

ACTA

Jordan Verrollot

MATURE SUPPLY
MANAGEMENT AS AN
ENABLER FOR RAPID
PRODUCT DEVELOPMENT
AND PRODUCT PORTFOLIO
RENEWAL

UNIVERSITY OF OULU GRADUATE SCHOOL;
UNIVERSITY OF OULU,
FACULTY OF TECHNOLOGY



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JORDAN VERROLLOT

**MATURE SUPPLY MANAGEMENT AS
AN ENABLER FOR RAPID PRODUCT
DEVELOPMENT AND PRODUCT
PORTFOLIO RENEWAL**

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Supervised by
Professor Harri Haapasalo
Doctor Arto Tolonen
Doctor Janne Härkönen

Reviewed by
Professor Petri Helo
Doctor Ilkka Sillanpää

Opponent
Professor Jussi Heikkilä

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University of Oulu, P.O. Box 8000, FI-90014 University of Oulu, Finland

Abstract

Bringing new products faster to the market is increasingly critical. To reach this goal, companies have been improving their product development practices and processes. Rapid product development (RaDe) is a type of incremental product development model, in which new sales items are created by redesigning existing products quickly and inexpensively. This study examines the RaDe challenges and enablers, particularly the ones from the perspective of supply management (SM) and product portfolio management (PPM).

The main objective of this study is to recognise and describe the significance of mature SM for RaDe, resulting in successful and efficient product ramp-ups and portfolio renewal. The present study follows a qualitative research approach, which consists of reviewing the literature and analysing the relevant practices and current process settings of several companies representing diverse business areas and industry types.

The principal results of this study involve acknowledging and describing the role of mature SM and organised PPM for effective RaDe implementation and product portfolio renewal. The study examines the mature SM from the perspective of 1) the definition of the SM objectives; 2) the alignment of the list of recommended products, buy-items and suppliers; 3) the creation of the product design guidelines, targets and metrics from the SM perspective; and 4) the establishment of the supply capability creation process.

The main implications of the present study highlight the importance of the SM maturity that can support managers in RaDe related planning and implementation activities. The originality of the study resides in the emphasis of the SM significance in terms of different aspects that are beneficial to RaDe implementation and product portfolio renewal.

Keywords: design for supply management, design for X, mature supply management, new product development, product portfolio management, product portfolio renewal, rapid development, rapid product development, rapid product development challenges and enablers, strategic alignment, supplier management, supply capability creation, supply chain capability creation, supply chain management, supply management

Verrollot, Jordan, Kypsä hankintatoimen johtaminen nopean tuotekehityksen ja tuoteportfolion uudistumisen mahdollistajana.

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Tiivistelmä

Uusien tuotteiden tuominen markkinoille nopeasti on enenevässä määrin tärkeää yrityksille. Tämän saavuttamiseksi yritykset ovat pyrkineet parantamaan tuotekehitystoimintojaan ja -prosessejaan. Nopea tuotekehitys (RaDe) on malli inkrementaaliseen tuotekehitykseen, missä myyntinimikkeitä luodaan uudelleen suunnittelemalla jo olemassa olevia tuotteita nopeasti ja halvalla. Tämä tutkimus tarkastelee RaDe -haasteita ja mahdollistajia, erityisesti hankintatoimen johtamisen (SM) ja tuoteportfoliohallinnan (PPM) näkökulmasta.

Tutkimuksen ensisijaisena tavoitteena on tunnistaa ja kuvata kypsän hankintatoimen johtamisen ja nopean tuotekehityksen merkittävyys niin onnistuneen kuin tehokkaan markkinoille tuonin sekä tuoteportfolion uudistamisen mahdollistajana. Laadullinen tutkimus tarkastelee monipuolisia liiketoiminta-alueita ja teollisuusaloja, koostuen sekä kirjallisuuskatsauksesta että useiden eri yritysten niille relevanttien toimintojen ja prosessien analysoinnista.

Keskeiset tutkimuksen tulokset osoittavat ja selittävät kypsän hankintatoimen johtamisen ja organisoidun tuoteportfoliohallinnan roolia nopean tuotekehityksen tehokkaassa toteutuksessa sekä tuoteportfolion uudistamisessa. Kypsää hankintatoimen johtamista tutkimus tarkastelee seuraavista perspektiiveistä: 1) hankintatoimen johtamisen tavoitteiden määrittäminen, 2) suosittelujen tuote-, ostoartikkeli- ja toimittajalistojen linjaus, 3) tuotesuunnittelun ohjeistusten, tavoitteiden ja mittareiden luominen hankintatoimen johtamisen näkökulmasta, ja 4) hankintatoimen kyvykkyyden perustamisen luomisprosessi.

Tutkimuksen merkittävimmät kontribuutiot organisaatioille korostavat sellaisen kypsän hankintatoimen johtamisen tärkeyttä, mikä tukee johtoa nopean tuotekehityksen suunnittelussa ja toteutuksessa. Uudenlaista näköalaa tutkimukseen tuottaa hankintatoimen johtamisen merkityksen tähdentyminen positioista, jotka ovat suotuisia nopean tuotekehityksen toteutukselle sekä tuoteportfolion uudistumiselle.

Asiasanat: hankintatoimen johtaminen, hankintatoimen kyvykkyyksien luominen, kypsä hankintatoimen johtaminen, nopea tuotekehitys, nopean tuotekehityksen haasteet ja mahdollistajat, strateginen suuntaaminen, suunnittelu eri näkökulmia varten, suunnittelu hankintojen hallintaa varten, toimittajien hallinta, toimitusketjun hallinta, tuotekehitys, tuoteportfolion hallinta, tuoteportfolion uudistuminen

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Oulu, Finland, March 2018

Jordan Verrollot

Abbreviations

B2B	Business to Business
B2C	Business to Consumer
CEO	Chief Executive Officer
cf.	confer
CMMI	Capability Maturity Model Integration
DfSCM	Design for Supply Chain Management
DfSM	Design for Supply Management
DfX	Design for eXcellence
e.g.	exempli gratia
etc.	et cetera
KPI	Key Performance Indicator
M	Milestone
NPD	New Product Development
P	Phase
PM	Product Management
PPM	Product Portfolio Management
R&D	Research and Development
RaDe	Rapid Product Development
RQ	Research Question
SCC	Supply Capability Creation
SCCC	Supply Chain Capability Creation
SCM	Supply Chain Management
SM	Supply Management

Original publications

This dissertation is based on the following publications, which are referred throughout the text by their Roman numerals:

- I Verrollot J, Tolonen A, Harkonen J & Haapasalo H (2018) Challenges and enablers for rapid product development. *International Journal of Applied Industrial Engineering* 5(1): 25–49.
- II Verrollot J, Tolonen A, Harkonen J & Haapasalo H (2017) Strategic alignment of product portfolio and supplier management. *International Journal of Management and Enterprise Development* 16(4): 337–364.
- III Verrollot J, Siddique A, Tolonen A, Harkonen J & Haapasalo H (2018) Mature supply management as a critical precondition for rapid product development. Manuscript.
- IV Verrollot J, Tolonen A, Harkonen J & Haapasalo H (2017) Supply capability creation process: key milestone criteria and activities. *Journal of Industrial Engineering and Management* 10(3): 495–521.

Three articles have been published in journals and subjected to a double-blind review process. The author of this dissertation has been the primary author of all the original publications. The researcher has been responsible for formulating the research problems, collecting the relevant literature, formulating the research questions, coordinating the collection of empirical material, analysing the material, drawing conclusions and finally being the primary author of all the four articles. The role of the co-authors included reviewing and commenting the article manuscripts of the first author.

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1 Introduction

1.1 Background and research environment

In current competitive markets, winning products is the absolute interest and central success of modern companies (Ebert 2007, Cooper & Kleinschmidt 2011). The product should satisfy the stakeholders' needs and requirements, which must be considered in the product development, production, selling, delivering, marketing, maintenance, disposal and recycling (Ulrich & Eppinger 2008). A large product offering is commonly thought to reach various customer segments and a larger market share (Xia & Rajagopalan 2009, Wan *et al.* 2012). Toward creating more product variety, the companies' focus tends to be on developing and adding more products to their product portfolio than phasing them out (Hoole 2006, Droge *et al.* 2012). This engenders a negative, unnecessary and unprofitable product portfolios proliferation (Randall & Ulrich 2001, Wan *et al.* 2012), which complexify the product development activities, the product design and the relation to the downstream business process such as supply management (SM), manufacturing or logistics (Orfi *et al.* 2011, Langenberg *et al.* 2012). The ensuing business impacts include a reduced profitability per employee, decreased on-time deliveries, increased numbers of sales items and longer lead-times (Cooper *et al.* 1997, Dickinson *et al.* 2001, Gunasekaran *et al.* 2004, Abbey *et al.* 2013). To address those challenges, the complete business process of product portfolio management (PPM) has been recently studied. PPM aims at strategically, holistically and profitably selecting and managing the companies' products over their lifecycle phases – including the removal of non-strategic and unprofitable products – and at different product levels from solutions to individual components (Haines 2009, Sadeghi & Zandieh 2011, Jugend & da Silva 2014, Tolonen *et al.* 2015b).

The literature emphasises the importance of new product development (NPD), which has been studied widely since the 1950s (Conway & Steward 2009). Because of the global competitive pressures, the shortening product life cycles and the growing product variety, NPD success has been critical for organisations (Koufteros *et al.* 2002, Petersen *et al.* 2005). The rapid and smooth development and launch of successful new products is crucial to provide market leadership, sustained growth, high competitiveness and profitability (Wheelwright & Clark 1992, Bernard & Fischer 2002, Minderhoud & Fraser 2005, Shapiro 2006, Dereli *et al.* 2008, Unger & Eppinger 2009). Companies that develop new products too slowly and fail to

satisfy unexpected customer demands in a timely manner often fall against those with better product development processes (Smith 1990, Cohen *et al.* 1996, Gupta & Souder 1998). Therefore, organisations are exploring different methods to bring new products to market at a faster pace (Millson *et al.* 1992, Langerak & Hultink 2008, Barczak *et al.* 2009, Zhou & Zhao 2010). One approach to organise the companies' product development resources more effectively is to establish different types of development projects (Barczak *et al.* 2009, Cooper 2014). New platforms, product lines, iterations or minor technical improvements can be created with different tailored product development processes to suit the requirements of the projects (Cooper 2009, Jarratt *et al.* 2011). Those different processes present different scope, risk, resource utilisation (Cooper 2008) as well as different organisational structure and culture (Tushman & O'Reilly 1996). Firms increasingly establish shortened product development models to reduce the development time of small-scale projects, and three-quarters of top performing companies adjust their product development process to suit various needs (Cooper & Edgett 2012). Although the scientific community has significantly studied ways to improve the process of developing new products, less consideration has been paid to small and fast product development projects, especially in the business-to-business (B2B) environment (Cooper *et al.* 2004, Kaikkonen *et al.* 2016). Recently, some studies have been implemented on this type of small-scale product development, which requires a minimal redesign of existing products in a short development time (e.g. Cooper 2008, Hänninen *et al.* 2014, Vigna *et al.* 2015, Niskanen *et al.* 2015, Kaikkonen *et al.* 2018). These studies focus, for instance, on the decision setting, team building and organisation of rapid product development projects. However, the way organised PPM, supply chain management (SCM) and underlying SM can support the RaDe type of development projects has not been adequately covered by the extant literature and should be better analysed.

SCM involves activities and connected decisions, including SM, from the supply of basic raw materials to the delivery of the final product (Tan *et al.* 1998, Tan 2001, Wook Kim 2006). The significance of SM has grown due to the tendency of companies to concentrate on their core competencies, eventually resulting in high levels of outsourcing and purchasing (Choi & Krause 2006, McIvor *et al.* 2006, Shamsuzzoha *et al.* 2010). The reuses of engineering designs and standardisation have been important strategies for reducing costs, which has caused a shift towards increased outsourcing (Hicks *et al.* 2001). Companies rely heavily on their suppliers (Wynstra *et al.* 1999), which have a major influence on their success or failure (Monczka *et al.* 1993, Ellram & Carr 1994, Carr *et al.* 2008). Suppliers commonly

receive fifty percent or more of a firm's total revenue and as a result, the success of the company in the highly competitive business requires an excellent SM (Burt 1989, Trent 2007). However, compared to the extensive literature on supplier involvement in NPD, relatively limited research has been accomplished over the specific SM role within NPD (Luzzini *et al.* 2015). Nevertheless, studies recognise the importance of SM involvement in NPD for the product introduction success (McGinnis *et al.* 1999, Nijssen *et al.* 2002, Luzzini *et al.* 2015).

