10% on top of it [laughing]." (45:2)

"But you feel rather limited openness for changes or optimizations or just for a grain of an extra effort, already to just look at alternative concepts. So they really stick quite stringently to the process, determining what our premises are, writing them on a paper and going out to a supplier. Then they need four months to just think about it and to invite all possible offers." (169:5)

"Playing it like all other components, that everyone does one's bit and then it's integrated in the regular process, this doesn't work for completely new innovative topics." (173:16)

"You have to see carefully that the new structure doesn't fight the old one." (129:27)

"Looking at the current project […], the processes that exist, they exist only on paper." (163:1)

[Product designer]: "I don't know what will come here, maybe we'll have another cable harness here or it remains a connecting block. It's changing all the time, and you can't really optimize for manufacturing if it's changing all the time." (16:3)

(n41) Liaison people lacking due to small size

[Talking about cross-functionally oriented liaison people, author's note]: "All of these functions are passed on and on like a hot potato, no one wants to have them on his cost centre. And as they sit naturally in between the functions, you push them around." (153:15)

"What is also a problem is the fragmented capacities, which you have when the projects are still small. There is a person, who takes care of topic X for 0.1% and topic Y for another 0,1%. Of course he can't do this very successfully at the end." (131:11)

[On the question why the manufacturing opinion is less heard in NPD, author's note]: "This goes pretty wrong I would say. If you compare it to the vehicle projects […], they have some kind of interface function between production planning and product design, who exactly cares about these manufacturability topics, [names a person, author's note] is doing this there. This role is too weak at our project, or doesn't exist at all." (157:18)

(o) Supplier relationships inhibit cooperative ability	***(o42) Supplier relationship as another difficult interface*** "Another problem is the high share of purchased parts, which is often a matter of fact for OEMs. There, the cooperation becomes even more difficult because, when the company Bosch comes, you don't know if that's their manufacturer of the two people that are there, it's just the company Bosch. So at the end, I don't know if I talked to the manufacturer or to whom I talked. And even the product designers don't do much by themselves any more, they outsource much to service providers, and there I don't know which cooperation or which alignment took place." (131:12) "At the moment, there is a gap in the process, because as long as it's not decided if the part is purchased or produced inhouse, no one looks at the manufacturability." (141:11) "And additionally, we have many external providers that plan our processes for us. Partially, you can't interfere with them at all, because of service contracts and so on." (159:31) ***(o43) Required experience lies with supplier*** "What is really sad, is that we really build up so much new, create new production lines, that we are really able to follow a greenfield approach. But in fact, that's just the suppliers that do all that, all the know-how lies with them." (142:28) "For production planning, if I'd formulate that in an evil way, I often have the impression, a subjective impression that they are just technical purchasers […]. They just develop some specifications that they hand over to the supplier, and sign off at the end if the supplier has fulfilled all of these specifications." (143:35) "Product design is often outsourced as well, they don't do barely anything themselves any more, only rough assessments, the actual work is done [name of a product design service provider], that work through the eight hours. That doesn't really facilitate the cooperation between product design and manufacturing." (153:17) ***(o44) Supplier distorts importance of manufacturability*** [Production planner on the dominance of material costs compared to production costs, author's note]: "But that's certainly a problem that we have created ourselves through our good [ironical, author's note] procurement. The suppliers get the money of course through product modifications, that's why it always comes out so expensive." (142:10) "It's a classic to compare material costs and production costs. The product designer sees that he could save 1 cent per part, and he has 1 million parts, so he has large amounts to save. Then we have of course the burden of proof, what this would mean for the production system, and of course we have difficulties there because the supplier provides an exact value, 1 € per battery or per component. And we always say well, the process behind that might be somewhat more complex, and that's always a bit like comparing apples to oranges. We try our best to bring all of that together, but those are the topics. How much is the effort, and where it gets exciting is for service costs and rework costs, because these are topics for which you'd need experience values, which of course you don't have." (170:21) "If I come into NPD in an early phase, then I can say to the product designer I'll save 0.2€ of production costs if you spend 0.1€ of material costs […]. But the supplier, he naturally adds the expenses only later in the process." (145:19)
(p) Functional structures are self-sustaining	***(p45) Corporate steering mechanisms work functionally*** "I think we never stand up and say yes, we can do that, if anything we stand up to say no, there's no chance we can do that. Also we don't have this cross-functional thinking, which we should have, and that's often entailed by the objectives, because there is no objective for the e-drive process chain but only for the functions." (157:20) "We have a functional steering, all our steering mechanisms at CarCo are functionally oriented." (125:16) "There's much of potential there, but we don't dare addressing this, we're prisoners there, also with the cost centre structure, because much is decided by money and budget, and as long as this is functional you will go on with this power and trench warfare forever, because everyone first sees that he's clean. In particular, when money is involved - and the higher you come in hierarchy, the more money is involved." (125:46) "Because we have totally different processes, the product design and production departments. As well regarding budget stuff, they are steered totally differently." (126:14) "There's little permeability […]. Usually, people remain in their department and they strongly differentiate each other from the others. Mostly, you don't know much about people in the other department, there are few connecting exchange platforms and little permeability of employees, it's not seen very positively if you change across. Likewise, HR does not encourage this, quite on the contrary, everything is organized such that this does not happen. HR is also organized following a departmental structure." (127:37)

	(p46) Power considerations entrench functional orientation "The thinking in the hierarchies, as you have created them, there are just too many well-beloved features that you maybe do not want to give off […]. Because that could mean as well that I'd have flat hierarchies, and therefore possibly not so many hierarchies anymore." (162:12) [On the question why agile structures are not enforced at CarCo, author's note]: "I mean, if you look at which companies act in such more open structures, there the salary differentials are not as large is here with us [laughing]." (129:28) "It's sad, but I feel that in large companies, much too often, that it still depends on these egos, in particular in the upper leagues, there is really much showing-off [verbally: snapping their braces, author's note]. You don't say we have, but I have." (158:48)
(q) Lack of cross-functional trust	***(q47) Trust as success factor for cross-functional integration*** "The best thing is simply to solve problems together. In 2013 or 2014 […],within 24h we had a team of fifteen people, ten product designers, five from production, and solved the problem on-site. And afterwards, we went drinking a beer together, and on the next day, it was as if this was one unit. Such stories weld people together, when you recognize that you have the same problems." (126:25) "If you come into a discussion for the first time, you'll see right away that this is hopeless. But if later, for the other it has become clear, through shared experiences and activities, that you've been through together, that you come to the table with some experiences which are also important for him – only then he's willing to really discuss the topic with you on a factual basis." (151:19) [Manufacturer on best practices for cross-functional integration, author's note]: "Ideally, you've eaten a bag of salt together at some point." (176:20) ***(q48) Lack of trust and openness across functions*** [Discussion with production planner on new cost estimation based on assessment of new product design, author's note]: [Interviewer]: "But you can easily argue that it's getting more expensive because the product has gotten more complex?" [Production planner]: "Yes, but no one wants to hear that. No wonder that everybody plays his cards close to his chest [verbally: no one lets down his pants, author's note], regarding saving potentials if you are always held accountable like that. Openness and transparency, they say [laughing ironically, author's note]." "I'd first question what's behind this calculation. And again, that's the trust problem between product design and production planning." (153:22) [On the question what company culture he wishes for, author's note]: "That for once, you simply trust what the department says, even if you don't fully understand it, but you agree before you lose the time for explaining the last 20%." (171:16) [On the cooperation with his cross-functional counterparts, author's note]: "Then you have some, and you don't notice it from the beginning, they say there are problems, and we don't know why – but in fact, there's something with the entire plant and it doesn't have to do anything with it, they set you on the wrong track with a hidden agenda to distract you from the real issues." (165:9) "Product design wants to be on the safe side, and we from production cannot prove the opposite, that's the problem." (166:7) "By nature, the manufacturer is in a position where he has a right to say something, but will not decide in the end. So he always has to pay for everything." (150:7)
(r) Integration dependent on formal process	***(r49) Formal process / agreements necessary for cooperation*** "They just want one thing, they want a specification sheet, that's what you have to do, and then that's what they'll do." (129:2) [Talking about a product design team, author's note]: "There is no feature, where you might say we have a problem there and we need to solve it, and the feature would help us. It costs just a few cents, but they won't discuss it, according to the motto we have our target value and we will stick to it."(163:21) "The specification sheet certainly drives product design. Production planning has to fill in their requirements, because later, they [product design, author's note] don't care anymore." (131:3) [On the push-back of innovative ideas, author's note]: "For him it is like, there's someone here who wants something crazy, doesn't really know why, and doesn't have an order or instruction, so he won't do it in the first place. Do you have a ticket, no, do you know how you can build that, no, can you tell me the sampling rate, no – well, bad luck." (164:13) ***(r50) Push-off mentality / no voluntary extra efforts made*** "That's exactly the CarCo approach, at first I try to find out how it does not work. I try to find out how to get the topic off my desk. That's really a problem here, it makes cooperation more difficult." (149:28)

	[On the question what he would do when he would be all-responsible for designing a flying car, author's note]: "Well at first trying to push everything away from my desk [laughing]." (153:10) "At first, they'll do finger pointing. If there's a problem, then this one or that one is to blame, but not myself. The culture at core is that, if there's a problem und it's not my problem, I won't take the task." (146:19) ***(r51) Dependency on formal process detrimental for innovative NPD*** "What hurts us is that we have to think like a start-up, we grow as fast as a start-up, but we're caught in the mechanisms of a large corporation." (125:44) "We handicap ourselves structurally, I think the NPD process is very well structured and well described, but we can't live these processes, I don't know any generic schedule that has been adhered to." (162:9) "We're no dictatorship, we take decisions in committees, and I think this is a good thing. That's a good way to find a decision. However, speed in the electrified mobility is different from the one of the combustion engine, and maybe that's just not enough." (149:15)

Table 14: Representative supporting data: research question 1 - cooperative ability

Representative Supporting Data for Second-Order Themes Competition	
Second-order Themes	**Representative Data**
(s) Little competition on the cross-functional optimum	***(s53) Design requirements with predetermined hierarchy*** "His product is brought to work in the first place. Afterwards, it's checked that the product can be integrated into the assembly space, so function, material costs, and only material costs, assembly space - and we're quite behind that." (180:21) "They take care that their product fulfils all functions and fits into the assembly space, and the rest actually doesn't matter." (176:18) "For significant product changes, it [the successful introduction of a production requirement, author's note] is only possible if we A) cannot at all sort out how the process could work, and B) after all we mostly manage to sort out the process in the end." (142:7) "If you say it's not producible, then the product designer says […] but then I don't get my product, and at CarCo, you never attack the product requirement." (82:107) "The product is firmly set, and we have to plan our production around it." (156:39) ***(s54) Functional orientation deters cross-functional optimum*** "Missing my own objectives, in favour of my neighbour or for the success of the entire company - even if it would be better for the cross-functional optimum – no one would do that." (125:15) "CarCo is a development-driven company, and therefore product design has the power." (160:25) "We are strongly following product design's sayings. We [from production, author's note] can mail some things, and say that these are high costs, and beg them to develop the product a bit differently. And the answer is well, okay, production wants something, but in the end we follow product design's will, in the end it's all about product performance and a neat technical solution." (166:4) ***(s55) Call for more competition on cross-functional optimum*** "Product design happens only once, it determines the product. But I have the production for quite a long time, and it determines the costs. You have to find the balance in the cross-functional optimum." (131:21) [Talking about his idea of a better NPD organization, author's note]: "There would of course be conflicts, but they would be exactly where you'd want to have them, that's the good thing […], it would be on the matter itself. A conflict could be like, a product designer often can build in his technically sophisticated functional solution, but the manufacturer could say if you build that in, every third part will be scratch, because it's not yet ready for series production. But that's exactly how such a sparring should emerge." (158:29) "If you have such a cuddle system, then it is like, oh well, it doesn't work, but that's not so important now." (165:11) "The overall optimum has to be the focus, and for this you have to talk to each other. It doesn't help if we only optimize manufacturing costs. Product design has its focus,

	production planning has its focus, but it needs to be the overall optimum, and for this we have to talk to each other." (152:24) ***(s56) Cross-functional structures create no competition*** "That's exactly the point, where I say, I now sit here, having my project work, having this theoretically cross-functional topic, having this cross-functional team with selected people from manufacturing, with a production planner, a process specialist… all of these people that should in fact be key figures for manufacturing, having the big overview and also the expertise. But nevertheless [pauses, author's note] - that's what I say, that's where it suffers." (163:8) "The communication base between product design and production has been created. The difficulty now really is integration." (183:2) "So these walls and borders, actually we've invented the simultaneous engineering for it, that you do not just throw things over, but these walls still stand strong. That's why they introduced the simultaneous engineering teams, to make the functions sit together. But only product designers are sitting in there." (181:23)
(t) Informal relations inhibit competition	***(t58) Informal relations inhibit competition*** "The production planner is only product design's attorney in the end. That's because the two of them discuss, against each other, but at some point they have to find an agreement. When the planner discusses with the manufacturer later, then of course the planner has to defend the result he achieved, and that's how he automatically defends the product designer's opinion […]. On a hardware concept workshop they are aligned to the point that also the process designer defends the product designer's concept just like an attorney. And certainly, the planner also takes the product designer's position. You see the sequence here." (131:33) "You do a lot of networking, and I notice that I learn more for myself, but the product is not necessarily becoming better through that." (154:36)
(u) Upstream functions wait out conflicts	***(u59) Upstream functions sit out conflicts playing for time*** [On the question what happens when manufacturing costs optimization is conflicting with material cost optimization by product design, author's note]: "They'd definitely wait it out. That happens quite often in our company. Then you would just wait, and hope that it's not there anymore next year." (182:37) "If you're a product design team manager, you've perfected your defined mechanisms. Then you have open ears, namely on both sides, here in and out there." (176:17) "Actually, there's always a CAD model available. But they often play it like that, that you don't get the access rights in an early phase, that the product designer doesn't release it." (145:25) "We bring in requirements for manufacturing-ready design. But you can see that the execution of these topics is often very very chewy, they only work off these topics very slowly, assess them, play them back. That's a lot of backbreaking work that's in there." (151:2) "The difficult thing is that in an early phase, you don't know yet exactly what will expect you, or you cannot describe the consequences of it exactly. And as you say, at some point the topic is over. Where you might say now is the point where we collected all the requirements, and now it's over, and afterwards you barely have any possibility left to still take influence." (148:19) ***(u60) Upstream functions play out information asymmetry*** "But of course, if I [production planner, author's note] tell him [product designer, author's note] that this screw hurts me, I could save that much money, he says to me I need it for the product stability, so when he says he needs it there's not much I can say." (180:27) "We're never on eye level with product design in the discussion, they always say, it doesn't work due to product design requirements. There's nothing we can say against it, we always sit at the smaller lever." (39:1) "When it's on manufacturability, for the battery for example, [names person, author's note] had quite many ideas, but they were always like, yeah yeah, it's alright. She was simply being ignored." (179:10) "There are always discussions that we wouldn't achieve our development or production goals [by implementing a manufacturability optimization, author's note], but I don't always believe that. Then it shows through, that it would be indeed achievable, it would just be a new way." (162:5) ***(u61) Path dependency from preceding products impedes competition*** "It's easier for the product designer to take an existing product and derive and optimize from it, than to go a new way that would maybe require me to perform a new product validation, unknown risks and the need to realize the whole thing." (162:3)