PPM, NPD, SCM and SM are interconnected with one another. The management of the NPD process and other business processes should be aligned (Bai & Sarkis 2013). The motivation behind the need for alignment lies in the PPM connecting to NPD and SCM as PPM determines the best set of products to – among others – create, supply, produce and distribute (Georgiopoulos *et al.* 2002, Sadeghi & Zandieh 2011, Tolonen *et al.* 2015a). Academics and practitioners acknowledge that the supply chains should be aligned with the company's product portfolio (Fisher 1997, Lee 2002, Langenberg *et al.* 2012) and several models have been proposed towards this goal (e.g. Kraljic 1983, Fisher 1997, Bensaou 1999, Seifert & Langenberg 2011, Langenberg *et al.* 2012). The product portfolio variety is perceived to affect the variety of the supplied product components (Fisher *et al.* 1999) which may result in inferior SM performance due to increased component prices, delivery times and inventory levels (McCutcheon *et al.* 1994, Krishnan & Gupta 2001). However, the connection and alignment of PPM and SM have not been specifically highlighted in the previous literature. In addition, SCM and NPD are strongly connected with each other because the supply chains supply, produce and distribute the product defined during the product development activities (Pero *et al.* 2010). Aligning SCM and NPD is recognised to enhance the product introductions and improve the overall firm performance (Salvador *et al.* 2002, Van Hoek & Chapman 2006, Selldin & Olhager 2007). The involvement of the NPD in the ramp-up of the supply chain processes enhances the commercialisation of the new product (Carrillo & Franza 2006). The supply chain representatives should prepare the supply chain processes – including the underlying supply readiness – from the beginning of the product development (Van Hoek & Chapman 2007). In addition, the product development decisions related to the product design influence the complexity of the SM (Pulkkinen *et al.* 2012, Brewer & Arnette 2016). Particularly in the case of RaDe, the time pressure imposes an anticipation of the SM constraints at the early stages of the product development (Lee & Sasser 1995, Pero *et al.* 2010). Accordingly, design for supply management (DfSM) concept is recognised to enable the knowledge of SM as a crucial part of NPD competences and professionals

as well as to enhance the performance and success of the products, NPD and SM (Pulkkinen *et al.* 2012, Brewer & Arnette 2016).

SM maturity models have been described in the current literature (e.g. Freeman & Cavinato 1990, Barry *et al.* 1996, Paulraj *et al.* 2006, Schiele 2007) to evaluate and demonstrate that a more advanced SM is associated with better firm performance. However, a comprehensive perspective of the SM role in NPD – and particularly in RaDe – has been relatively disregarded (Eriksson 2015). Tools and methodologies to assess the product aspects from the SM point of view and to prepare the supply readiness of a new product along the NPD process should be better addressed and represented in the literature (Kaski 2002, Tolonen *et al.* 2017). The SM maturity introduced in the present study differs from current literature and models as it is meant to evaluate and enhance the SM readiness for the RaDe projects.

1.2 Objectives and scope

The key motivation for the present research arises from the growing significance of small and fast incremental product development in companies (Cooper 2008, Kaikkonen *et al.* 2018). Towards the aim of responding to all sorts of product development needs, companies should have a responsive model specifically intended for rapid development projects. In this study, the rapid product development (RaDe) projects are defined as fast and small-scale product development activities resulting in new sellable items, which complement the company's product portfolio. RaDe does not aim at replacing nor accelerating the regular NPD process. The new products created through RaDe projects are based on the existing product portfolio and are significantly smaller in size and scope than projects requiring multiple stages and gates. RaDe has become critical to fulfilling unexpected market and customer needs which cannot be realised through the current offering. Although organisations may not define RaDe as a part of their product development process, product development needs emerge suddenly which require creating new products quickly. Companies should be prepared to address those needs and reserve resources exclusively for RaDe type of projects. This environment has led to challenges, making it crucial to obtain an improved understanding of the issues related to the growing necessity of responding quickly to customer needs. This research focuses on mature SM as an enabler for RaDe and product portfolio renewal. The managerial viewpoint of RaDe is a relatively new research area; hence, this present research aims at improving the understanding of how the efficiency of RaDe is influenced by

mature SM and PPM. The study objective is to analyse the process settings related to SM and PPM supporting rapid product development. The research problem of this study is formulated as followed:

How do a mature SM process and organised PPM relate to RaDe, and how do they support accomplishing successful rapid product development and ramp-ups?

Various ways may be utilised to approach the research problem thoroughly. In the present study, the problem was studied from four complementary angles: 1) RaDe enablers, 2) strategic alignment of PPM and SM, 3) maturity requirements of SM for RaDe and 4) supply capability creation (SCC) process. These four viewpoints correspond to the four research questions (RQs) which have been answered in four different original studies (Table 1). This study presents the main contribution of each article, which altogether addresses the research objective and contributes to forming the whole study.

Table 1. Research questions and the related original publications.

RQ#	Research question of this study	Title of the original studies	Publication
RQ1	What are the enablers of rapid product development?	I Challenges and enablers for rapid product development	International Journal of Applied Industrial Engineering
RQ2	How to align product portfolio management and supply management?	II Strategic alignment of product portfolio and supplier management	International Journal of Management and Enterprise Development
RQ3	What are the metrics and maturity requirements of supply management? for rapid product development?	III Mature supply management as a critical precondition for rapid product development	Manuscript
RQ4	How can the supply capability creation be systematically handled as a process?	IV Supply capability creation process: Key milestone criteria and activities	Journal of Industrial Engineering and Management

The present study integrates each article, which provides a partial solution to the research problem. The contributions of these original studies are combined in this compilation study. RQ1 is answered in the research paper one, which covers the overall RaDe challenges and enablers. The more specific topics of PPM and mature SM for RaDe are then described in detail in the following original studies. RQ2, RQ3 and RQ4 are respectively answered by the articles II, III and IV. The scope of the study and relationship between the research articles is represented in Figure 1.

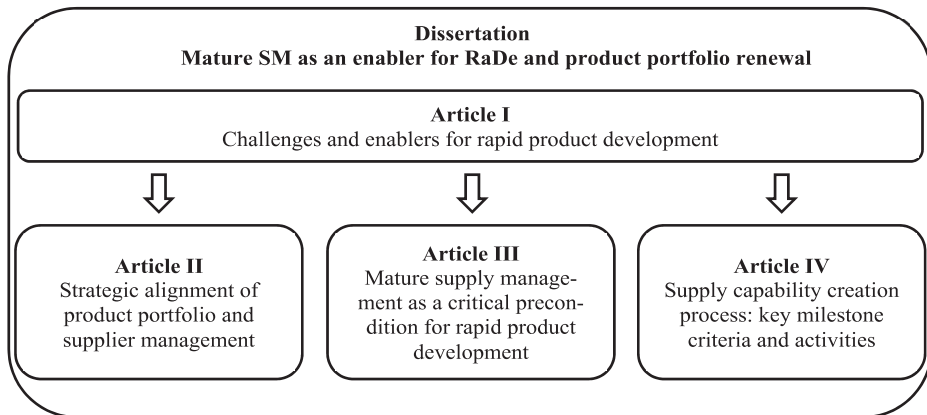


Fig. 1. The scope of the study and research articles.

The four original studies complement each other and provide a significant contribution to the overall research objective of the present study. The RaDe challenges and enablers, derived from the literature review and empirical analysis in case companies, are examined in the article I. The enablers related to PPM and SM are analysed deeper in the second, third and fourth articles. Article II aims at examining the interactions and strategic alignment of SM and PPM. This study recognises the need of aligning PPM and SM to enhance the competitiveness as well as to focus on the strategic and profitable products and associated suppliers. The article III covers the topics of product design concept and DfSM. The aim of this original study is to develop a framework to analyse and ensure that the product design is aligned with the existing SM process, thus supporting the core idea of RaDe. Finally, article IV answers RQ4 and focuses on the SCC within the NPD process. The SCC process describes the main SCC activities and milestone criteria in preparing the supply process for newly developed products.

1.3 Research process

Research philosophy entails epistemological, ontological and ethical issues, which need to be considered by the researchers. The questions to be considered include: how one can believe and know of the reality based on the scientific research; how the scientific knowledge is obtained and when this knowledge is scientific; and when a researcher abuses his research object or act unethically against the scientific community. (Lancaster 2005.)

Epistemology is involved with what is, or should be, regarded as acceptable knowledge in a discipline. The main issue in this context is the question of whether the social world can and should be studied according to the same principles, procedures and philosophy as the natural sciences. (Saunders *et al.* 2009.) Practically, epistemology can be characterised into positivism and interpretivism and viewed along that axis. Positivism is a natural science epistemology that is recognised as extremely difficult to be delineated in a precise manner. Only the phenomena and knowledge that can be assured through senses can be considered knowledge according to positivism. (Saunders *et al.* 2009.) Contrastingly, interpretivism shares the view that the subject matter of social sciences, people and their institutions is fundamentally different from the one of the natural sciences. (Saunders *et al.* 2009.) When viewing the epistemological positioning of this study, it locates nearer to interpretivism than positivism, since the main goal is to analyse and interpret company-wide, unstandardised organisational practices that cannot be assured through senses as required by the natural science epistemology of positivism.

Ontology is concerned with the nature of social entities. The central focus of ontology is whether social entities can and should be considered objective entities with a reality external to social actors, or if they can and should be considered as social constructions built up from the perceptions and actions of social actors. These relate respectively to objectivism and constructionism and can approximatively constitute the axis of ontological positioning. (Bryman & Bell 2007, Saunders *et al.* 2009.) Objectivism implies that the social phenomena confront us – social actors – as external facts that are beyond our reach or influence. Organisations can be discussed as tangible objects with rules, regulations and standardised procedures to accomplish objectives (Bryman & Bell 2007, Saunders *et al.* 2009). Contrastingly, subjectivism questions the suggestion that categories such as organisation and culture are pre-given and that social actors are external realities. Accordingly, social phenomena are created by social actors and are highlighted as their individual experiences. (Bryman & Bell 2007, Saunders *et al.* 2009.) Concerning the present research, the ontological position is, however, pragmatism. Indeed, the researcher can choose the viewpoints from both approaches, and the guiding factor is the suitability of those approaches for the research questions (Saunders *et al.* 2009).

The *research strategy* encompasses considerations over the type of reasoning and the manner of investigation. The type of reasoning aims at understanding and making a distinction whether the data is utilised to test existing theories or to form a new theory. Testing existing theories is realised through deductive reasoning

while developing new theory is inductive. The deductive research aims at forming hypotheses based on existing theories and testing them, whereas the goal of the inductive research is to make a generalisation based on observations and analysis to form a new theory. (Bryman & Bell 2007.) In the present study, the type of reasoning is inductive as a generalisation is sought and the conclusions are based on factors arising from the analysed data. Concerning the manner of investigation, because this study investigates the question of how (Yin 2003) mature SM and organised PPM relate to RaDe and how they support accomplishing successful rapid product development and ramp-ups, the case study methodology is the most suitable research strategy to obtain practical insights on the issues. The study did not aim at analysing and comparing quantitatively the actual performance of RaDe related to different conditions and maturity levels of SM. It could be, however, feasible to study the topics applying the quantitative approach or a combination of both methods.

The qualitative approach has been selected as it provides more in-depth knowledge of SM practices that support rapid product development and product portfolio renewal. Furthermore, the lack of possibilities to obtain suitable data for statistical and quantitative analyses justifies the use of the qualitative method as a manner of investigation. Qualitative research aims at clarifying the meaning and significance of a phenomenon, typically through selected samples. The samples utilised in qualitative approach are at the researcher's discretion, the emphasis being on the quality of the research objects that must be suitable for the related analysis and interpretations (Siggelkow 2007). The data is usually collected directly from the field through interviews and/or observations. Although the research samples are limited in number, they are studied and analysed thoroughly. Qualitative research provides some freedom to the researchers but also constrains them in their own values and limitations when describing the true realities. Hence, complete research objectivity can be questioned as the researcher and studied phenomenon are intertwined. Therefore, all research activities can be recognised as subjective because the researcher's own perception may influence the results to some extent. (Kasanen *et al.* 1993, Yin 2003, Patton 2005, Siggelkow 2007, Marshall & Rossmann 2014.) Individual case study presents issues concerning the generalisation of the results (Yin 2003), therefore several cases have been selected for this study. However, even individual cases can support the creation of new theory by specifying gaps in existing theory and filling them (Siggelkow 2007, Yin 2013).

To summarise, the present research utilises a qualitative, inductive and multiple case study research approach. Figure 2 illustrates the philosophy and research strategy along which this study is positioned.

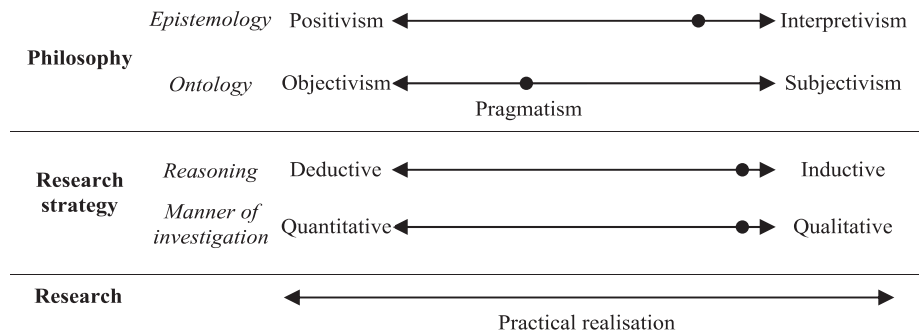


Fig. 2. Positioning of the philosophical and research strategy choices.

The present research was carried out in four studies involving different enterprises, practitioners and academic researchers. The researcher participated in the planning of every study and the related data collection. Additionally, the researcher oversaw analysing the data and drawing conclusions. The co-authors of the articles included in this study supported the research and provided feedback during the writing process. A typical research process used for every individual study is described in Figure 3.



Fig. 3. Typical research process in the four original studies.

Each individual study began with the first phase, the literature review, which formed the theoretical basis for the research. The literature review allowed to obtain the necessary understanding of the topics related to new product development, rapid product development, supply management, design for supply management, product portfolio management and supply capability creation. During the second phase, an interview questionnaire for each individual study was created. The studied journals, conference papers and books provided the basis for developing the four different interview questionnaires.