	“What you’ve seen in product design is that […], manufacturing tries to optimize, for understandable reasons, as much as possible in the new product generation, what they didn’t like in the old one, what was inconvenient. However, on part of product design, there is the statement that we’ve got order to design a technical overhaul of the old generation, in which some things are changed but the rest is take it or leave it.” (167:20)
(v) Downstream functions avoid conflicts	***(v62) Bridging functions don’t live challenging role*** “Process design is continuously driven to, hey, please also think of series production. The process design employee, however, views himself as a designer.” (177:29) “They [prototype production, author’s note] get their work orders from product design, and they have their interfaces there. They simply don’t know anyone from manufacturing.” (145:12) [Process designer]: “Sure, we know the problems of the manufacturer, but in fact it’s not our daily problem and we can’t represent it the way it would be necessary from the manufacturer’s view.” (170:8) “Process design does it just the other way round, so he doesn’t live the role but even rather backs off, and, as you say, rather takes sides with product design instead of manufacturing.” (157:18) ***(v63) Downstream functions react with cynicism*** “That’s certainly poka-yoke [ironical, author’s note].” [Process designer to an evidently not poka-yoke cable harness, while no to-do list point is attributed for the topic, author’s note]. (68:1) “That is all well thought through [ironical, author’s note].” [Prototype worker to a not well thought-through plug, without any further call to the present product designer to change it, author’s note.] (68:1) “Oh man, I hoped no one would notice this.” [Prototype worker on an extra manual activity, author’s note.] (68:1) [Process designer on production management’s proposal how manufacturing costs could be reduced, author’s note]: “It’s clear anyway that we won’t make any money with this car. That’s just to satisfy the market.” (67:1) ***(v64) Targets bring downstream functions to the table*** “The closer we come to target agreement, where it’s all about agreeing targets long-term and irreversibly, the higher is the own incentive to join the discussion.” (155:6) A service representative, as another downstream function, is always present in all hardware concept workshops, and service requirements are as well quite present at product design. This corresponds to the fact, that service representatives have strict quantitative objectives regarding the amount of time and effort a service employee needs to dissemble a component. (189:1). [Production planner]: “We know exactly what it costs to insert a screw here that might have to be disassembled in service. And that under no circumstances may it happen that something more or less has to be done there. But with regard to production, I’ve never seen a similar discussion.” (161:25)
(w) Cross-functional conflicts are escalated away	***(w65) Cross-functional conflicts are escalated quickly*** “I’m not involved in any conflicts between the product design and the production department at the moment. I have the feeling that these are relatively quickly handed over to the management hierarchy, maybe because the interlinking on the operational level is not the closest.” (127:38) [On the question if conflicts between production planning and manufacturing are rather solved on an operational level due to their organizational interlinking, author’s note]: “No, I don’t quite think that […]. Unfortunately, this is also often sorted out on the management level.” (127:39) [Product designer on conflict handling, author’s note]: “If there’s something with the production plant, or something already in series production, then the management level is quickly getting involved.” (128:25) “I said to the foreman, please invite him [the product designer, author’s note], we knew who he was, but he just didn’t come to look at it. We have to solve it together, but no reaction from him, we followed this through for quite some time. Then our direct manager send him a note, still nothing happened. And only when we went through the very upper level, he came down to us with quite some anger.” (154:41) ***(w66) Management avoids conflicts for political reasons*** “What I notice are topics that are discussed on a management level – well it’s political there, [...] and many conflicts are avoided […]. On the working level, or the group leader level, I didn’t notice any real clashes with product design.” (127:29) “Often, on a working level, we had quite cool ideas, and we also knew that our competition is better than us partially. But as soon as you brought it onto the management level, we

	know we have objectives, and you have to be better than competition, and the whole thing was looked at from a political view - let's better not show this bar, it looks so negative." (143:30) "Regarding manufacturability, there was one example for the battery, [names production planning person, author's note], he had quite some ideas, where they always said yeah yeah, it's alright. Who was quite ignored, in fact. And then, at the SOP of this battery, we really had these problems […]. So [names production planning person, author's note], he could tell you quite some things. But in the end he was made a victim of all that." (179:11)
(x) Low decisiveness holds up competition	***(x67) Instances of weak decisiveness in NPD*** "We are a bit weak in decision-making. But that's not because the facts are not on the table, it's because we don't dare to decide." (160:14) "The department interfaces, you need them, and they're not super-efficient, but internally we go around in circles more often […] but that's related to the decisiveness around here. Because we analyse the same topic 100.000 times." (82:35) "They have difficulties to sustain a decision." (82:39) "That's all quite a bit indecisive here, they keep on dithering." (45:5) "In a later NPD phase, we start throwing over everything that we've defined in an early phase, we're incredibly bad at this." (82:45) ***(x68) Time pressure impedes competition*** "By now, there's not much you can change anymore, anyways. If you now start to run at each other [at the cross-functional counterpart, author's note], you'll get your stuff done even less so." (128:18) [On the question why manufacturing does not engage more for manufacturing-ready design, author's note]: "If people are so much working to capacity, then they do their daily business and when they're done with that the day is over. Only if you have a bit more time, then you come up with such ideas, or have the time to push something significant through." "At the beginning, they did it really well [to discuss manufacturability concerns with product design, author's note] but since we came into this rush mode, all they say is, the main thing is that the product's okay." (82:103) "It's quite a spiral, the less projects you decide the more you get into such situations, and the more you come into situations where you have to provide some security aspects to avoid something like that, but if everyone builds his own small buffers…" (148:10)
(y) Complexity allows for smokescreening	***(y69) Financial steering logic induces buffers*** "Somehow, we always reach our objectives, however this works [laughing, author's note]. And just in case, there is a bit of turning or discussing until we arrive there." (153:34) "The largest problem that production planners have is, that in large companies as CarCo, you're always praised when you give back budget. And you always get hit at the head if you calculate your product very sharply, hoping if it's really on the edge you'll receive another few millions. If we would manage to introduce a shift in this thinking, I'm sure that cost-efficiency would raise by 10% in the next years. I'm a 100% sure, because we hide 10% and we are educated by top management to hide this 10%. […]. It's a two-sided medal, I'm aware of that, but sadly it's steered like that, that every, and really every reasonable project leader relies on buffers. And for the manufacturer it is the same." (158:15) "What makes the whole thing a bit difficult, we give a plan value, and then there is a savings potential just drawn over it, and from your plan value only a target value is left over […].The consequence is that in the next project, the planners pack 30% on the value which is given to the company. And this is a whole lot of money, and these are wrong values. But just because there comes a savings potential (180:22)" "And then perhaps it's cut, so it's clever to go in there with a bit more, because generally there's always a cut." (124:41) ***(y70) Border walk of handling complexity*** "In an early phase, you need a certain abstraction level, where in the past it was said that you shouldn't simplify it to the point where it becomes wrong. And here we are at a point, where you can't give a generic answer. It's a border walk, a certain simplification is necessary, such that things stay manageable, but on the other hand, the things you simplify can lead to large problems, and we've experienced masses of them ourselves." (148:42) "That's a bit the crux of the entire matter. We stand in our own way with that way of calculating [the business case of our products, author's note]. I discussed with the other OEMs, and they all have the same problem. Although the solution is so close. It's damn complicated, you barely get to achieve any transparency." (158:37) [Member of headquarters project team, who consolidates the individual plan values or production planning, on the question if he challenges the numbers as some kind of

	lawyer of the cross-functional optimum, author's note]: "I only draw the numbers together, I don't actually look into them. My boss is quite technology-loving, and he looks into the numbers in detail, but surely he's an exemption among the product line leaders." (137:28)
(z) Governance functions unable to challenge results	***(z71) Governance functions with insufficient insights*** "Controlling, as the guardian of the entire product-related costs, has a large interest in minimizing them, and with them we have most discussions around manufacturing costs. They're always too high in their view, in general, and likewise the calculation methodology. We had a discussion with one of the controlling colleagues earlier this year, and they have not a clue of an idea how we calculate that." (155:8) "You should actually have some kind of training process for the manufacturing costs, you would need experts that know the content. Who can say, are you crazy, for such a process you want 20 workers? Or who say, for this assembly content of five minutes, you'll be able to get that down to three minutes." (156:20) "Procurement controlling for example, they countercheck our planning. But we have production processes at the new product, which they just don't have […]. What came out at the end, we talked about it, and they just took our values minus 5%. Well, thank you. Because they just don't know any better." (163:22) "The controllers have a completely different focus on it than someone from product design or from production, and it's just not possible to clear up all questions to 100% […]. It's quite complex, and quite cumbersome across so many hierarchical levels." (143:23) ***(z72) Governance functions versus operational functions*** "The designer himself does barely arrive to do his job, because he's permanently externally steered and controlled, because we pack on a product design team, with two to three designers on board, we pack seven to eight controllers on it." (158:2) "Sadly, we had more hand-raising functions than people that actually do the job." (158:2) "We create nothing but managers, no experts anymore." (158:66) "From my view, honestly, it's overcontrolled, the whole thing. Sure, I have many interfaces, and I can all put them down on such a process chart […]. If I only follow the process, then often it doesn't work, and maybe that's the danger, because you create a super process, but which is somehow so complex that many would say, that's too complicated for me, I'll do it on an informal level." (164:14) "There are departments that take more time for themselves than you as a value-creating department have. For example controlling, It's really like that, they sometimes have four weeks of time to evaluate and you yourself have only two weeks to do the work." (171:12) "Now I know why the stage-gate evaluation takes half a year, but the actual evaluation is granted only one week of time: until all the evaluation assumptions and guidelines are worked out and match up, most of the time is already over." (137:2) ***(z73) Acceptance of target setting process*** "Controlling derives a target for product-related costs from different methodologies. Implicitly, a target for manufacturing costs is included in there, mostly via preceding products, profitability ambitions and so on. Controlling derives that out of the blue, just as he likes." (126:36) "Before target agreement, they [targets, author's note] are rather spongy, but as soon as the product steering committee gives its okay to the overall sum, then the whole thing is through and the target is set. They're measured hard against this target, but before, they have the chance to build up endless buffers." (143:64) [On the acceptance of NPD guidelines set by controlling, author's note]: "That's always difficult, as most of the guidelines that controlling provides, it's not always transparent and understandable." (168:6) "The target guideline, actually it's there relatively early on the vehicle project level and on the platform level, but just not as granular as it would be of relevance for us." (155:25)
(ab) Competition scarcity around innovative projects	***(ab74) More interface conflicts for brown field projects*** [On the question where there's competition between functions, author's note]: "Always for product changes, who caused the change, has to pay, there is quite some competition. For existing processes, for example if you look at the combustion engines, where the production plant exists already, that's also a point in the NPD process. Because real costs would emerge from a change. For us, with a new product, it rather starts close to SOP. " (131:27) "I know that my colleagues from the combustion engine, they have conflicts [between manufacturing and production planning, author's note], but there the starting point is a different one. You have a grown structure there […]. For us, at the end of the day, everything we plan is on a green field and therefore there are less conflicts." (148:35)

	“When I started here, there wasn’t anything, there was no manufacturer who could have intervened in product design […]. And likewise production planning, they had never planned an electrified engine before, they just had no clue.” (147:2) ***(ab75) Path dependency pitfall for succeeding projects*** “Actually, at the beginning, you should invest a lot more of thinking into it, I have the chance to make it right for once – because when an idea has been established at some point we’re in the same situation as all are, that you say I’ve created a solution somehow, which emerged from out of my guts or on short term, then it’s perhaps not the optimal solution, but nevertheless I have to live with it in the long run.” (148:36) “I think what is very important are the volumes. In the case where we start a new project and are in the early phase, volumes are still quite manageable when compared with other projects at CarCo […]. And I think that product design still has that perspective, that those few high voltage batteries, we’ll get them manufactured somehow.” (170:36) “For us in the electro mobility, this all has been just toys. No one has taken that seriously, the processes and all.” (149:4)

Table 15: Representative supporting data: research question 1 - competition

Representative Supporting Data for Second-Order Themes Impact of constraint introduction on coopetitive behaviour	
Second-order Themes	**Representative Data**
(A) Increased interaction	***(A1) Increased interaction downstream*** [On the question how interaction frequency with downstream functions would change, author’s note]: “It would rise by many times. If I had only the [mentions constraint value, author’s note], then I indeed would have to ask them every time. Then I had to choose, if I get someone from them on board from early on, who does the first constructions together with me, and instructs me there.” (161:1) [On the question how he would start working if he’d be given a manufacturability constraint, author’s note]: “I would first have to get a manufacturer or production planner, saying so here’s what the tool’s displaying me, how do you view this value, is that realistic from your point of view? Because they are the ones who determine the process times, calculate them and procure the plants and make the investments. Without an exchange with them, I wouldn’t be able to optimize the product.” (162:23) [On the question how interaction would be with manufacturing given the constraint introduction, author’s note]: “I, as a production planner, would have to sit on the manufacturer’s lap […]. I’d go to manufacturing to get my own impression, how does it look like, do you have enough workers, where does the shoe pinch, where doesn’t it, let’s be clear here […]. Transparency, as early as possible, that’s the first step towards optimization, but so far we often don’t have it.” (158:45) ***(A2) Increased interaction upstream*** [On the question how he would start working if he’d be given a manufacturability constraint, author’s note]: “I could go to product design, saying give me five screws and not seven. Or to process design, can’t you join this in another way. I’d have to go to the designing functions, to everyone who’s involved before me.” (181:27) [On the question how he would start working if he’d be given a manufacturability constraint, author’s note]: “If I’d be able to say to the product designer with the help of this tool, please take out some screws, then my problem is solved, clearly. I’d discuss more with the product designer.” (166:27) [On the question how he would start working if he’d be given a manufacturability constraint, author’s note]: “If I’d see already in the benchmarks with others, 85 minutes is the goal, no one else builds it below 110 minutes, then I’d get the product designer on board, saying I’m your counterpart from production, I’ll be having a huge problem if we don’t work together from early on.” (158:42) ***(A3) Increased interaction of non-adjacent interfaces*** [Process designer on the question how he would start working if given a manufacturability constraint, author’s note]: “I think I’d prefer to ask the person who actually does the work […]. Because they have the best feeling where they lose time.” (154:10) [Product designer on the question how he would start working if he’d be given a manufacturability constraint, author’s note]: “I’d talk with them [manufacturer, author’s note] more often, in any case at the beginning. I’d start with something like, how do you say in new German, a brainstorming, or a kick-off. Sure, the guys from production don’t

	have to sit side by side with me when I do my lines in the CAD. But as a first input, I'd sit together with them in a workshop. And subsequently, I'd align with them regularly in any case, we'll see if that would be monthly or weekly. But the guys from production would have to sit in there from the beginning on, quality also. That would really be a good thing. And I don't try to kiss your feet here, I really mean it." (149:29) [Product designer on the question what he would do if he would not be able to fulfil the constraint, author's note]: "I'd ask manufacturing, what they would do." (182:7)
(B) Interaction required to be effective	***(B4) Constraint should be trigger for discussion*** "You'd nevertheless need the exchange, meetings where you discuss and hardware where you say, no we can't do that. You don't want to fight this creative part." (166:10) "This will be difficult [introducing a constraint to product design without further explanation, author's note]. It's always the topic for me that you have to talk with each other." (145:22) "Probably a platform, to convince the two departments to talk with each other, to bring them together." (141:35) "If I had a constraint, I'd always rail, are they too stupid to manufacture or what… I don't care. I think you'd have to explain the big picture to them first, saying, if that takes 75 minutes longer to assemble, it's gonna cost us that much money. But you have to know that first." (179:35) ***(B5) Constraints should not be thrown over the wall*** "If I only had the constraint, I'd probably don't know what to do with it." (170:32) [On the question if he would be in favour of introducing constraints, after having explained the idea, author's note]: "I'd say we should do it. Maybe starting it initially in a project, but you should accompany it in way that ensures it doesn't end in a KPI fetishism. Because often, you simply look at the KPI, it's green, and if it's green everything's fine. But the problem is in between. If two departments show they're green, the problem isn't solved." (162:42) [On the introduction of constraints, author's note]: "If you show them the manufacturer's view, then it has the potential to be really effective. Sure, if you only execute it in a hard way, if you just hold the gun against their heads… but if you don't, it has the potential to bring them together." (179:40)
(C) Manufacturing encouraged to get involved	***(C6) Encourages manufacturer to get involved*** "I think it's a fundamental thing that you try to assess it [the current product design, author's note] from a realistic assembly time perspective, and try to cover the worker perspective. I believe it's a good thing. And what's good is that, the manufacturer, he's well acquainted with MTM and the line balancing, and with this method he might be more open to approach future processes from early onwards." (150:16) "In an early phase, manufacturing is still relatively open […], the people from production become angry quite quickly if it's only about the question whether we can or cannot manufacture it, then they say we can't do it, because the process is very error-prone. But if it's about minimizing assembly time, I don't see a problem, I think they'd be open and would cooperate here." (150:12) [Product designer on the question how he would start working if he'd be given a manufacturability constraint, author's note]: "I'd go indeed to manufacturing, really getting the specialists' opinion. We did that for a recent workshop, and it's really cool. First, they are really up to it, because they usually are not involved enough, and second they really know if they can assemble it or not. A production planner can do it as good as he wants, he just doesn't do it every day. With that tool, you manage to interlink design and manufacturing, that's what I meant, the chain that's still missing." (166:19) ***(C7) Pressures manufacturer to get involved*** "It would be the right approach that production determines the value. And of course, then they'd be forced to cooperate, because they know it best." (149:24) "I would have to align that with manufacturing, I would have to talk with them anyway." (153:26) "And it's quite important, that manufacturing is not able to say that they haven't been asked." (147:21)
(D) Focus is set to interaction	***(D8) Prioritizes interaction topics*** [On the question how he would start working if he'd be given a manufacturability constraint, author's note]: "In the first moment, seeing which topics are present, and maybe then, clustering them. These topics, we'll examine them correspondingly faster and deeper, going down to an operational level here, and screen it in much detail." (163:15) "I would know exactly, for these fasteners, I could make better savings, and I could as well look at these with the [cross-functional, author's note] colleagues. Maybe they don't have an MTM training, but they'd still understand nevertheless what's it's essentially about. In a sense that, this costs me so and so much time, and if you could remodel it somehow, we could do the math quite quickly in front of the colleagues." (168:14)