The third phase involved the data collection through interviews in the selected companies. The companies included in the individual studies consist of representative cases for the respective study purposes. The main selection criteria were the companies' activeness in product development/rapid product development projects as well as their aims to develop the interactions between PPM and SM. Additionally, the companies' selection aimed at providing the best possible information to extend the emergent theory of the phenomenon under study (Eisenhardt 1989). The companies, selected as a data source, serve as a basis for empirical studies on different business areas and types of industry. The qualitative research data were collected by implementing study-specific semi-structured interview frames and by analysing the companies' documentation (such as product development process descriptions). Altogether, the interviews were conducted with 53 specialists, selected based on their professional background and expertise (cf. Eisenhardt 1989). For each study and at each company, interviews were mostly conducted face-to-face with all the informants present at the same time. The simultaneous presence allowed "multiple respondents to provide relevant input across functions and hierarchy within each organisation [to] yield a more comprehensive view of new product development management practices" (Barczak *et al.* 2006: p. 518) and help to identify common problems that may affect the interviewee's responses (Yin 2003). The selected case companies' characteristics and interviews' settings are presented in Table 2.

Table 2. Characteristics of the case companies.

Case	Company type and size (according to EU definition)	Product type	Business type	Interview sessions and informants	Role of the interviewees (examples)
A	Manufacture of basic metals Large	Tangible	B2B	3 sessions 5 informants	<ul style="list-style-type: none"> • Head of product development • Product development manager • Product Manager
B	Manufacture of communication equipment Large	Tangible Intangible	B2B B2C	3 sessions 6 informants	<ul style="list-style-type: none"> • Head of product development • Head of product engineering • Product manager • Supply chain manager
C	Manufacture of irradiation, electro medical and electro-therapeutic equipment Large	Tangible	B2B	3 sessions 5 informants	<ul style="list-style-type: none"> • Chief technical officer • Project management director • Product manager • Supply chain manager

Case	Company type and size (according to EU definition)	Product type	Business type	Interview sessions and informants	Role of the interviewees (examples)
D	Manufacture of construction installation equipment. Medium	Tangible Intangible	B2B	2 sessions 8 informants	<ul style="list-style-type: none"> • CEO and vice CEO • Head of R&D • Product manager • Head of operations
E	Manufacture of machinery and equipment Large	Tangible Intangible	B2B	2 sessions 13 informants	<ul style="list-style-type: none"> • Product owner • Supply chain manager • Sourcing manager • Product development manager
F	Manufacture of electronic products Medium	Tangible Intangible	B2B B2C	2 sessions 4 informants	<ul style="list-style-type: none"> • R&D manager • SM specialist • After sales manager • Supporting tasks manager
G	Manufacture of chemical products Large	Tangible	B2B	1 session 2 informants	<ul style="list-style-type: none"> • R&D, global processes and projects director • Supply chain manager
H	Manufacture of medical instruments & supplies Medium	Tangible	B2B	2 sessions 3 informants	<ul style="list-style-type: none"> • Chief operations officer • Logistics manager • Supply chain manager
I	Manufacture of medical instruments & supplies Large	Tangible Intangible	B2B	2 sessions 3 informants	<ul style="list-style-type: none"> • R&D manager • Logistics manager • Production manager
J	Manufacture of consumer electronics Large	Tangible Intangible	B2C	2 sessions 4 informants	<ul style="list-style-type: none"> • Demand/supply manager • R&D director • SM director
K	Manufacture of communication equipment Small	Tangible Intangible	B2C	2 sessions 3 informants	<ul style="list-style-type: none"> • SM specialist • R&D manager • Board member

The fourth stage includes analysing the data. The interview results were examined according to the respective research focus of each study. The analyses were made by the qualitative approach of studying the interview frames several times to discover connections, patterns and comparisons. After every interview and for each

company, follow-up questions were sent to additional specialists to further gather and clarify experiences on the related topics. In all the studies, the case-specific results were introduced to the analysed companies, in order to provide an opportunity for feedback and confirm the research outcomes. Finally, the implications and conclusions were formulated based on the analysis. The involved co-researchers took part in verifying the results to avoid any misinterpretations. The overall structure of the doctoral research is presented in Figure 4.

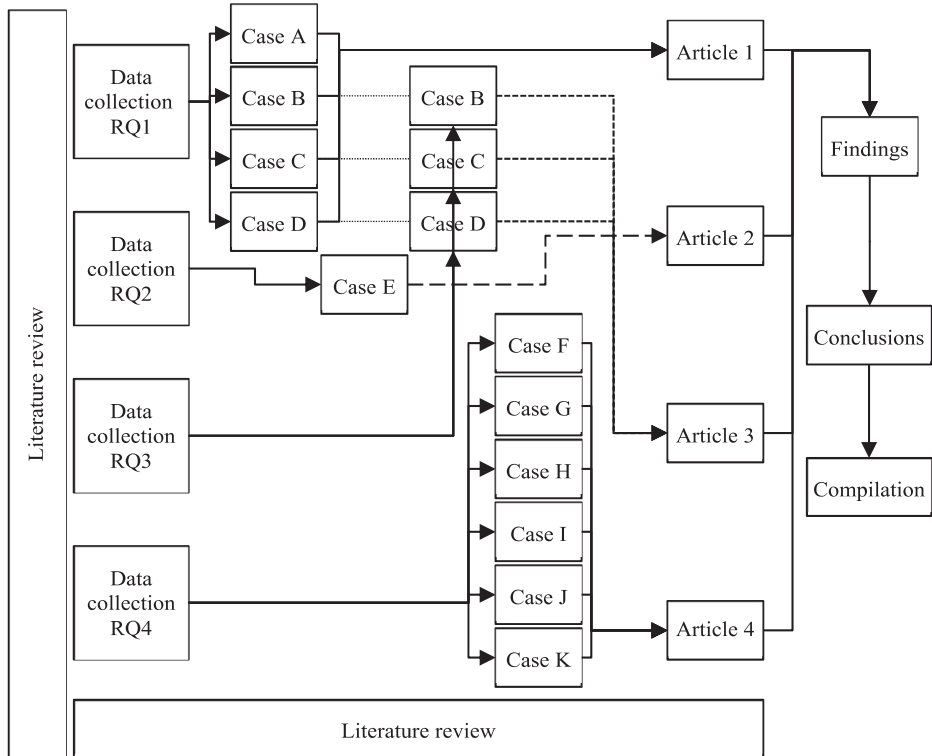


Fig. 4. Overall structure of the research.

2 Theoretical foundation

The theoretical foundation provides an outline of the main literature concepts that are relevant to this study. To address the research problem regarding the mature supply management as an enabler for rapid product development and portfolio renewal, the present study is initiated on two main business and management fields: product management (e.g. Cooper *et al.* 1999, Haines 2009, Tyagi & Sawhney 2010, Tolonen *et al.* 2015a, Stark 2015) and supply management (e.g. Phusavat *et al.* 2007, Trent 2007, Spina *et al.* 2013, Jack & Powers 2015.). Additional scoping on these fields was necessary to be selected as the key theoretical concepts relevant to the present research (Figure 5).

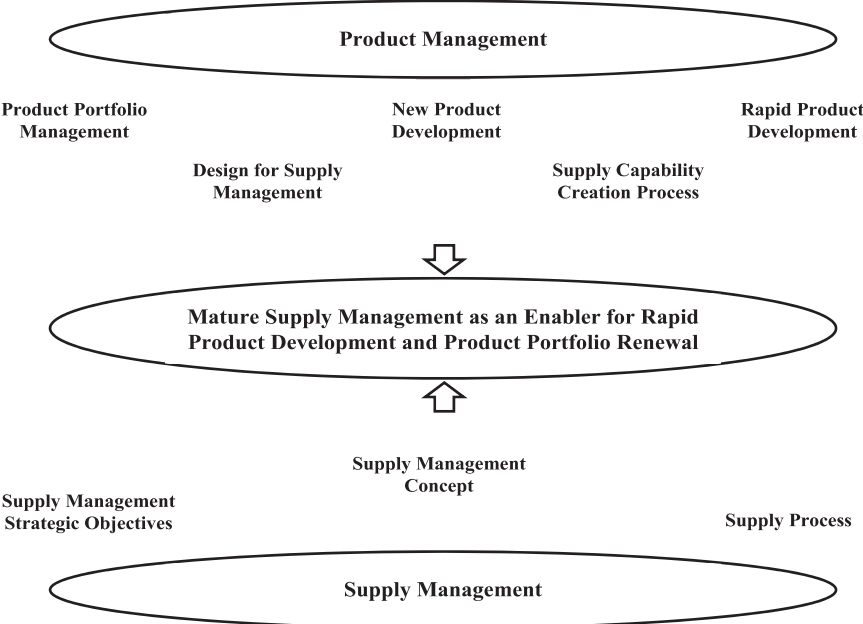


Fig. 5. The theoretical foundation for this study.

The literature review of the selected theoretical fields and key concepts is presented in the next sub-sections. The two main studied fields have many other connecting concepts that are excluded from the present study to remain in the selected scope. For instance, RaDe key performance indicators (KPIs), process, business case calculation, governance models (e.g. Poolton & Barclay 1998, Madison 2005,

Schmidt 2009, Kinnunen *et al.* 2011, Pekuri *et al.* 2011, Dombrowski *et al.* 2013, Kinnunen *et al.* 2014a) are out of scope of the present study. Neither are the concepts of product marketing (e.g. Henard & Slymanski 2001, Singh 2012) nor product data management (e.g. Saaksvuori & Immonen 2008, Silvola *et al.* 2011, Silvola *et al.* 2016, Silvola *et al.* 2018) included. SCM is related to the theoretical foundation of this study but the focus is exclusively on the supply management. Other SCM topics related to the planning and management of manufacturing, testing and logistics (e.g. Mather 1992, Binder 1994, Shewchuk & Moodie 1998, Gilgeous & Gilgeous 1999, Maxwell *et al.* 2000, Kuo *et al.* 2001, Waters 2003, Kao 2006, Jonsson 2008, Mottonen *et al.* 2009, Rushton *et al.* 2014) are as relevant to the topic but secondary in importance to address the specific research problem related to SM. Stakeholder management (e.g. Mitchell *et al.* 1997, Post *et al.* 2002, Trott 2012), mainly the issues relating early stakeholder involvement, are also connected to this study. Yet, the focus is solely on one type of stakeholder – the SM – and other topics related to stakeholder definition, identification, salience and prioritisation (e.g. Aaltonen & Kujala 2010, Aapaoja *et al.* 2013, Kinnunen *et al.* 2014b) are excluded.

2.1 Supply management

2.1.1 Supply management concept

Supply chain management involves activities and connected decisions, which include planning, supply management, manufacturing, transportation, warehousing and distribution (Tan 2001, Wook Kim 2006). As part of the SCM, SM is a strategic and cross-functional process for obtaining the company's current and future needs through the management of suppliers. SM aims at determining the total supply requirements, establishing supply strategies, as well as selecting and managing a base of innovative suppliers to realise performance advantages for the focal company and its suppliers. (Goffin *et al.* 1997, Trent 2007, Spina *et al.* 2013, Jack & Powers 2015.) SM focuses on the identification, acquisition, access, positioning, management of resources, and the related capabilities the organisation needs or potentially needs in the attainment of its strategic objectives (Institute for Supply Management 2010). In the literature, the terms supplier management and supply management are employed with the same meaning. Supply management will only be utilised

later in the present study. Spekman *et al.* (1999) provided the principles for effective SM such as integrating suppliers into the supply chain, focusing on total costs or rationalising the supplier base. SM is an essential business area since it can influence significantly the costs, quality, innovativeness and competitive position (Lemke *et al.* 2000, Zhao *et al.* 2014).

SM differs from the traditional purchasing approach that is no longer recognised as a purely tactical function but a strategic one (Kraljic 1983, Ellram & Carr 1994, Goffin *et al.* 1997, Dyer *et al.* 1998). Conventional purchasing concentrates on unit price (Lamming 1993), quality conformance and speed of delivery (Dickson 1966, Goffin *et al.* 1997). The connected buyer-supplier relationship is short-term (Kraljic 1983), multi-sourcing (Harland 1996, Krause 1999) and opposing (Monczka & Trent 1991, Scott & Westbrook 1991). In most industries, the traditional purchasing method is not recognised to produce competitive advantages anymore because of issues including the complexity and high cost of managing a large supplier base (Gadde & Snehota 2000) or the decreased economies of scale due to purchases divided across multiple suppliers (Dyer *et al.* 1998). Contrariwise, SM aims at managing comprehensively and concurrently seven main criteria related to suppliers (Phusavat *et al.* 2007). The focus is on the total cost (Kraljic 1983, Larson 1994, Morssinkhof *et al.* 2011), quality record (Larson 1994, Foster *et al.* 2011), delivery performance (Lee & Wellan 1993, Prajogo & Olhager 2012, Singh & Ahuja 2012), financial stability (Chan *et al.* 2008), technology capabilities (Monczka *et al.* 1993), service (Ho *et al.* 2010) and risks (Blome & Schoenherr 2011, Hoffmann *et al.* 2013). In SM, the buyer-supplier relationship is long-term (Kraljic 1983, Hartley & Choi 1996), single or dual sourcing (Swift 1995, Harland 1996) as well as based on dependence and trust (Hartley & Choi 1996).

2.1.2 Supply management strategic objectives

The comprehensive SM objectives have traditionally been expressed through the “seven rights”: right quality, right quantity, right material, right price, right source, right time and right terms (Fearon *et al.* 1993). However, this perspective is shifting into building strong capabilities so that SM can position itself in the market and acquire products efficiently and effectively (Cavinato & Kauffman 2000). The overall objectives for SM can be characterised as ensuring economic procurement of goods, supplies and services to keep the company in operation and contributing to profits by efficiently controlling the total cost of the operation (Pooler *et al.* 2007). Specific SM objectives can include developing integrated SM strategies to

support organisational goals and strategy, acquiring superior quality purchase at minimal cost, establishing adequate sources of supply as well as negotiating, maintaining good relationships and securing optimal performance with suppliers. Furthermore, SM goals can also consist of discovering new and enhanced goods and services, maintaining supply continuity by keeping optimised inventories throughout the supply chain and managing the SM process efficiently. (Burt & Pinkerton 1996, Pooler *et al.* 2007, Monczka *et al.* 2015.)