	"If I don't have pressure here, I'll invest my time differently, where I'd maybe have more pressure. And also invest less thinking effort, and move less." (157:47)
(E) Increased understanding and interest	***(E9) Increases cross-functional understanding of production*** [On the question how the understanding of the production would change with the constraint introduction, author's note]: "Better, definitely. I assume, if I wouldn't have this value, I would maybe have over-engineered the design, I simply would not have cared for assembly time at all. So I would have taken more screws than clips fasteners, I wouldn't have had that in mind." (182:4) "It makes it possible to not only have the designer's perspective, but somehow simultaneously take production's perspective into consideration. And I find that helpful." (164:17) "I think it improves comprehension [of production, author's note]." (162:31) "I get at least a feeling for what the cost drivers in production are." (154:23) [On the question if the understanding of the production would improve with the constraint introduction, author's note]: "Yes, of course." (158:49) ***(E10) Increases interest in manufacturing*** "I think that it would indeed raise interest [in manufacturing topics, author's note]. And that you would take care of it a bit – sure, everyone would, even if it's not his target constraint, see how his targets can be achieved […]. But if it's in there as a constraint, the interest would naturally grow." (161:7) [On the question who he would involve to check a design idea triggered by a manufacturability constraint, author's note]: "I'd have to go into the production plant to see if it will work for 100%." [On the question how he would address problems in fulfilling the manufacturability constraint, author's note]: "In each case, as a production planner, I'd try to find out as much as possible about current production processes. If I'd be in a very innovative project again, then I wouldn't have a manufacturer who I could ask by that point in time, then I'd approach the people in the prototyping plant. And ask them, because they work with the plant and the processes day by day, asking their expertise what you could shorten, what you could make quicker." (150:10) ***(E11) Increases mutual respect across interfaces*** [On the question if the introduction of manufacturability constraints would weld product design together with production or infuriate them against each other, author's note]: "Weld them together. And that's the interesting point. Because transparency, when the department really says, have a look at it, I know it's annoying. And if you really show them the manufacturer's perspective on it, then it can weld you together […]. It has the potential to make them weld together, saying that, well, the other one is an expert, too." (179:40) "I think they'd had a bit more respect of each other, such that, you think, well, the other one had quite a few thoughts on the matter, and now we'll just have the details optimized […]. That will simplify the whole work." (182:15)
(F) Internalization of manu-facturability	***(F12) Constraint leads to internalization of manufacturability*** [On the question how introduction of constraints would alter cross-functional alignment efforts]: "I think it would be reduced […]. If I've worked with my counterpart on an operational level in beforehand, then communication will be easier. Simply because I'll know, what I have to pay attention to." (182:11) [On the question if manufacturability constraints should be introduced as a method, author's note]: "Yes, from an entrepreneurial perspective it would be very reasonable. Because you bring together these two worlds, and reduce those parallel structures a bit. Because I think this barrier is the largest problem, and I had, right on my PC, my production counterpart. Probably I'd save myself a lot of meetings, in which I'm told that the component is too complex or too difficult to manufacture." (182:47) "From my point of view, this would not only concern product design, but every interface area. With this tool, or the overall approach with the constraints, you could improve the interface between all departments. Or reduce iteration loops, because you see the consequences at once." (182:51) ***(F13) Interest for consequences of design on manufacturing*** "It would be useful if I had some guidance, some kind of sensitivity analysis, which product design or which component needs the most assembly time in manufacturing. At the moment I wouldn't know, how complex these differences are […]. Because actually, without that, I wouldn't be able to construe. At the beginning, some big rubbish would come out of my design, which I would have to entirely discard again. Because I wouldn't know that a clip takes longer than a plug. Thus, actually, I'd need an info how long takes what. At first, I'd need to gather that." (182:6)

	"At first, I'd try out what leads to the assembly minutes. So, I'd see where I build in screws, and how many minutes one screw causes. How many minutes one module connector or a nut causes. Such that I see, where do I have the levers to reduce down to the 56 minutes." (167:34) [When asked for feedback on the constraint introduction of assembly minutes, author's note]: "Maybe some other visualization. Sure, at the end, the minutes count, but just as a compensation, as a gamified element, that you're shown, hey you're saving that much money with it, I'd find that important. And, that you get some list how the elements contribute to it […]. I need that transparency such that I can learn from it. Generally, everyone who uses it, will have to learn, by this transparency or trainings or so, which components have which consequences on assembly time." (182:48)
(G) Immediate feedback on constraint fulfilment important	***(G14) Immediate feedback for constraint consideration*** [On the question which pathway would be best to bring manufacturability requirements to product design, author's note]: "It's all about the channel. If it's a PDF file, then of course it would be the worst conceivable solution. Then no one would react to that. But if there would be some tool to calculate the fulfilment of these assembly requirements automatically… It would have to be intuitive and playful, then you could introduce as many [constraints, author's note] as you like. Only, controlling and tracing these values should not produce any additional effort for the designer." (141:41) "At the moment, it's like that, the product designer construes and only when he has finished the design, he gets feedback. Weight, manufacturing costs, eHPV. And that's only after his construction is finished. But what it actually should be, is that you have to get improvement suggestions all the time, such that feedback accompanies design. In a sense, you have to co-develop. " (176:16) [Asked about the frequency in which he would look at the current status of constraint fulfilment, author's note]: "So, if I get the info where I'm standing currently at a push of the button, depending on the project's responsible level – on an operational level, I'd look at it weekly, almost daily, as soon as there's a product modification […]. It should be assessable at once on a digital basis. If you look at our evaluation phases, for example, we're in the sixth evaluation run now for the new product generation. And now you discard all premises again, we'll experience a seventh or eighth run probably […]. Thus, I believe that a quick assessment is important. That you can get the values at once." (172:16) ***(G15) Immediate feedback for constraint optimization*** "The cool thing is that you can easily try things out. At some point, you'll start to optimize the thing yourself. You construe it, and I can't imagine that there's only one solution in the end, and then you think you're at a point where you could go left or right. And until now, you would have always gone left, because as a product designer, you'll follow the function. But now, if no big differences with regard to the function are there, and you don't see cost differences in your view, then you might more easily try the other path." (166:15) "It would be a cool effect if, if you're working at it and understand at some point – well, one example: You construe one or two quick-fasteners at the housing, then you think, what would actually happen if I put in a third one. And then I suddenly see that the value explodes, because it causes a huge time amount for the transport. Then I'd think okay, if it's so extreme, I might try to get down to just one. So you could play around a bit in the beginning." (165:17) "It would be important, well, option 1, that's x minutes and y €, and it has a function of this and that. Then it would be interesting to see where the real pain threshold is […]. Generating options, you can do that super easily with that thing, and see how much you can get down, you'll try out an extreme option. So, generating quick options, that would be the solution." (166:17)
(H) Discussion on cross-functional optimum encouraged	***(H16) Encourages production to critically discuss with design*** "I find it quite good, because you would discuss with them [product design, author's note] much more intensive, how it would work [for manufacturing, author's note]." (162:26) "I'd have the values earlier, and with them sound arguments to influence something [at product design, author's note]. Not taking away from him the development function, but helping him to modify his design. It's not that much more power for me […], but I can help him to reach his targets and I can also discuss his targets." (166:29) "If the constraint would be 20 minutes, with or without the tool, I'd have to discuss with both of them, with all functions [process design and product design, author's note] anyway." (168:13) "With regard to the product, I'd ask design which processes have to be done in any case and which ones we could maybe omit to simplify manufacturing." (150:11) "Every project leader, who would get the constraint, would have to design his production system in accordance. And would have to influence product design in accordance. I

mean, we’ve tried already many things, like clips instead of screws, but until now, that has always failed.” (155:16)

(H17) Optimization first within production, then design

“I would first see where I can - which lever I can draw, without having to change something in the product design. Because if I had to fight in the product design teams with product design, and they would have to alter the entire design to make me save 20 minutes... Then, I would have to prepare a presentation, why do I want that, and I’d have to take care that the developers jump on that train, and if it’s not working, I’d have the same struggle again. Thus […] my first step would be to look for the quick wins.” (168:12)

“I’d draw a value stream analysis, from the broad view to the details. Then I’d look at processes which are existent already, asking for expertise from the plants, asking other planners, and I’d get the assembly times out of the plants, of the processes that really match. It has to be detailed, it has to be an exact match, because just a little bit of a different technology has different, very different assembly times. Then I’d jump into the value stream to identify exactly where I’m too slow […].” “And if you’ve asked everyone there, if you’ve taken out everything, and still wouldn’t reach the value? If everyone says to you, with that product, it’s not gonna be possible to get anything more out of it?” “Then I’d address the product and ask the product designer.” (159:36)

„I’d also have a look at the logistics around, the provision of material around is important as well. How is the provision of material, building the shelf differently somehow. Let’s say, the interface of how material provision and the work place is, and how I can improve it. And only after that, I’d approach the separate system, product design, to change something there.” (168:17)

(I) Transparency on cross-functional optimum increased

(I18) Quantification allows for transparency on optimum

“From a production planning point of view, you could underpin requirements significantly better, saying, look, you have 48 screws and 15 module connectors here. If we’d do it like this, we’d save 5 module connectors and 24 screws, so on hand we’d have savings in the material costs, and we’d have savings in the assembly time. I don’t see the material costs here yet, but in the end I’d have a starting point where you can say, from an entrepreneurial, overall perspective, this is the right way to go. Here we should try to find a solution.” (162:32)

“It’s beautiful here, because you try to approach each other [the cross-functional counterpart, author’s note] by making something [objective, author’s note], which is perceived to be very subjective. You make it quantifiable, by means of these assembly time blocks that we’ve defined.” (150:18)

“I’d go to the responsible production planner, asking, hey, I found a possibility to save 10 screws, they said that’s five minutes, what’s the consequence thereof? What would you save, because for me it’s so and so much additional costs. A bit like business case calculations.” (170:31)

“Product design has its focus, production planning has its focus, but it needs to be the overall optimum, and for this we have to talk to each other, because otherwise I can’t determine what the overall optimum is. And you’ll have the easiest time in this discussion when you have numbers, data, facts." (152:24)

(I19) Encourages systematic approach for optimization

“I’d give some thought on what the main driver of these [assembly times, author’s note] is, and knowing this, I’d address these correspondingly and would try to adjust them accordingly.” (172:24)

“Sure, I’d look for alternatives. Going new ways. Because I’d see that with my current approach, I’d manage to get down to 50, but from there, the we’ll-do-as-we’ve-always-done-it approach doesn’t work anymore. I’d go and ask other groups, asking [names department symbol of other product designers, author’s note], do you have an idea? Do you have an idea how to construe it? Maybe you can omit it, I’d save 20 minutes, Would that work? Thus, asking around, maybe someone has an idea.” (179:30)

“You’d probably have to allocate the 125 minutes to their respective components based on their complexity […]. In this manner, I’d distribute and in principle, I’d then start to think, which one of these costs me the most.” (172:1)

(I20) Discourages from including non-transparent buffers

“Why do I put the screws, what’s their design-related value-add, and how much security buffer did I maybe plan in. So now, I’d maybe have a factor of three, and it’ll be fine and it will hold - it’s like that pretty much. Because for design, screws are a simple thing, but they didn’t have the assembly aspect in focus. And now I’d look at that, seeing, well, the screws have the highest impact, then I would of course, from a design perspective, now try to reduce the screws to a minimum.” (164:20)

[On the question with which functions conflicts might emerge from the introduction of constraints, author’s note]: “It’s all dependent on the kind of analysis that you do, do you grant a longer way time [time designated for walking distances on the shopfloor,

	author’s note] or an additional walk – of course as a planner, you can eliminate all of that, because you have to achieve the 20 minutes target, which means that you plan to the edge.” (168:15) “I mean, with that, the manufacturer is actually naked.” (165:24)
(J) Risk of overemphasizing constraint	***(J21) Risk of neglecting trade-offs to other design requirements*** [On the question which drawbacks he sees from the constraint introduction]: “Well, that he comes into a target conflict at some point, because he can’t do it all. It’s always a question of what I put first. What do you want to achieve, if you say you want to save construction space, it’s gonna be smaller, then it’s gonna be more complex with regard to the geometry, and then variable manufacturing costs are going to rise. The wider you pull apart the target range, the more difficult it will be to land in the middle of it. And then you’d have to think about what the second priority is instead.” (156:27) “Quality could be a discussion, so time needed for quality measure would be a target conflict, if I take out time there. In the end, they have a purpose somehow, at least someone brought them in for some reason. The question here is, if I would take quality risks by taking out checks or something similar.” (157:33) “I think the difficulty is to have these trade-offs, what do I accept and what don’t I accept. For example, what may material cost me for one minute [of assembly time, author’s note]?” (166:21)
(K) Additional effort for design functions	***(K22) Additional effort for product design*** “At first, this is an additional effort for product design.” (149:39) “For the product designer, it’s principally an additional effort, because actually he has reached his goals, because assembly time is usually not a goal for product design. Indirectly maybe, because it causes production costs. But now it would be, and of course, an additional target value is always annoying.” (171:33) “I know some product designers who would be 100% against it. Because they say, I do the design, and the rest is production planning’s task.” (162:27) “It would annoy me, because suddenly I have a target from [names department symbol of production, author’s note], which I actually don’t care about. So I’d have a new target, and targets are, first of all, annoying.” (179:39) ***(K23) Risk of prolonging the design process*** “It would be critical if it would force it up too much, if people would need too much time to design, and wouldn’t simply hand out the component design. That’s a general problem, because before [constraint introduction, author’s note] you didn’t have it. Then, the component was done when it was done. But if I see it now, it’s just like a bachelor or master thesis which you want to adjust more and more, and you’re unable to stop. And there’s the enormous risk that you only optimize for assembly time minutes without looking how long it has taken you to design.” (182:22) “Product design has different goals, they want to fulfill them as quick as possible, do the product validation, and don’t want to touch again what they’ve designed.” (157:34)

Table 16: Representative supporting data: research question 2 - impact of constraint introduction on coopetitive behaviour

Representative Supporting Data for Second-Order Themes Moderating Impact of Constraint Types	
Second-order Themes	**Representative Data**
(L) Presupposition-less tangibility at the interfaces	***(L24) Tangibility and easy calculation important*** “That’s why I like the € goal, it makes it tangible. Everyone can easily conceive €. I can give a € target, saying here’s the deal, variable manufacturing costs are well present in the company, everyone knows what’s in there. There are these [names committees on variable manufacturing costs, author’s note], everyone knows it. That’s why in principle I’d consider it as the right value, quantify it in € and the consequences will be clear to everyone.” (172:27) [Being asked why he prefers variable manufacturing costs as a constraint, author’s note]: “Personally, I find it more tangible. The value with a € at the end.” (157:39) [On the question what the constraint type would need to gain his acceptance personally]: “We simply work by €. And certainly, that’s a fundamental condition.” (166:31) “No one gets this, the €. Thus, minutes. Even I myself have problems with variable manufacturing costs.” (179:38)

	(L25) Meaningfulness for involved interfaces [Product designer]: "With the minutes alone, that wouldn't mean something to me, there's little that would spring to my mind […]." (182:21) [Product designer]: "What I could imagine to be a main conflict, is that this assembly time doesn't mean anything to me, and I wouldn't know what comes next. And as a first experience, it would be a black box for me." (182:26)
(M) Comparability to other design requirements	***(M26) Quantifiability required for constraint acceptance*** "If there would be someone who said from the beginning on, we can't make it, we don't manage to, we don't get down to this 8-minutes target. I'm afraid that this would be accepted, and I believe that it would always have third priority in such a scenario. Except if you can convert it into some costs, which at some point are higher than development costs or material costs. Because at the end, it's all about that number anyway." (161:18) "Experience tells us that, if it's justifiable with numbers, data, facts, why it is like that, then they [product design, author's note] are willing to support it. We once had a case of quality issues, with the interlocking. There, we went together with product design to the manufacturer. And the quality specialists presented information on which defects they've had in comparable products, and what it means in terms of rework or defect volume. Then it was decided to do a monetary assessment to see if the design of a new plug would pay off […]. And it turned out to be a big lever, of course it's always a bit of reading the crystal ball, but the facts and numbers were accepted and the designer said ok. And they did it." (151:28) "For me, it would be essential to know what it costs, if I as a product designer wouldn't know this, if I say ok, it's in there everywhere but I nevertheless have no idea what it costs me to assemble a screw, or what is the cost difference to a clip and the overall costs. Is the clip at the end cheaper, because it maybe costs me much more to produce it?" (154:19) "Of course, if you know, that it serves the company and reduces its costs, then it should actually be possible." (171:34) ***(M27) Assessable contribution to cross-functional optimum*** [Being asked why he prefers variable manufacturing costs over the other constraints types, author's note]: "Automatization is a topic, I can't weigh up a plant investment against assembly time, but only against manufacturing costs." (157:39) "And probably it's also a topic of, down here [pointing at all different constraint types, author's note], talking about what kind of target we get, what I consider in the end, that you lay them out in a floating manner, that you exchange credits. Maybe you could think about something like that." (172:17) [On the question what he would do if the product designer would refuse to make a design change that would bring down the assembly time, author's note]: "Costs: 10 minutes times 100.000 pieces, that's much more than a month of [product design's, author's note] work. So, expressing it as the overall time or overall money, one way or the other, if you multiply it with volumes, even if it's only a second, two or three, then it will be coming out of this, that a design change is indeed reasonable. And usually, they will acknowledge that." (157:35)
(N) Allowing for actionability	***(N28) Achievability by the constraint recipient*** "It has to be achievable." (153:30) "It should be well substantiated […], he should somehow be able to – how should I say, it shouldn't be too far from reality, this constraint. Thus, the organization who generates it, should be in some way familiar with the product concept and with the production concept." (169:27) "So there's one large condition in this company, targets that we set ourselves should be realistic and achievable. It's one of our principal values, and I would like to take this up here as well." (169:28) "It's important that the value is halfway realistic. It should be motivating." (182:27) ***(N29) Granting flexibility how to fulfil constraint*** "It would really be depending on, if I make this [introducing the constraint, author's note], on a product level, so really for every variant, instead of an overall value." "What would you like better?" "As an overall target, so that you have a bit of leeway. It's all so uncertain in the NPD process." (153:31) [Explaining which constraint type he likes better, assembly time or fasteners, author's note]: "So, the 48 minutes of course provide me, as a product designer, freedom in a sense of how I can achieve these 48 minutes. If I directly break this down to the details, then you almost already predefine the solution […]. That's why, saying 48 minutes, if this is explained to me why I need 48 minutes, but then I'm granted the freedom, if I reduce the screws by 90% but have to set 3 clips for it […]. So it would be somehow the designer's freedom, and in the end we'll get to a technically better product, than we