The supplier base rationalisation is an important component of effective SM (Spekman *et al.* 1999, Gordon 2008). An excessively large supplier base generates an increase of the required resources and time to manage the suppliers, while single sourcing can increase the supply risk for critical components (Trent & Monczka 1998, Yu *et al.* 2009, Nunes & Cruz-Machado 2014). The main motivation in supplier base rationalisation and reduction arises from the intention to manage suppliers more effectively by retaining more time and resources to develop improved relationships with each supplier (Goffin *et al.* 1997, Cadden & Downes 2013, Talluri *et al.* 2013). Operating an optimal size of supplier base is considered to improve the competitive advantage of the buyer due to diminished costs as well as to enhance the product quality and innovativeness resulting from the supplier support in the product or process development (Leenders *et al.* 1994, Chen & Paulraj 2004, Talluri *et al.* 2013).

2.1.3 Supply process

The supply process can be defined as a sequence of activities required to transfer products from the suppliers to a final destination (Knudsen 1999, Kanda & Deshmukh 2006). The literature provides numerous models to describe the supply process, which can be represented from four main phases: information, negotiation, settlement and after-sales phase (Kim & Shunk 2004, Behncke *et al.* 2014). At the information phase, the material/service needs are identified and anticipated; potential new suppliers are sought; and proposals, quotes and bids are requested from the preferred and contracted suppliers (Dobler & Burt 1996, Kraut *et al.* 1999, Zsidisin & Ellram 2001). Following, the acquisition terms such as price, quality or payment conditions are agreed during the negotiation phase (Kraut *et al.* 1999, Gebauer & Scharl 1999, Goodchild *et al.* 2000, Grieger 2003). During the settlement phase, the activities such as purchase, shipment, payment or quality monitoring occur based on the contract terms (Lindemann & Schmid 1998, Grieger 2003, Skjøtt-Larsen *et al.* 2003). Eventually, the after-sales phase includes activities related to

the assessment of orders, the evaluation of the supplier performance as well as the consumption, maintenance and disposal of the supplied goods (Kraut *et al.* 1999, Goodchild *et al.* 2000, Scharl *et al.* 2001).

2.2 Product management

Product management (PM) is a cross-organisational function involved in planning, organising, executing and controlling all the activities that aim at successful conception, production, and marketing of the products provided by an organisation (Pohl *et al.* 2005). In a wider context, PM aims at managing product portfolio, individual products and their data over the entire lifecycle including new product development, maintenance and disposal phases (Stark 2015). Haines (2009) defines PM as a “business management at the product, product line or product portfolio level.” PM is conducted by product managers whose responsibility is to integrate various segments of a business into a strategically focused ensemble in order to deliver superior customer satisfaction while simultaneously maximising a product’s market position and financial return (Gorchels 2000, Haines 2009). PM function should influence the product-related decisions (Silvola *et al.* 2011) to maximise the profit by increasing product revenues, reducing product-related costs and maximising the value of the current and future product portfolio for the company, their customers and their shareholders (Stark 2015). PM can be characterised as the business management of products at every level of the product structure and across their lifecycles.

Before examining the literature wider, significant terms and concepts related to PM need to be defined. *Product* can be defined as something sold by an enterprise to its customers (Ulrich & Eppinger 2008). Haines (2009) extends this definition to all goods, services and knowledge sold by an organisation, whether tangible, intangible or both. *Product strategy* is connected to the general corporate strategy and includes aspects such as the competitive edge of products and technologies that influence product development and portfolio management (Trott 2012). *Product portfolio* is the total ensemble of company’s products, including various types of items at different levels (hardware, software, systems, services and documentation), which are connected to one another (Kropsu-Vehkaperä & Haapasalo 2011). *Product line* (or family) is an association of products serving similar markets or solving a specific type of problem (Haines 2009). *Product creation* refers to any activities and processes creating new products. *Productisation* comprises activities of combining different items (such as software, hardware and services) into a product that

can be sold (Harkonen *et al.* 2015, Harkonen *et al.* 2017). *New product development* is an innovation process to transform market opportunities into new commercial products (Krishnan & Ulrich 2001). More specifically, *incremental product development* focuses on adding or modifying something from an existing product to create a new product (Gautam & Singh 2008). *Rapid product development* is a specific type of incremental product development with short delivery time (Hänninen *et al.* 2014). The present study focuses on some aspects of the PM: PPM, NPD, RaDe, DfSM and SCC.

2.2.1 Product portfolio management

Product portfolio management is an important process for companies as it is responsible for determining not only projects for new products but also revisions, updates, and discontinuation of products that are currently produced and commercialised (Cooper *et al.* 1999, Kester *et al.* 2011). The objective of PPM is to maximise the product portfolio profitability, balance the range and number of products in a portfolio as well as align with the business strategy. PPM allows businesses to achieve strategic, market, financial, and operational balance across every product in an organisation and over the lifecycle. (Belliveau *et al.* 2004, Haines 2009, Tolonen *et al.* 2014a.) PPM is a general business concept involving active analysis and decision-making to determine the best set of strategic and cost-effective products to be created, sold, delivered and cared (Georgiopoulous *et al.* 2002, Sadeghi & Zandieh 2011). PPM applies generic portfolio management methods and techniques, such as financial methods, strategic approaches, scoring models or bubble diagrams (Cooper *et al.* 1999, Cantamessa 2005).

In companies, an inefficiently managed portfolio can lead to many challenges, which affect the business performance negatively. For instance, unimportant and low-value projects as well as deficient go/kill decisions result in unnecessary extensions, modifications, enhancements, short-term projects and lack of focus (Cooper *et al.* 2001, Ward *et al.* 2010). An excessively wide product portfolio consisting of multiple similar products lead to an increase of the demand volatility, the complexity of product portfolios, as well as the cost of operations, R&D, marketing, administration and overall products over their lifecycle (Dickinson *et al.* 2001, Ward *et al.* 2010, Jacobs 2013). The lack of systematic PPM process and data may result in intuitive and subjected decisions related to product portfolio operations (Kester *et al.* 2011). Concerning the overall idea of PPM, Tolonen *et al.* (2014a) identified

challenges such as the growing size of the product portfolio, the product cannibalisation or the lack of understanding of the PPM role as a strategic level analysis and decision-making process for the entire product portfolio over the lifecycle.

PPM requires a holistic approach to achieve an optimal product portfolio and towards this objective, Tolonen *et al.* (2015a) introduced a PPM framework to cover the commercial and technical product portfolio structure over the product lifecycle. The framework suggests the utilisation of the acknowledged key product portfolio performance focus areas: strategic fit, balance and value maximisation of the product portfolio (Cooper *et al.* 1999, Mikkola 2001, Miguel 2008, Barczak *et al.* 2009, Oh *et al.* 2012). Strategic fit ensures that the current and future product portfolio is aligned and consistent with company's strategic goals (McNally *et al.* 2009, Jugend & da Silva 2014). The product portfolio balance should be considered across the different product levels, lifecycle phases and organisational functions – such as marketing, product development and supply chain management – as well as in terms of long/short-term objectives, risk-reward, profits, markets and technologies (Cooper *et al.* 1999, Oh *et al.* 2012). The maximisation of the product portfolio requires optimising the relationship between resources used and projected returns. It considers the sub-targets as return-on-investment, profitability, success or business value. (McNally *et al.* 2009, Kester *et al.* 2011.) Furthermore, effective PPM also includes other aspects such as the alignment between the key product portfolio performance focus areas with the business processes' strategic targets and KPIs as well as the creation of sub-portfolios, governance model and ownership over all the product lifecycle phases and product structure levels (Tolonen *et al.* 2014b).

2.2.2 New product development

New product development is an innovation process to transfer new products, which meet the customer's needs and company's strategic goals, from idea generation into market introduction, including product design, market study and marketing analyses (Cooper 2005, Browning & Ramasesh 2007, Ulrich & Eppinger 2008). NPD is often organised with decision gates and activity stages beginning with the perception of a market opportunity and ending in the production, sale and delivery of the product (Ulrich & Eppinger 2008, Conway & Steward 2009). The content and number of stages and gates vary according to the complexity of projects and the companies (Shepherd & Ahmed 2000, Ulrich & Eppinger 2008). The stages may be combined in small-scale projects, while in larger ones more phases and gates are

utilised (Cooper 2008). Several NPD frameworks (e.g. Anthony & McKay 1992, Cooper 2001, Ulrich & Eppinger 2008) have been formulated to satisfy the various needs of organisations. These frameworks incorporate essential characteristics that enhance the NPD performance when performed in an efficient manner. Those features include 1) a structured development process that describes milestones' criteria, tasks, schedule, and resource assignments; 2) a review board who provides the oversight of the projects by resolving cross-project issues, setting projects' priorities, and make go/kill decisions; 3) realisation and cross-functional teams; 4) phase/gate reviews at major development milestones (M), in which funding, resources and project schedules are approved, rejected, or postponed by the review board (Gehani 1992, Shepherd & Ahmed 2000, Ahmed 2002). The product development time varies greatly according to numerous factors such as the type of industry, the firm's characteristics, the project strategy or the innovativeness of the product (Kessler & Chakrabarti 1996, Griffin 1997). Accordingly, different categories of product development can be defined such as large NPD, medium-sized NPD and rapid incremental NPD (Cooper 2008, Kaikkonen *et al.* 2018). Wheelwright and Clark (1992) also define three different sorts of new product projects. Completely new products requiring a high level of investment are developed through breakthrough projects, platform projects aim at developing architectural innovations, and new module or component innovations are generated in derivative projects. The Product Development & Management Association's (PDMA) Best Practices research provided the average product development cycle times for physical goods commercialised by B2B firms. The cycle time fluctuates between 36 and 53.2 months in large NPD (new-to-the-world and new product lines), medium-sized NPD (next generation improvements) averages 22 months and 8.6 months for incremental improvements projects. (Griffin 2002.)

The different NPD phases (P) can be defined as P0 feasibility study, P1 project planning, P2 concept development, P3 development and integration, P4 piloting and P5 ramp-up (Cooper 2001, Ulrich & Eppinger 2008, Pahl & Beitz 2013). The NPD begins with the project order that is based on the long-term firm and product strategies. From this, the generation, collection and evaluation of business opportunities and ideas occur (P0). Those activities aim at an early reduction of technical and market uncertainty. At the next step (P1), the product first definition and requirements, the objectives and the project planning are established. Those activities should be aligned with the firm's organisational capabilities and strategy to guarantee a constant flow of new products that contribute to the overall company performance. Intensive and effective initial planning at an early stage of the NPD aims

at diminishing uncertainties. During the concept development (P2), the product definition and architecture from the perspective of its functions and components are established. The detailed and concrete design and development of the product occur during the product development and integration (P3). The supply chain is also fully involved in this potentially long and laborious stage. Product design may involve conceiving mechanics, hardware, software, electronics and their integration that should provide value to the customers and make the product efficient to manufacture and commercialise. During the next phase (P4), the tests and trials aim at validating the product and the related production, supply management, marketing, etc. Eventually, the full-scale production and selling start during the ramp-up phase (P5). (Cooper 2001, Koen et al 2001, Otto & Wood 2001, Ulrich & Eppinger 2008, Pahl & Beitz 2013, Behncke *et al.* 2014.) An example of such NPD process is illustrated in Figure 6.

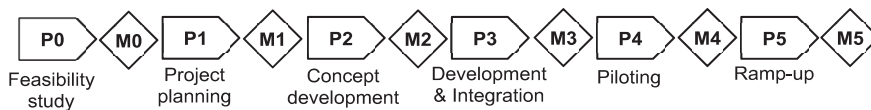


Fig. 6. Generic perspective of the NPD process.

2.2.3 Rapid product development

NPD processes have been created to be repeatable in order to reduce the costs, risks and non-quality (Cooper *et al.* 1986, Ulrich & Eppinger 2008). However, milestone-driven NPD projects have been criticised to be too linear, too rigid and too planned for small and dynamic projects (Cooper 2014), which require quick reaction to sudden product development needs. Milestones may also suspend the projects for a long time and delay the product development (Ottosson 2004). One single NPD process is not sufficient to suit all the various ranges of product development in terms of cost, time or risk (Becker 2006, Cooper 2008). The risk of utilising an identical process for every development project includes fast projects being rushed ahead longer ones, which generates delays due to handoff and task switching (Ward 2007). During the last thirty years, several NPD models (e.g. Wheelwright & Clark 1992, Cooper 2001, Ulrich & Eppinger 2008) have appeared to meet the various needs of organisations. As the complexity of individual product development projects diverges, the scope, decision-making process, number of activities, risk level, amount of resources and funding committed also differ greatly (Cooper

2008). In the current business environment with unexpected and substantial changes, product development delays may prevent company’s success, while rapid commercialisation of new products has turned into a primary priority in many organisations (Harmancioglu *et al.* 2007). Utilising a fast and productive NPD process partly strengthens the financial success of the product (Brown & Eisenhardt 1995).

During the last two decades, the share of incremental NPD has considerably increased compared to radical innovations through full-scale and traditional product development frame (Cooper 2013). In incremental product development, features of existing products are added or modified to create new sellable products (Ulrich & Eppinger 2008). Incremental product development aims at providing a more attractive and valuable product offering for the customer, therefore leading to expanded sales and profit (Gautam & Singh 2008). In incremental innovation, involving the customer is important to improve the development project timeliness via capturing their needs faster and more accurately, leading to reduced development efforts (Johnson & Luo 2008). Cooper (2008) introduced the next Generation Stage-Gate® including a shorter and lighter version of the recognised milestone-driven product development model. To accommodate different NPD project needs – such as minor changes projects – phases and gates are combined and reduced. Rapid product development can be defined as a specific type of incremental product development that requires a minimal engineering effort and a short development time (e.g. Hänninen *et al.* 2014, Niskanen *et al.* 2015, Vigna *et al.* 2015, Kaikkonen *et al.* 2018). An example of such RaDe model (adapted from Cooper 2008 and Kaikkonen *et al.* 2018) is illustrated in Figure 7. During the front-end phase, collection, evaluation and screening of business opportunities and ideas occur. Based on clear criteria to separate the different product development processes, the RaDe projects can be appropriately assessed in the decision-making phase. During the back-end, the actual development and ramp-up of the product take place. (Cooper 2008, Kaikkonen *et al.* 2018.)

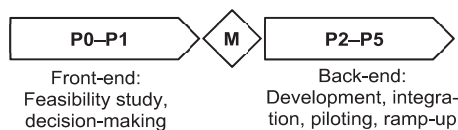


Fig. 7. Generic perspective of the Rapid product development model.

Bringing new products faster to the market results in increasing challenges such as the inability to predict the development duration or managing changing requirements (Ledwith *et al.* 2006). The application of the traditional NPD process – even in a lighter way – does not suit the RaDe requirements and thus causes issues for companies. The organisations must balance the short-term needs of incremental product development with the long-term product requirements for radical innovation (Birkinshaw & Gibson 2004). These circumstances necessitate different and usually contradictory structures, processes and cultures within the same organisation, which lead to challenges (Tushman & O’Reilly 1996). Hänninen *et al.* (2013) examined the practical challenges related to the need to respond quickly to customer preferences (e.g. how to understand, identify and document the customer preferences right from the beginning; how to ensure a rapid turnaround time for the specification and development plan). In RaDe, issues also occur related to the supplier involvement in the product development. In comparison to traditional NPD and due to time constraints, the probability of product defects increases, the cost tends to rise, and delayed deliveries may occur because of poor communication or inadequate supply chain capability. (Niskanen *et al.* 2015.) Eventually, RaDe may only slightly redefine an existing product but these small changes will also affect the delivery operations relevant to the product and result in additional work for the SCM (Bernard *et al.* 2009, Anderson *et al.* 2006).

Lean product development has been a recognised approach adopted by organisations to optimise the NPD process and shorten lead-times. For instance, overlapping of development phases, product platform strategies, good cross-functional involvement and communications, as well as supplier capabilities, are identified to decrease NPD projects’ length (Clark & Fujimoto 1991, Cusumano & Nobeoka 1992, Robertson & Ulrich 1998, Kärkkäinen *et al.* 2001, León & Farris 2011). In regard to accelerate NPD, five approaches are seen to decrease the time-to-market: supplier involvement, lead user involvement, speeding up activities, training and rewarding of employees as well as simplification of organisational structure (Langeraak & Hultink 2008). However, techniques recognised for full-scale NPD might increase the development time in case of fast product development projects (Niskanen *et al.* 2015). More specifically, Smith (1990) specified key elements for a successful fast-cycle product development, such as a product structured for rapid product development, a co-located and dedicated team designed for rapid decision-making, streamlined management techniques, or a sensitivity to time’s value. In addition, a good balance between the different competencies available is recognised to improve the RaDe capabilities (Hänninen *et al.* 2014). Furthermore, modular

product structure is considered as an enabler in responding to new customer requests by redesigning product modules (Kangas *et al.* 2013). Implementing a RaDe model with a similar focus in terms of planning, resource utilisation and management as long-term product development is seen beneficial and more effective for NPD organisations. In this way, tasks from the different product development models, prioritisation and resource utilisation can be done more effectively, which supports the company's profitability. (Kaikkonen *et al.* 2018.)

Companies utilise different order fulfilment strategy depending on the structure of their supply chains such as make-to-stock, assemble-to-order or engineering-to-order (ETO) (Olhager 2003, Yang & Burns 2003). In ETO supply chain model, the customer order decoupling point is established at the design phase; the customer order penetrates the design phase of a product (Gosling & Naim 2009). The customer order decoupling point is the point in the material flow where the product is tied to a specific customer order and where the product specifications are fixed in most cases (Sharman 1984, Olhager 2010). ETO is primarily associated with large and complex project environments; however, related literature review has recognised an argument on the definition concerning the design dimension (Wikner & Rudberg 2005, Gosling & Naim 2009). Porter *et al.* (1999) and Hill (2000) define design-to-order (DTO) order fulfilment strategy where a company designs, engineers and manufactures a new product to meet specific customer needs. In this manner, ETO represents the situation when modifications are made to standard products. The introduction of DTO clarifies the conventional definition of ETO by dividing it into two groups: new product introductions with new design, engineering and manufacturing (DTO) and existing products engineered to satisfy customer specifications (ETO) (Porter *et al.* 1999, Hill 2000, Gosling & Naim 2009).

The ability to share and transfer technologies across a portfolio of NPD project has become a competitive advantage in many industries (Ellison *et al.* 1995, Nobeoka & Cusumano 1997). These capabilities refer to multi-project strategy and management and deal with the linkages between different projects (Nobeoka & Cusumano 1997). In the literature, an important aspect of inter-project linkages has also been the differentiation between radical innovation and incremental change (Kleinschmidt & Cooper 1991, Banbury & Mitchell 1995). Products developed through incremental changes can maintain a firm's position in an existing market (Hollander 1965, Banbury & Mitchell 1995) as well as provide a better opportunity to grow compared to products based on unfamiliar technologies (Meyer & Roberts 1986). Nobeoka & Cusumano (1997) proposed four different types of multi-project

strategy, which categorise new product development projects depending on different criteria such as the magnitude of changes (new design, rapid design transfer, sequential design transfer, design modification). Alongside developing new design, the rapid design transfer was found to be the best strategy towards the goal of increasing sales. Leveraging new designs quickly through overlapping projects appeared to be more beneficial than transferring designs to another product in a sequential manner. (Nobeoka & Cusumano 1997.)

2.2.4 Design for supply management

SCM and NPD are strongly connected as supply chains supply, produce and distribute the product defined during the product development projects (Pero *et al.* 2010). New product introductions and companies' overall performance can be improved by aligning SCM and NPD (Salvador *et al.* 2002, Van Hoek & Chapman 2006, Selldin & Olhager 2007). The products can be aligned with the supply chain or vice versa (Pero *et al.* 2010). Specifically for RaDe projects, the time pressure prevents the changes of supply chain capabilities and implies an anticipation of the supply chain constraints at the early NPD phases (Lee & Sasser 1995, Pero *et al.* 2010). Design for supply chain management (DfSCM) concept aims at synchronising the product design with existing supply chain processes by considering the supply chain operations during the product development (Dowlatshahi 1997, Singhal & Singhal 2002, Gubi *et al.* 2003, Klevås 2005).

Design for eXcellence (DfX) is the broader concept of DfSCM, which addresses potential design issues into the product development phase so that it can fit and support the existing business processes (Holt & Barnes 2010, Lehto *et al.* 2011). It aims at aligning and coordinating NPD with the other main functions of a company (Appelqvist *et al.* 2004, Perks *et al.* 2005, Sharifi *et al.* 2006, Ellram *et al.* 2007). The product features defined during the product development affect the supply chain performance (Crippa *et al.* 2010). The impact of the product features on the supply chain performance is determined by the supply chain decisions about the structure of the supply chain (Blackhurst *et al.* 2005), the supply chain strategy, (Childerhouse *et al.* 2002) as well as the collaboration magnitude of the supply chain actors (Doran *et al.* 2007). Consequently, coordinating the supply chain decisions with the NPD decisions is increasingly important to enhance the product launch and supply chain performance (Lee & Sasser 1995, Van Hoek & Chapman 2006, Tolonen *et al.* 2017). Product design impacts to a large extent the supply chain decisions and performance (Salvador *et al.* 2002). Around 70% of the overall

product lifecycle cost is determined by the product design, thus making it crucial to influence it at the early NPD phases (Barton *et al.* 2001). The product design can be mainly represented through the product architecture and the bill of materials (Crippa *et al.* 2010). The product architecture has a central role between NPD and SCM (Krishnan & Ulrich 2001). Scholars have investigated the relations between product architecture and SCM (Fixson 2005) and notably related to the supply management (Hsuan 1999, Novak & Eppinger 2001), and supply chain structure (Salvador *et al.* 2004). Additionally, mathematical models have been proposed to select the best bill of materials which minimise the total cost of the supply chain (Blackhurst *et al.* 2005, Huang *et al.* 2005). The interface between NPD and SCM can also be examined through the product complexity. Product complexity can be characterised as the number of materials, components, different technologies or levels in the bill of materials within a product (e.g. Novak & Eppinger 2001, Salvador *et al.* 2002, Fixson 2005). The product complexity is an aspect which determines the complexity of the supply chain (Christopher 2000, Lamming *et al.* 2000, Bozarth *et al.* 2009), in other words, the number of suppliers and levels within the supply chain. A higher product complexity results in a higher supply chain complexity; the integration of NPD and SCM is a method to control these two sorts of complexity, whether within or across the company boundaries (Caniato & Größler 2015).

The main objectives of DfX are to minimise the product lifecycle cost as well as to ensure an efficient product design and short time-to-market (Gatenby & Foo 1990, Barbosa & Carvalho 2013). The product design is influenced so that the supply chain cost and performance are optimised (Lee & Sasser 1995). The informed decisions made early minimise the need for changes in the later phases, which help to reduce the total lifecycle costs (Lehto *et al.* 2011). Successful NPD requires a holistic view from strategy to commercialisation (Chi-Jyun Cheng & Shiu 2008, Barczak *et al.* 2009, Kotler *et al.* 2009, Schmidt *et al.* 2009), which implies that the supply chain competencies (such as supply management, manufacturing or logistics) should be involved early in the NPD. Cross-functional NPD teams are an important component of NPD (Kotler *et al.* 2009) to reduce time to market and NPD cost (Carillo & Franza 2006, Van Hoek & Chapman 2006). The DfX principles can be implemented efficiently through a cross-functional NPD team who can address precisely the needs of relevant stakeholders (Tichem 1997, Aurich *et al.* 2006, Majava *et al.* 2014). The NPD team members should evaluate the supply chain process and decisions such as the supply network, the logistic channels, the transport or the inventory levels (Aitken *et al.* 2003, Tolonen *et al.* 2017). The DfX goals are usually realised through the utilisation of product design guidelines,

checklist and software tools (Bralla 1996, Gungor & Gupta 1999, Huang & Mak 2003). Successful DfX implementation can result in benefits, which include product simplifications, quality improvement and shortened time-to-market (Kuo *et al.* 2001). As part of DfSCM, Design for supply management is connected to other DfX disciplines including Design for Logistics, Design for Cost and Design for Quality (Pulkkinen *et al.* 2012). Following the DfX goals, DfSM aims at enabling SM activities' knowledge to the product designers as the product design decisions influence the procurement operations complexity (Sharifi *et al.* 2006, Brewer & Arnette 2016). An excellent coordination between the design team and SM organisation is seen to optimise the performance of the NPD and SM processes as well as to improve the long-term product performance (Pulkkinen *et al.* 2012, Brewer & Arnette 2016).

Product design guidelines act as a knowledge vault of product design decisions, to facilitate the downstream efforts. Their objectives are to control, improve or invent specific product characters through generating and applying technical knowledge. (Osorio *et al.* 2014.) The product design guidelines facilitate the transformation of non-concrete design information to systematic procedural knowledge (Roller & Dalakakis 2004). Practically, the guidelines provide a qualitative list, allowing the designers to take appropriate design decisions to consider and optimise the downstream processes – such as supply management, manufacturing or logistics – and the related organisational effort (Fiksel *et al.* 2009, Dombrowski *et al.* 2014). The product design guidelines and structure from SM point of view have not received significant attention in the literature (Brewer & Arnette 2016). However, product development decisions on the product, its structure and its level of standardisation, as well as the suppliers' relationship, affect the ease of the SM process (Pulkkinen *et al.* 2012, Brewer & Arnette 2016).

The product structure and component commonality are important concerns for the SM process. Part standardisation across the product portfolio minimises the SM complexity, time-to-market, resource requirements and post-launch product changes (Ulrich 1995, Simpson 2004, Brewer & Arnette 2016). The product structure and part standardisation should be influenced by the SM professionals. The optimisation of the product structure layers and the increase of part standardisation results in better product similarity, improved material availability as well as reduced number of tier suppliers, supply complexity and associated risk (Fixson 2005). Standardisation is increased through modularisation that aims at organising complex designs more efficiently by decomposing systems into independent mod-

ules. These modules can be combined into component groups to develop and customise larger quantities of products in a product family. (He & Kusiak 1996, Gershenson *et al.* 2003, Jose & Tollenaere 2005.) Therefore, fewer unique parts can be utilised allowing companies to procure and produce parts in greater quantity resulting in economies of scale (Erixon 1996, Duray *et al.* 2000, Gershenson *et al.* 2003). Minimising the number of parts and product structure levels, as well as increasing component reuse, contribute to the NPD and SM performance in terms of cost, time and quality (Ulrich *et al.* 1993, Huang & Kusiak 1998, Gershenson *et al.* 2003, Fixson 2005).