	would have by just applying a flat watering can principle, that we have to take out 20% of all fasteners." (168:9) [Explaining which constraint type he likes better, assembly time or fasteners, author's note]: "Minutes, because you have more flexibility with it. Because the other thing is my competence in the end, I can assess it. With the minutes, I'm flexible to distribute them to my will." (179:37) ***(N30) No arbitrary determination*** [On the question how the constraint should be to foster his identification with it, author's note]: "It should be plausible. It must not be determined by just rolling the dices. It has to be some kind of understandable target value." (149:35) "I just want to understand a target, that's enough for me. And if it's not plausible, I would like to be able to say that it isn't. No explanation is not an option." (166:43) "It's quite like, if it makes sense, it also makes sense to me." (161:22) "You always have to create the transparency. If I always say only, yes I give you that constraint, just because I'm having fun to do so - but if I say it's simply an obligation for them because otherwise it doesn't work, and it's simply many bucks. So if you provide transparency to the product designer, then it makes sense." (179:46)
(O) Accuracy of constraint calculation	***(O31) Calculation of constraint needs to be accurate*** "I was expecting that someone has calculated that, that this is accurate somehow." (161:22) "A precondition is of course, that it is well thought through. Maybe you can […] define it with some kind of standard, whatever it is, thoroughly defining these values, maybe if there are some kind of macros or something like that, that these calculations are really clean, because much is based on them. If the production planner relies on them, and the calculation is wonderful but in the end it actually calculates some kind of bullshit, then you'll have even more problems because you cannot straighten it out anymore. That would be my demand, to ensure that." (165:29) "The fundamental condition is that it's correct by 100%, and that there aren't any parallel structures where it says well, it says 56 minutes here, but with the 48 nuts I actually know that this is calculated too high. It really has to be strictly specified." (182:50) "The question that I'd ask myself: Is this reliable, what it says. Just because I construe one more screw into it, is that still true now or is that based on some kind of premises, how are they set?" (170:30) ***(O32) Absolute value to avoid tricking with transitions*** "Namely, not with any transition bridges, but as an absolute value. You could maybe say you have a preceding product, for example [names a CarCo product, author's note], that was a great car and sold quite nicely, we had 300€ variable manufacturing costs. So let's say, as an overall tension, minus 10%, and that's 270€." (172:13) [Being asked why he would prefer an absolute value as a constraint value, author's note]: "Because otherwise, everyone would fake that. That would be a big classic […]. It wouldn't be possible with an absolute value." (172:15)

Table 17: Representative supporting data: research question 3 - moderating impact of constraint types

Representative Supporting Data for Second-Order Themes
Organizational Embedding

Second-order Themes	**Representative Data**
(P) Constraint rigidity	"If you want to get things moving, you have to introduce it hard." (167:36) "Where you really have to fight, and where you have the discussions going on, my experience is that you must not soften in no way […] And these 56 minutes, what you said, then you can really escalate it and make it clear to these folks, ok, there's something not right" (165:27) "I tend towards demanding this quite rigidly. Alone with that background […], there's more behind this 180€ than just manufacturing the whole thing. There maybe is a market behind that, a sales target and all of that. In the end, it all boils down to this topic, and some things stand or fall with it. That's why for me, it's a rigid value." (163:40) "If it's a requirement that comes down from above, and coming down from above meaning that it has been recognized that it's a very important topic, then they will absolutely attempt to abide by it […]. But otherwise, if there's no such requirement, then these are demands that they will definitely not accept, because they would feel limited in their creative freedom." (151:27) "This place is hierarchically driven, that you simply assume that targets are well thought through. And fair enough, they are most of the time." (165:20)

	"I'd say it depends on the phase, what you enforce in the organization. Even severely, depending on how much uncertainty there is. So in an early phase I'd rather go into the direction of a committee decision. And if you really know what's possible, you would have to look at sensitivities, when you really know what goes on in the system, then I'd go into this direction [pointing at stage-gate criterion, author's note]." (166:32) "I'd say an organizational objective, because I believe if you set the value too rigidly, everyone runs towards this value and the other targets get neglected. So you optimize only to this point, and everything else falls off the table." (164:23)
(Q) Priority with regard to existing design requirements	"Principally, € are € and that's why it should be equivalent." (172:18) "Equivalence of manufacturing and material costs. In the end, both are costs in the vehicle and the customer has to pay for both." (149:41) "No matter if these are development costs or are manufacturing costs, I just try to reach the global minimum." (166:33) "In the end, what matters, is the bottom line, the overall result counts. That's why I'm heading towards equivalent, because I have to look at all sides and manufacturing costs are only one aspect of the overall enterprise, and I need to have the overarching overview." (163:41) "I'd say equivalent […]. If I say, I need to optimize all simultaneously, then I optimally get the best out of all worlds." (164:25) "I'd say equivalent in any case. Between automatization and investment, it's always manufacturing costs, that's virtually inversely proportional. That's why we have to optimize it on the same level in any case." (156:43) "Inferior, because if you look at the relation at the moment, it is out of all proportion […], you would make a huge effort to come down 2 minutes." (171:39)
(R) Incentivization	[Pointing between fulfilment monitoring and organizational objective, author's note]: "If I rate it too high, then I get exactly the thing, that as a planner I wouldn't allow manufacturing costs to be three cents higher to get five € of material costs." (157:42) "I consider a monetary incentive as the wrong path here. It possibly leads to a situation, where you attach importance to the one thing, and what happens at the other side may fall off the table. That's the wrong incentive." (162:36) "Bonus in no way, you cannot punish someone if you give him a target, of which you do not yet know if it's realistic." (179:42) "It would have to make sense with regard to the project phases." (153:29) "It depends a bit on how ambitious the target value is in itself […]. If you take a reference product and tighten this value by a not-so insignificant percentage value, I'd be quite a friend of a certain incentive. If you simply say, derive a value and it's only about realizing it, then it would certainly be only monitoring or something like it." (169:25) "There are so many topics, if I really want to prioritize them, and really want to introduce them, then I really have to incentivize it." "What would happen if you wouldn't?" "It would be waited out. I think that happens quite often. You would simply wait, and hope that it's not there anymore next year." (182:36)
(S) Recipient hierarchy level	[Pointing at project manager, author's note]: "He's responsible for the production system and the value stream that is linked to it. So he's virtually the custodian of the entire thing, who also needs to keep a project in balance. I have several component areas, and all are somehow interlinked based on the minutes [minutes of assembly time, author's note], and I need to balance these costs somehow. So he's the one who needs to adopt a global approach to it." (162:37) "For me, the difference is that he's in the project [pointing at project manager, author's note], and he's in the line [pointing at group manager, author's note] – I wouldn't see it with him in any case. Either with the production planner or with the project, high up [in the hierarchy, author's note] of course." (157:43) "Actually, the alignment should be as low as possible on an operational level, but it just needs a bit of pressure from above." (149:43) "The group manager, maybe he can really demand something from the interface partners, an individual employee can't actually do this." (156:44) "Not too low regarding the hierarchy, because they would be able to just calculate something to make it suit." (182:40) "I'd make the department manager responsible. Then you'd know – because an individual employee, forget about that, because he'd argue that some other reason was even more important, there surely will be some reason, and then it falls off the table." (181:30)
(T) Recipient function	"Production should be responsible as well in any case. Because if it's only product design, they don't care. It has to be a common responsibility. Either they drown together, or they both swim." (149:42) "I'd say it must be strategic project management, because design and production would fight each other anyway. For example, if you would make production responsible, design would say again that he doesn't care. Then these cockfights would start again." (159:43)