The procurement lead-time is an important component of the overall time-to-market, where most time is consumed in selecting suppliers and maintaining the related relationships (Brewer *et al.* 2013, Brewer & Arnette 2016). Additionally, maintaining long-lasting supplier relationships requires the involvement of a significant amount of resources (Zsidisin & Ellram 2001, Brewer *et al.* 2013). Accordingly, SM specialists should influence the product designers to select the components and modules that can be sourced from the existing supplier base. It can thus ensure a continuing access to proven supply, reduce the overall product development time and supply risk, as well as increase the volume within the existing suppliers enabling better relationships and economic performance (Trkman & McCormack 2009, Brewer & Arnette 2016).

The impacts of the product design guidelines and the manner they influence the product design should be monitored. Toward this aim, the product design metrics are variables inherent to the product design, guiding the NPD to meet the requirements along the downstream supply chain and product lifecycle (Galbraith & Greene 1995, Kaski 2002, Kaski & Heikkila 2002). Such metrics can be related to the current and efficient supplier base, which enables the design of products to be based on proven component-suppliers and to decrease lead-time in the part/supplier qualifications (Humphreys *et al.* 2007, Wasti & Liker 1997). The designers should maximise the use of recommended materials and components from the approved, contracted and qualified suppliers (Plank & Kijewski 1991, Wallace & Hill 2011). The monitored product design metrics support an optimal supplier base size leading to a competitive advantage through reduced costs, higher quality and innovativeness. The reduced number of suppliers supports the product and process development (Chen & Paulraj 2004, Talluri *et al.* 2013). Furthermore, the design metrics facilitate the product structure improvement and provide an opportunity to set product design goals within the NPD (Kaski 2002, Kaski & Heikkila 2002).

2.2.5 Supply capability creation

The new technologies investments, the product development cost, the shortening product life cycles, the growing number of new products as well as the complexity of product structures, projects, production and supply chain networks make the success of ramp-ups an increasingly challenging and important managerial topic (Almgren 1999, Cooper 2001, Terwiesch *et al.* 2001, Pufall *et al.* 2007, Von Cube & Schmitt 2014). The product ramp-up speed influences the time-to-volume and subsequently the financial success of the developed product (Haller *et al.* 2003). Integrating NPD and supply chain processes through the supply chain capability creation (SCCC) activities is meant to support those preceding issues (Lakemond *et al.* 2001, Ball *et al.* 2011, Elstner & Krause 2014, Surbier *et al.* 2014, Caniato & Größler 2015). The SCCC can be described as a sub-process of the NPD process, which handles the supply chain readiness to deliver the product from the product ramp-up phase (Tolonen *et al.* 2017). The SCCC process encompasses sub-processes such as supply, production or logistics capability creation (Tan 2001, Kim 2006). The overall objective of the SCCC is to prepare efficient and economical product ramp-ups, established from the mature supply chain process (Carrillo & Franza 2006, Hüntelmann *et al.* 2007).

In present business environment, NPD success relates to the importance of rapidly developing products and moving them efficiently to the market (Carrillo & Franza 2006, Van Hoek & Chapman 2007, Kotler *et al.* 2009). Time to market is not exclusively determined by the NPD process but also in the ramp-up of the supply chain as well as other related activities supporting the commercialisation of the product such as marketing and sales. The NPD process role is not only to develop new products but also to assist the ramp-up of the supply chain activities in advance (Van Echtelt *et al.* 2008, Hilletoft *et al.* 2010). Consequently, product development projects should integrate the supply chain representatives – such as supply, production and logistics sub-processes – into the NPD process (Kärkkäinen *et al.* 2001, Cooper *et al.* 2004, Barczak *et al.* 2009, Schmidt *et al.* 2009). Involving the supply chain specialists before the actual new products launch is essential to ensure the product ramp-up capacity and increase the NPD success (Ragatz *et al.* 1997, Wynstra & Ten Pierick 2000). In this manner, the supply chain stakeholders can provide feedback during the product development phases so that the product and supply chain design is conducted in parallel (Chen *et al.* 2005, Carrillo & Franza 2006, Hilletoft *et al.* 2010). The role of SCM operations during the NPD is to take

care of critical aspects, including the material availability for production, the readiness of finished products for ramp-up as well as the product placement in the market according to the schedule (Van Hoek & Chapman 2006, Van Hoek & Chapman 2007, Hilletofth *et al.* 2010, Tolonen *et al.* 2017). Hence, the NPD and SCCC processes are required at the beginning of the product development to prepare the supply chain readiness in a timely manner and to prevent product ramp-up delays caused by the late creation of the supply chain capability (Tracey *et al.* 2005, Carrillo & Franza 2006, Kahn *et al.* 2012). The coordination between NPD and SCM do not only support efficient product introductions on the market but also allows effective updates of the product assortment according to the product life cycle as well as proper termination of obsolete products (Hilletofth *et al.* 2010).

As a part of SCCC, supply capability creation within the NPD process aims at efficient product ramp-ups through mature supply process (Almgren 1999, Pufall *et al.* 2012). The usual challenge for production ramp-up related to the supply is the materials and components shortage from suppliers because of competence gaps, unprepared processes and long supply lead-times (Almgren 1999, Pufall *et al.* 2012, Brewer *et al.* 2013, Brewer & Arnette 2016). Wynstra *et al.* (1999) introduced a framework, which analyses specific activities related to the purchasing involvement in product development. A few tasks are connected to the SCC (e.g. formulating policies for purchasing activities, coordinating development activities between suppliers and manufacturers, ordering prototypes); however, it mainly suggests activities related to influencing the product design and supplier involvement in product development. Furthermore, Behncke *et al.* (2014) proposed an SM process capable of capturing the early involvement of SM in NPD. This process presents some aspects somewhat related to the SCC including sharing suggestions regarding availability, quality, cost and delivery times of components to be supplied; SM as a coordinator between the in-house product development and the one from the supplier; monitoring the vendors' performance. However, the study does not specify the chronology of the activities alongside the NPD process and presents elements out of the SCC scope (e.g. DfSM).

2.3 Synthesis of the literature review

In the present study, the theoretical foundation was formulated based on the selected literature scope related to PM and SM. SM, supply process, PPM, NPD and RaDe are the main studied concepts. DfSM and SCC are the principal researched topics regarding the SM involvement in NPD.

PPM affects the NPD process as it strategically and cost-efficiently selects the best set of products to be created. Consequently, new product introductions by the NPD process without eliminating existing ones will generate an explosion of the portfolio (Tolonen *et al.* 2015a). PPM also affects the supply chain processes because it determines the products to be supplied, manufactured and shipped (Georgiopoulos *et al.* 2002, Sadeghi & Zandieh 2011). Specifically, PPM and SM are connected through the products' components, modules and assemblies that need to be purchased from suppliers (Fixson 2005, Jacobs & Swink 2011). Therefore, PPM and SM are interlinked (Jiao *et al.* 2007, Mansoornejad *et al.* 2010, Pashaei & Olhager 2015). The product proliferation and cannibalisation can result in increased numbers of sales items, purchased components, suppliers and longer lead-times resulting in an explosion of costs (Fisher *et al.* 1999, Abbey *et al.* 2013). SCM and NPD are also connected as the supply chains supply, manufacture and distribute the products defined and developed during the NPD (Pero *et al.* 2010). RaDe is a specific type of NPD model in which the time pressure particularly requires an efficient anticipation of the supply chain and SM constraints from the beginning of the product development (Pero *et al.* 2010). DfSM is meant to address this exercise by synchronising the product design with existing SM process (Sharifi *et al.* 2006, Brewer & Arnette 2016). Besides, the SCCC process and the underlying SCC process are seen significant in preparing the operational supply chain capabilities in a timely manner as well as in preventing ramp-up delays due to late establishment of the capability creation (Almgren 1999, Carrillo & Franza 2006, Khan *et al.* 2012, Pufall *et al.* 2012). The main key concepts of the literature review are introduced in Table 3.

Table 3. Synthesis of the key theoretical concepts.

Key theoretical concepts	Synthesis of the key concepts related to the research problem of this study	Main references
Product portfolio management	A general business concept involving active analysis and decision-making to determine the best set of strategic and cost-effective products to be created, sold, delivered and cared.	Georgiopoulos <i>et al.</i> 2002, Haines 2009, Sadeghi and Zandieh 2011, Belliveau <i>et al.</i> 2004, Tolonen <i>et al.</i> 2014a
New product development	An innovation process to transfer new products, which meet the customer's needs and company's strategic goals, from idea generation into market introduction, including product design, market study and marketing analyses.	Cooper 2005, Browning & Ramasesh 2007, Ulrich & Eppinger 2008

Key theoretical concepts	Synthesis of the key concepts related to the research problem of this study	Main references
Rapid product development	A specific type of incremental product development that requires a minimal engineering effort and a short development time.	Hänninen <i>et al.</i> 2014, Niskanen <i>et al.</i> 2015, Vigna <i>et al.</i> 2015, Kaikkonen <i>et al.</i> 2018
Supply management	A strategic and cross-functional process for determining the total supply requirements, establishing supply strategies, as well as selecting and managing a base of innovative suppliers to realise performance advantages for the focal company and its suppliers.	Goffin <i>et al.</i> 1997, Trent 2007, Spina <i>et al.</i> 2013, Jack & Powers 2015
Design for supply management	A concept to enable the SM activities' knowledge to the product designers because the product design decisions influence the procurement operations complexity.	Sharifi <i>et al.</i> 2006, Brewer and Arnette 2016
Supply chain capability creation	A sub-process of the NPD process, which handles the supply chain readiness to deliver the product from the product ramp-up phase.	Carrillo & Franza 2006, Hüntelmann <i>et al.</i> 2007, Tolonen <i>et al.</i> 2017
Supply capability creation	An underlying process of SCCC, which handles specifically the supply readiness and aims at efficient product ramp-ups through mature supply process.	Almgren 1999, Pufall <i>et al.</i> 2012

3 Research contribution

3.1 Enablers for rapid product development

The original study I addresses RQ1 and relates to the challenges and enablers of rapid product development, based on literature review as well as on the current state analysis of the four case companies A, B, C and D. According to earlier research, RaDe is a type of incremental product development complementing the organisations' existing NPD process. In RaDe, new sales items are created promptly and inexpensively by redesigning or upgrading existing products and avoiding new product-specific technology investments, new materials and suppliers. The literature linked to rapid product development is mostly concentrated on tools and processes to accelerate the NPD, whereas the managerial viewpoint and challenges related to implementing and running faster development projects are still lacking behind. The four companies utilise various NPD models to fulfil different product development needs. Table 4 presents the average schedules of the different models and the amount of RaDe type of projects per year. The different timeframes are estimated in this study based on the practices of the analysed companies. The estimation, however, does not involve analysing a high number of companies to clarify the timeframe further, nor whether there are industry sector-specific differences in the related timeframes.

Table 4. Different NPD models in the companies.

NPD models	Company A	Company B	Company C	Company D	Average
Large NPD timeframe	1-2 years	1,5-2 years	1 year	1-1,5 years	1-1,5 years
Medium-sized NPD timeframe	Not in use	8 months	4 months	6 months	5 months
RaDe type of NPD timeframe	1-2 days, up to one month	1-2 months, up to 6 months	2-3 months	1-6 months, up to 9 months	2-3 months
Number of RaDe projects per year	Hundreds	Hundreds	Tens	Tens	

Practical rapid product development challenges arose from the data analysis and the discussions with the case companies' representatives. Rapid product development appeared as a generic challenge regardless the maturity, the history and the industry sector of the company. Selecting the appropriate product development

model is not always clear even to companies with strict selection criteria. The decision-making process to initiate the RaDe type of development model projects was found uncertain, and tools for prioritisation and evaluation were lacking. In three companies, new products developed through RaDe type of development model do not result in new commercial sales items. New technical version items replace the previous ones, which is similar to the scope of engineering change management. The timeframe of RaDe type of projects may differ greatly from one month to nine months. However, the RaDe governance model was found uncertain in every company, and product ownership and responsibilities were not clearly defined. Dedicated RaDe team and project management were lacking and deficient. The RaDe type of development model has not been described as a clear process and companies lack the supporting processes such as PLM and PPM. Getting detailed data for the product development and RaDe was seen complex due to fragmented databases and sources. The follow-up of the business case has also been an issue. The products developed through RaDe were not consistently evaluated to analyse if the agreed targets have been met. RaDe project cost, progress and duration were also not consistently monitored. Finally, the lack of DfX guidelines and requirements management in case of RaDe has caused complications for companies to deliver the products rapidly. The product design changes may cause issues in supply chain processes (including supply management, manufacturing, logistics and service) which extend the product shipment to the customer and cause challenges because of the time pressure in case of RaDe. The DfX concept has been understood and implemented differently, and the case companies partially document the product design guidelines. One company has been developing this area for many years and currently implement the process systematically while in other cases, the DfX concept is scarcely utilised.

The enablers for implementing RaDe are connected to the main challenges. The primary enabler is to define the concept of RaDe, followed by the creation of the related targets and KPIs according to the company strategy. Thereafter, RaDe processes, tools and governance model can be defined and implemented. Furthermore, the data requirement specification should be created according to the needed information for initiating and performing the RaDe projects. Finally, the utilisation of the existing supply chain – including SM – platforms and the fit of the product to be developed with the current business processes are also a prerequisite for RaDe. The created RaDe enablers are described in detail in Table 5.

Table 5. RaDe Enablers (Article I, reprinted with permission of IGI Global).

Enablers	Explanations
1. Definition of RaDe	Determine the fundamentals of RaDe to respond rapidly to new product requirements and business opportunities. Define the scope of RaDe to create new sales items quickly by modifying existing sales items. Analyse the product development effort based on the defined criteria to select the RaDe model appropriately. Structure the product portfolio as a configurable commercial portfolio and modular technical portfolio to enable efficient RaDe projects.
2. Creation of the RaDe targets and KPIs	Define the criteria for RaDe analysis and decision-making according to the strategic PPM targets and KPIs such as strategic fit, value maximisation and portfolio balance. Define the targets and metrics for efficient RaDe project execution such as project cost and time-to-market.
3. Creation of RaDe governance model and team setup	Establish a permanent, co-located and self-adaptive RaDe teams based on competent individuals and efficient people management approach. Define a fast and lean governance model in relation to PPM. Acknowledge and consider the different stakeholders and their requirements.
4. Creation of RaDe processes and tools	Implement RaDe process as a clear and flexible workflow to ensure efficient and fast analysis, decision-making and execution. The RaDe tools should facilitate the accomplishment of all the activities in a coordinated manner. Rely on the experts (those who develop the product and related supply chain capabilities) instead of employing a too rigid or hierarchical process, which may delay the product development.
5. Data availability and reporting	Develop the product data management as well as PPM capabilities and concepts to support the RaDe type of product development model. Specify and document the original requirements for RaDe at an early stage. Consider and preserve the lessons learned for future activities.
6. DfX product design guidelines	Support RaDe by understanding the product design requirements of the supply chain processes (including SM process). Create the product design guidelines, targets and metrics to make sure the products created through RaDe can be supplied, manufactured, ordered, distributed and invoiced the with existing and planned supply chain and SM processes without new product related changes or investments.

As a result of the original study I and answer to RQ1, the practical challenges and enablers related to RaDe implementation have been presented. The further research questions and original studies address more precisely, how the organised SM and PPM processes are enablers for RaDe.

3.2 Strategic alignment of product portfolio and supply management

The second original study addresses RQ2 by analysing the interactions between PPM and SM as well as proposing a way to align these two processes strategically. RaDe enables a quick product portfolio renewal but also involves a risk of product portfolio explosion. Therefore, PPM has an increasingly crucial role in avoiding product proliferation and cannibalisation. PPM aims at a strategic and cost-efficient determination of the best set of products to develop, sell, deliver and care. PPM affects the product development process and the supply chain processes by analysing and deciding which new products are to be developed as well as which existing products are to be maintained or removed. Also, aligning the strategic intent of SM with PPM is a prerequisite for RaDe projects as the supply chain processes, including SM, should not be modified to allow a fast response to the customer.

PPM-SM cooperation and alignment are recognised to produce positive outcomes such as avoiding the use of outdated buy-items, improving product portfolio profitability, limiting the supplier base and product portfolio proliferation, and thus delivering efficient products that meet the customers' expectations regarding quality, cost and time. PPM affects the SM performance by renewing the product portfolio and thus enables the SM to manage the suppliers only related to the products that create the highest strategic fit, maximised value and balance for the company. Likewise, SM can be identified as a portfolio management of suppliers and related buy-items. Accordingly, the role of SM is to manage – in a balanced manner – the suppliers representing the highest strategic fit and minimised cost. To recognise PPM as a business process that establishes the products to be created, sold, delivered and cared, the PPM-SM connection is necessary to be analysed.

The relationship between PPM and SM is crucial. They are connected through the product portfolio structure. PPM analyses and manages strategically and economically all items of the commercial and technical product portfolios from the highest commercial solutions to the lowest level of technical components. As an integral member of the portfolio management, SM analyses what will be the buy-items, which will be provided by the suppliers. To provide a deeper understanding of PPM-SM alignment, an analysis template (Appendix 1) has been created by utilising the literature and the empirical data from the analysed company E. The alignment is evaluated from the perspective of strategic targets, business process targets as well as product related design rules, targets and metrics. Resulting from the PPM and SM alignment (Figure 8), the list of recommended products and related buy-

items with the corresponding list of recommended suppliers can be created and agreed. The potential facilitators for improving the PPM and SM connection include strategic supplier segmentation, product variety and supply chains coordination, product modularity development and efficient product data management.

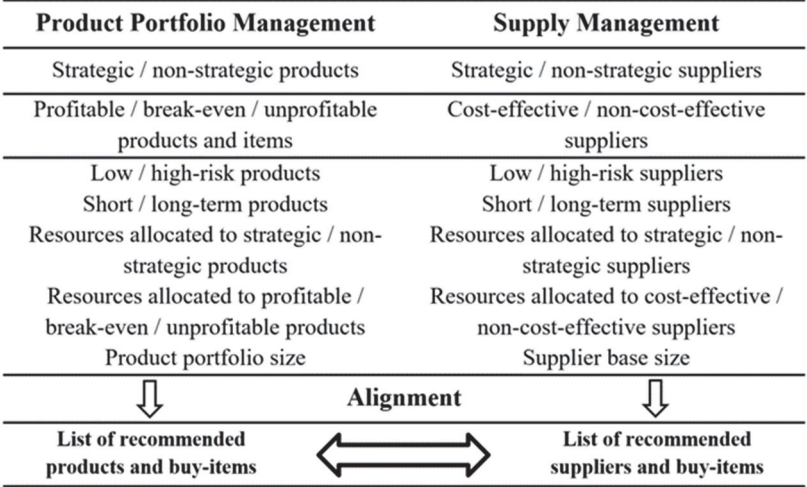


Fig. 8. The proposed strategic alignment between PPM and SM (Article II, reprinted with permission of Inderscience Publishers).

3.3 Mature supply management and DfSM as a critical precondition for rapid product development

The original study III addresses the RQ3 and focuses on mature supply management as an enabler for efficient execution of the RaDe activities. The maturity requirements of SM for RaDe are analysed utilising an SM evaluation framework. The framework is then further utilised to evaluate three case companies. The earlier literature emphasises well the importance of SM involvement in the NPD for the success of new product introduction. The NPD decisions affect the SM, and the DfSM concept has been studied to facilitate the SM knowledge towards the NPD specialists. DfSM product design concept aims at influencing the product design to simplify the SM process. However, the holistic and crucial role of mature SM for RaDe has been neglected. The different SM maturity models proposed in the literature do not assess the readiness of the SM process for RaDe regarding SM objectives, performance measures or product design guidelines, targets and metrics.

Table 6 illustrates the SM process related objectives, performance measures, product design guidelines, targets and metrics that have been integrated based on an extensive literature review. This compilation forms the basis for evaluating companies and assess their SM maturity for RaDe.

Table 6. Compilation of SM objectives, product design guidelines and metrics.

Performance objectives and measures	Product design guidelines	Product design targets and metrics
Total cost savings (<i>Humphreys et al. 2007</i>)	Select qualified and	Number of suppliers per product
Cost avoidance (<i>Humphreys et al. 2007</i>)	contracted suppliers	and number of different parts per
Defects per million (<i>Dasgupta 2003</i>)	(<i>Zsidisin and Ellram 2001,</i>	supplier (<i>Ahonen & Salmi 2003</i>)
Percentage of order error rate (<i>Kumar et al. 2005, Chao et al. 1993</i>)	<i>Brewer & Arnette 2016</i>)	Number/share of recommended
Material non-acceptance rate (<i>Axelsson et al. 2002, Kumar et al. 2005</i>)	Align product design	parts supplied by contracted and
Material acceptance rate (<i>Hwang et al. 2008</i>)	features according to the	qualified suppliers (<i>Wasti & Liker 1997, Wallace & Hill 2011, Kaski 2002</i>)
Buyer-supplier partnership level (<i>Bhagwat et al. 2007</i>)	preferred suppliers'	Number/share of purchased parts
Percentage of qualified and certified suppliers (<i>Hwang et al. 2008</i>)	capabilities (<i>Dowlatshahi 1992, Liker et al. 1996</i>)	matching the requirements
Total number of suppliers used (<i>Axelsson et al. 2002, Easton et al. 2002</i>)	Ensure that the	(<i>Humphreys et al. 2007</i>)
Perfect order fulfilment (<i>Hwang et al. 2008</i>)	outsourced critical	Extent of suppliers' engagement in
Cycle time: supplier order delivery (<i>Bhagwat et al. 2007</i>)	components are dual	collaborative design (<i>Von Corswant & Tunälv 2002</i>)
On-time supplier delivery rate (<i>Bhagwat et al. 2007, Hwang et al. 2008</i>)	sourced (<i>Yu et al. 2009</i>)	Number/share of interchangeable
Material availability (<i>Hwang et al. 2008</i>)	Ensure the use of	parts per product (<i>Dowlatshahi 1992,</i>
Inventory turnover rate (<i>Gunasekaran et al. 2001, Hwang et al. 2008</i>)	platform-based modular	<i>Liker et al. 1996, Twigg 1998</i>)
Inventory accuracy (<i>Gunasekaran et al. 2001, Hwang et al. 2008</i>)	product structure (<i>Lehtonen 2003, Fixson 2005</i>)	Number/share of standard or off
Supplier fill rate (<i>Humphreys et al. 2007</i>)	Maximise the use of	the shelf parts per product
Quality cost per supplier (<i>Youssef et al. 1995</i>)	standard components (<i>Burt & Soukup 1985, Ulrich 1995</i>)	(<i>Dowlatshahi 1992, Liker et al. 1996, Twigg 1998</i>)
Supplier order documentation accuracy rate (<i>Gunasekaran et al. 2001, Hwang et al. 2008</i>)	Maximise component and	Number/share of substituted parts
Frequency of supplier evaluation (<i>Axelsson et al. 2002, Kumar et al. 2005</i>)	part reuse (<i>Fixson 2005,</i>	per product (<i>Dowlatshahi 1992, Liker et al. 1996, Twigg 1998</i>)
	<i>Pulkkinen et al. 2012</i>)	Number/share of parts excluded
	Minimise individual parts in	per product (<i>Dowlatshahi 1992, Liker et al. 1996, Twigg 1998</i>)
	the design and maximise	Degree of modularity (<i>Abdelkafi 2008</i>)
	ready to assemble	Level of supplier design expertise
	components (<i>Duray et al. 2000</i>)	or innovativeness in the product
	Ensure minimal varieties	design (<i>Humphreys et al. 2007</i>)
	of sourced components	Number of components, modules
	(<i>Pulkkinen et al. 2012</i>)	and structure layers in the product
	Maximise product	(<i>Kaski 2002, Fernández & Kekäle 2005</i>)
	modularity (<i>Duray et al. 2000</i>)	

The capability maturity model integration (CMMI) scale (Chrissis *et al.* 2003, CMMI Product Team 2006) is utilised to assess the SM maturity level, concerning the availability and utilisation of the above-proposed objectives, performance measures, product guidelines and metrics within the companies’ SM processes. The maturity is categorised from level one to level five (Table 7). The SM maturity framework comprises two sub-concepts:

- The supply management process including the related objectives and performance measures.
- The DfSM product design concept consisting of the product design guidelines, targets and metrics, described as a part of the product development process.

Table 7. CMMI scale to assess the SM maturity for RaDe.

Level	Explanations
Level 1 <i>Initial</i>	The framework features (SM objectives, performance measures, product design guidelines and metrics from SM viewpoint) are not defined nor documented. All or some of the features are case-specific and used individually or informally as per requirements.
Level 2 <i>Managed</i>	Some framework’s features are defined but not managed holistically nor systematically. The interrelationships among the features of the framework are not understood nor defined.
Level 3 <i>Defined</i>	The framework features are defined. Targets are defined but not monitored. The interrelationship between the features is understood and defined.
Level 4 <i>Quantitative</i>	The process parameters’ targets are quantified and controlled (including the sub-process level). These quantifiable targets are embedded in the product development process.
Level 5 <i>Optimising</i>	The SM maturity framework is holistically taken into use, continuously improved and optimised based on quantifiable measures or evidence.

This framework is utilised to evaluate the SM maturity in three companies. The SM objectives and performance measures, and DfSM product design product design guidelines, targets and metrics are analysed for each case. The company B presents the most advanced characteristics in terms of SM maturity. The systematic knowledge and utilisation of existing suppliers and components positively support the RaDe projects. The success of RaDe projects is enhanced by the collaboration between the RaDe team and SM people as well as the predefined guidelines. In the companies C and D, the maturity of SM and related product design requirements is

less significant. Company C is currently focusing on implementing the DfX concept (including DfSM) to better transfer the requirements from downstream departments into the product design. Company D does not currently perceive the necessity to develop the SM maturity, even though the firm aims at integrating more efficiently the SM knowledge into the product development projects. Subsequently, the SM objectives, measures, DfSM product design guidelines, targets and metrics are compared between the case companies. Based on this comparison, analysis and the CMMI scale to assess the SM maturity for RaDe, the maturity of SM is determined for the three case companies (Table 8).

Table 8. Comparison of the SM objectives, the related product design guidelines and SM maturity level for RaDe in the analysed companies.