	“I’d make project management responsible, because they represent both departments. If you only make production responsible, it’s gonna be difficult.” (170:39) “I’d say production and design. Because if they don’t talk to each other, it won’t work […]. They both have levers, design and production, that’s why it would be wrong to just look at design, but it would also be wrong to just look at production.” (179:43) “But if production provides not enough input, so if they say, stay below 50 minutes but don’t give any input – you need more input from them than just the time […]. That why there should be some co-responsibility from the production department.” (182:39) [Pointing at product design, author’s note]: “He has to receive the target, because he designs, thus he has to receive it.” (167:39)
(U) Fulfilment tracking hierarchy	“I’d hang the whole thing up at a higher hierarchy, because they should have the sum of all targets, the overall optimum in their view. And if only the operational level looks at it, then they’d only consider their own goal but not if it’s synchronous to the other goals which the project has […]. They [management, author’s note] have to decide, because they have the overall view and optimally know the sum of all designers, with one of them having his focus on the screwing, and another one on the material quantity, and the third one on weight and they can decide where the optimum is.” (164:27) “The main thing is how the project team is made up, and that’s indeed a point. Of course, someone from product design has to be in there, and here it becomes important. It’s not much of an help if a project manager is in there to moderate a bit, there really should be a production planner, a process designer and a product designer who really discuss on this level, and maybe also someone from procurement.” (169:26)
(V) Fulfilment tracking frequency	“Regularly, but I don’t have to – then I’d just come into some steering frenzy – dependent on the project phase, in the beginning of the strategy phase probably not at all. And the closer I get to SOP – from a certain point in time, maybe 18 months before SOP, I’d not look at the designer anymore at all.”(158:61) “I’d say it’s dependent on the project phase.” (164:28) “In the beginning more often, there you might have to discuss the topic quite intensively, in the beginning you might still question if often, if it’s an achievable goal, what is the feedback from different design areas. And then you could let things run for a bit until it has advanced a bit in the series development, and then review it. So in the beginning, weekly in every case.” (170:38) “Depending on how long iteration loops are. If it’s a component which is construed within half an hour, then I could talk monthly about it. So I’d make it dependent on the time it needs to design.” (182:42) “You are not told every week, or more than every week, that it has to be functionally working either, or that it has to be cheap - at some point you should know this for yourself, hopefully. I think that once a month should be sufficient, as long as it’s communicated and discussed” (161:20)
(W) Introduction point in time during NPD	“It’s important that they get it early enough, such that they still have scope for action. It shouldn’t be as it is now for us, that everything is already decided but you still have to achieve your goals.” (159:42) “As soon as we’re in series development, too much has been decided already, bringing in correcting measures at bearable costs would be difficult.” (162:34) “I’d enter in the initial phase, during concept phase it should already be fully installed […]. As soon as product design teams start their work, I’d want to directly integrate production.” (158:62) “In the strategy phase, I would be able to already figure out if I reach the target with the normal incremental improvements, for example just taking a larger screw […]. Or do I need something completely new which is not yet done, that I wouldn’t take a screw but would weld it. I would have to figure that out already early, because in the concept phase it could already be too late, then I could only recourse to topics which lie already in the drawer.” (164:29) ”Probably during concept phase, when everything is defined more clearly, such that I know how the component is dimensioned. So rather late concept phase.” (182:43)
(X) Introduction mode in existing enterprise	“If you really want to create a dogma shift, you have to work disruptively sometimes. Then you really have to say, we’ll do that in this project. And talk about lessons learned afterwards. But if you let it slowly flow into the existing process, then it would probably always being pushed away […]. So either you say, you make everything new for this project, this goes up and this goes down, and let’s get started. Or you introduce it successively in small steps, so others have to give off more and more, and you get a bit more. But I think this would be more difficult […]. We’re too big for that, the whole company is too complex for that, that you could just introduce something step by step. ” (156:48) “Take it as a requirement for completely new projects. Not for existing ones, for new really products. Don’t introduce it if the car is launched in one or two years, and the production plants are already there, that would be non-sense.” (165:30)

	"You could start a pilot project, and calculate it, maybe for a sub-project and try it and see if it works, and if you see advantages you can roll it out to the big picture." (163:47)

Table 18: Representative supporting data: research question 4 - organizational embedding

Representative Supporting Data for Second-Order Themes
Impact of manufacturability constraints on creativity

Second-order Themes	**Representative Data**
(Y) Pressure to conceive radical ideas	"I think more creative […]. Because necessity is the mother of invention." (157:46) "He has to become more creative, because he has to accommodate an additional requirement which he didn't consider before, and this will force him to think outside the box." (167:40) "Overall, I think rather more creative solutions, maybe because you are forced to think completely different. And maybe you move away from the typical thinking in clamping rails or supporting rails, and rather rethink how could I avoid fasteners overall." (182:45) "You only start to really give some thought in such cases, if you receive targets which are not necessarily easy to solve." (164:31) "I think it would expand it, so you would become more creative. Because otherwise, I'd say you put three screws in it, or maybe a bit different, but now I'd think ok, I know how long screws, they take a long time, what else could you do, maybe gluing or other things which I never had thought of. Thus, I believe there would be more creative approaches in any case." (161:21)
(Z) Increased interaction inspires creativity	"Foster it [creativity, author's note]. Because I have to go figure it out. Just going on doesn't quite work anymore. I have to find new ways, have to give some thought, trying it out like this, maybe some new materials… And I have to go talk to people, also talking with production, and that's not bad. Therefore, it would foster it." (179:45) "When we say we just don't manage to make this leap anymore. With all the optimization we can do, we just come to 17.50€, and that's simply because we have a screw here. And we can only save it if we take out the screw, It just doesn't work in any other way. There's always much you can do, but at some point you've arrived at a point in time where you have to say, this is the end. And then you have to talk with product design." (156:37) "If I'm at my wits' end, then I'd go and ask colleagues, or ask process design, what could you do differently." (164:21)
(AA) Contingent on NPD phase	"I'd say neutral, because you could say that it would encourage creativity, if you already have a specific goal, and within this scope it can indeed encourage creativity. But too much creativity could also be counterproductive, if you set the goals much later, and before that you were free as a bird and now you have to make it fit somewhere into this." (150:19) "I think that he'd become more creative […], because you'd be inclined more to think about alternative concepts. Because you'd realize early that the standard path doesn't work, and he doesn't figure that out only late, when it's too late already maybe, but ideally already early. And he'd sit down and think fundamentally, do I need to screw this at all, or do I need a lid at all. I'd start like that, ok if I'd have to screw on a lid, thinking quite revolutionary, do I actually need a lid? If I'd be a product designer, then this would be the next logical step. We build some kind of block, and it has to be waterproof and fit into the assembly space in the car. And I have the high voltage battery, and I have the underbody, so it would actually be logical to say that I take the underbody as a lid of the high voltage battery." (164:30)
(AB) Contingent on granted scope for action	"It is such and such with creativity; at least I know this from my old department, you have to put forward a shift in thinking at least once to make something start. For example, if you say, how would a car without wheels look like […]. Such that the colleague would start to think, ok how could this be done completely different?" (165:18) "If it encourages or impedes creativity? In my view, it's encouraging if he has the freedom to use these things to the full limit. If they say to him, design it to 56, you'll get a tap on the head if it's 57, and if it's 55 I take away your bonus. Then it's impeding, then you'll have a system which restricts you even further." (166:41)
(AC) Limiting solution scope	"For me, it would limit me as a production planner, if I get this constraint. Because it's something else that I have to consider." (181:32)

“Rather less creative. For example, there was a workshop recently, and I intentionally decided not go there, because I wanted to give them the maximum possible solution space, and these and those possibilities are there, and decide only later which possibilities would be the best ones for production. Otherwise, they’d be already limited from the beginning.” (171:41)

Table 19: Representative supporting data: research question 5 – constraints’ impact on creativity

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