Company B	Company C	Company D
<i>Supply management objectives and measures</i>		
The main objectives of SM are to ensure the quality of supply and minimise the purchasing lead-time. The related performance measures and targets are well defined and documented.	The main objectives of SM are to ensure the purchase quality and flexibility. The related performance measures and targets are not consistently defined nor documented. However, some measures are characterised and followed.	The main objectives of SM are to ensure the supply quality and minimise the purchasing cost. The related performance measures and targets are not consistently defined nor documented. However, some measures are available and managed.
Critical measures for RaDe: Suppliers' delivery lead-time, material quality and utilisation of contracted and recommended suppliers.	Critical measures for RaDe: Suppliers' on-time delivery, material quality, supply risks and utilisation of recommended suppliers.	Critical measures for RaDe: Suppliers' delivery lead-time, utilisation of recommended suppliers.
<i>DfSM product design guidelines, targets and metrics</i>		
The product design guidelines and metrics are well defined and strictly followed under the scope of DfSM.	The product design guidelines and metrics are not defined. Some ad-hoc guidelines and metrics are available for each specific project. DfX is in the implementation stage.	The product design guidelines and metrics are not defined. However, some ad-hoc guidelines and metrics are available.
Examples of product design guidelines: minimise individual parts in product design; minimise the number of suppliers.	Examples of reported product design guidelines: select qualified and contracted suppliers; maximise component/part reuse.	Examples of reported product design guidelines: align product design features according to the preferred suppliers' capabilities.

Company B	Company C	Company D
Examples of product design targets and metrics: number of components/modules; share of locally sourced components.	Examples of reported product design targets and metrics: number/share of parts supplied by contracted and qualified suppliers.	Examples of reported product design targets and metrics: number/share of standard parts per product.
<i>SM maturity framework level for RaDe</i>		
Performance measures and targets are clear and defined. Product design guidelines and metrics are strictly followed under the scope of the DfSM discipline. All features are embedded into the workflow process. No evidence of Quantifiable improvement.	Performance measures and targets are currently not well documented from the SM perspective. However, some measures are defined and in use. Product design guidelines and metrics are not defined, but some ad-hoc guidelines and metrics are available. DfX is in the implementation stage. Design targets are set for each project.	Some performance measures and targets are available and managed. Product design guidelines and metrics are not defined, but some ad-hoc guidelines are available in terms of lessons learned.
Maturity level: 4	Maturity level: 2	Maturity level: 2

In the case of RaDe, the pressure of fast response to customer requests affects the SM process and its integration with product development. The supply involvement and the utilisation of the current SM capabilities are seen crucial by the companies. The utilisation of the approved and recommended suppliers and related materials are among the cornerstones of RaDe projects. The DfSM product design concept is seen beneficial for RaDe projects as it can enhance the use of existing design and suppliers leading to an increase of component standardisation and commonality.

In RaDe, the product design changes affecting the SM process should be limited, as product-specific changes in SM – such as introducing a new supplier – will negatively increase the product development time and costs. Therefore, the aim is to influence and align the product design with the current SM capabilities through DfX/DfSM design guidelines, rules and metrics. The proposed framework addresses this by evaluating how and ensuring that the product design is aligned with the existing SM process capabilities, hence supporting the core idea of RaDe. As it was analysed in the case companies, a mature SM process and DfSM concept are enablers for RaDe. As a result of the article III and answer to RQ3, this study presents the metrics and maturity requirements of SM for RaDe. The maturity levels correspond with the implementation of the introduced framework's parameters into companies' processes. A higher maturity of SM process and DfSM concept results

in more capabilities in aligning the developed products with the current SM capabilities, leading to smoother RaDe projects. A mature SM supports every product development model but is more necessary in the case of RaDe projects.

3.4 Supply capability creation process: Key milestone criteria and activities

The original study IV addresses the RQ4 and focuses on the SCC within the NPD phase. The systematic process for SCCC and SCC are created and integrated as a part of the NPD process to avoid potential challenges such as excess costs in supply processes, increased time-to-market and customer dissatisfaction during the product development, ramp-up and operational order fulfilment phase (e.g. supplying, manufacturing and shipping). Clear SCCC and SCC roles, responsibilities, activities, milestones, metrics and targets should be established. The SCC should be managed from the beginning of the NPD projects. An effective and efficient SCC process can assist the SM by determining the right materials and qualified suppliers at the right moment of the NPD, thus maintaining an optimal stock value, limiting delays to achieve successful product ramp-ups and operational supply process. Qualifying and contracting suppliers in a timely manner may ensure quality supplies and appropriate reliability from the suppliers. This ability is particularly substantial in the case of RaDe projects. This concept refers to the SCCC process and more specifically in the original study IV, the SCC process. Previous research highlights the advantages of involving the SM stakeholders during the NPD process but does not introduce how the supply readiness can be established systematically along the NPD process phases and milestones. The original study IV provides an SCC process that has not been presented earlier in the literature and highlights the important role of the SCC for successful product ramp-ups.

Based on the literature review, six main SCC areas were determined. The comprehensive requirement for SCC consists of an integrated and cross-functional NPD in which supply specialists are involved early in the NPD process (1). Beneficial SCC implies a structured and described NPD process (2) including the milestone criteria (3). Furthermore, the SCC process should be represented in the form of activities implemented during the NPD process (4) to prepare the supply process for the product ramp-up phase. Milestone criteria for the SCCC process and underlying SCC process should also be formulated (5). The main activities of SCC con-

sist of selecting, qualifying and contracting suppliers and materials promptly alongside the NPD process (6). Those six SCC characteristics have been investigated in the context of six companies. Six findings resulted from this analysis:

- Finding 1. Integrated NPD and early involvement of cross-functional specialist are necessary for effective and efficient product creation.
- Finding 2. NPD process description supports reaching company project goals, including launching new products and carrying out product enhancements.
- Finding 3. Milestone criteria at NPD process gates support managing and monitoring projects but can lead to challenges when excessive.
- Finding 4. SCCC/SCC activities alongside the NPD process, reactive or proactive are necessary for the efficient ramp-ups of new products.
- Finding 5. The significance of milestone criteria for SCCC and SCC process is recognised, but not widely implemented.
- Finding 6. Selecting, qualifying and contracting suppliers and materials on time along the NPD process has significance for product success.

Based on this study, a cross-case analysis has been realised to compare the SCC practices in the six analysed companies. The usage of the SCC practices varied, and the individual aspects are presented in Table 9.

Table 9. Characteristics of SCC identified in the case companies.

Characteristics of SCC	F	G	H	I	J	K
1. Integrated NPD – early supply specialists involvement during the NPD	O	X	X	X	X	O
2. NPD process description	X	X	X	X	X	O
3. Milestone criteria for NPD process	X	X	X	–	X	–
4. SCC related activities implemented during the NPD process	O	O	O	O	X	O
5. Milestone criteria for SCCC and SCC process	–	–	–	–	–	–
6. Select, qualify and contract suppliers and material on time along the NPD process	O	O	O	O	X	O

X = applies to the organisation

– = does not apply to the organisation

O = somewhat applies to the organisation

Every analysed company understands the benefit of an organised, described and integrated NPD. All describe their NPD process (although the company F does not map it formally) and somehow involves specialists unrelated to the product engineering itself (such as marketing, supply chain and supply specialists). However, not every organisation utilises milestone criteria in their NPD process. Even though none possesses an SCCC/SCC process, some SCC activities are completed during the NPD. Every company aims at selecting, qualifying and contracting suppliers and materials promptly during the NPD process, but none, except the company J, do it systematically. The informants considered the proactive management of SCC activities and the use of a mapped process to prepare the supply readiness to be beneficial. Accordingly, based on the literature, the analysis of the current practices of the six companies and the cross-case analysis, a systematic SCC process is provided as a part of the SCCC and NPD process.

The SCC process should be described in detail the activities to be done during each phase of the NPD project. The instruction set should be integrated and followed in parallel with the NPD process (milestone-driven process adapted from Cooper 2001, Ulrich & Eppinger 2008). The SCCC process specifies the milestone criteria to be met for each milestone (M) so that the NPD project can move to the next phase (Figure 9).

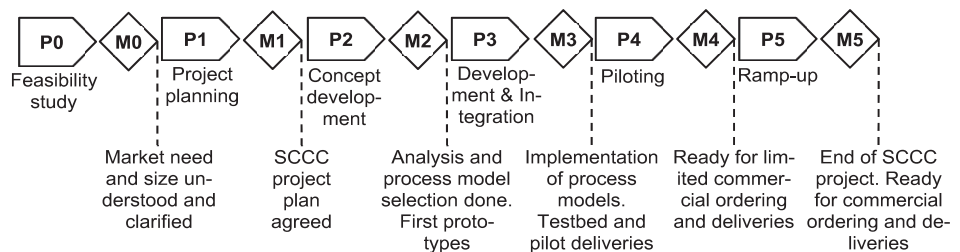


Fig. 9. Overall SCCC milestone criteria aligned with the NPD process.

The SCC process consists of the key activities and milestone criteria. The introduced SCC process (Table 10) covers all stages from P0 to P5 and contain the main activities to meet the milestone criteria. According to the size of the company and the nature of the NPD project, a nominated SCC or SCCC manager is part of the NPD team and responsible for the SCC activities.

Table 10. SCC process: key activities and milestone criteria.

Phase	SCC activities and milestone criteria
P0 Feasibility	<u>SCC activities</u>
Study	Establish the SCC team. Inform the SM staff of the upcoming product development. Clarify the supplier base, the preferred/strategic suppliers and components.
<i>Market need and size clarified,</i>	Inform the NPD team of the possible long lead-time materials.
<i>process models selected</i>	Screen the new technologies and materials from the preferred suppliers (mature technologies from the supplier point-of-view but new for the focal company). <u>Milestone criteria</u> SCC team established. Current supply capabilities clarified. SCC targets are pre-established. Preferred suppliers and components identified.
P1 Project	<u>SCC activities</u>
Planning	Create the SCC plan as a part of the SCCC team. Select the preferred supply models for the different types of supply according to the company's supply strategy.
<i>SCCC project plan agreed and started</i>	Qualification and agreement of critical suppliers. Set the targets for the total cost of ownership of the purchased materials and items. <u>Milestone criteria</u> SCC plan created and approved as a part of SCCC plan. Supply models selected. SCC targets are agreed. The critical suppliers have been qualified and agreed.
P2 Concept	<u>SCC activities</u>
Development	Identify the items to be supplied (e.g. raw materials, auxiliary materials, wearing parts, tools and packing material). Identify and examine the supply market.
<i>Testing process models, make first prototypes</i>	Identify, evaluate and update the existing suppliers and contracts. Evaluate the new suppliers and contracts and select the most suitable suppliers. Evaluate the total cost of ownership of the material and items. Begin the supply of long lead-time components and tooling. <u>Milestone criteria</u> All the items to be supplied are pre-identified. Agreement discussions with the potential suppliers started.
P3 Development and Integration	<u>SCC activities</u> Establish new suppliers and contracts in accordance with the supplier strategy. Finalise the list of the supplied items as well as the related supplier base.
<i>Implement process models, pilot deliveries</i>	Implement the supply models for all the supplied items. <u>Milestone criteria</u> The list of supplied items is finalised. All the related suppliers are contracted, and purchase prices are agreed.

Phase	SCC activities and milestone criteria
P4 Piloting (Testing and Validation)	<p><u>SCC activities</u></p> <p>Ensure all the involved suppliers are aware and ready for the expected business and the objectives of the incoming product. Set backup plans.</p> <p>Establish the payment process for the supplied material and items.</p>
<i>Ready for limited commercial deliveries</i>	<p>Pilot and validate the supply models for all the supplied items.</p> <p>Optimise and fine-tune the SM capability.</p> <p>Establish supplier relationships and supplier performance management.</p> <p><u>Milestone criteria</u></p> <p>All the suppliers are established and ready to supply every needed item in the right condition and according to specifications.</p> <p>The supply models are validated and meet the quality, time and cost targets.</p> <p>The SM and supply process workforce is trained.</p> <p>Supply process is piloted, ready for product ramp-up and for any inconveniences.</p>
P5 Ramp-up (Launch)	<p><u>SCC activities</u></p> <p>Manage and facilitate suppliers ramp-up and improve collaboration.</p> <p>Establish regular and mass volume supply and SM capabilities.</p>
<i>Ready for commercial deliveries. End of SCCC project</i>	<p>Document the best practices and lessons learned during the SCCC project.</p> <p>Transfer all the SCC responsibilities to the SM organisation.</p> <p>Disassemble the SCC team.</p> <p><u>Milestone criteria</u></p> <p>Supply process is ready for mass volumes.</p> <p>Supply responsibility is handed over to the operational SM organisation.</p> <p>The SCC team is disassembled.</p>

Different preconditions support the creation of the SCC process. Firstly, the supply process and the related process owners, requirements, targets and metrics should be defined. Secondly, the NPD process and governance should manage the product development activities and its progression. Thirdly, gates should be implemented within the NPD process.

3.5 Results synthesis

This study describes the role of mature SM in successful RaDe implementation and product portfolio renewal, thus allowing economic, strategic and fast product ramp-ups. The current RaDe challenges and enablers are analysed. Particularly the enablers related to SM maturity, PPM-SM alignment and SCC were considered thoroughly (Table 11).

Table 11. Research summary and contribution of the individual original studies.

RQ#	Main Results
1. What are the enablers of rapid product development?	<p>RaDe enablers:</p> <p>RaDe concept and supporting processes (PPM & PLM)</p> <p>RaDe targets and KPIs</p> <p>RaDe governance model and team setups</p> <p>RaDe processes and tools</p> <p>Data availability and reporting</p> <p>DfX product design guidelines, utilisation of the existing supply chain processes (including supply management)</p>
2. How to align product portfolio management and supply management?	<p>PPM – SM are connected through the product portfolio structure and every buy-item of the product portfolio is subjected to SM.</p> <p>The strategic fit, balance and value maximisation of PPM and SM can be put in parallel.</p> <p>Synchronised PPM and SM result in the alignment between the list of recommended products and related buy-items with the list of recommended suppliers.</p>
3. What are the metrics and maturity requirements of supply management for rapid product development?	<p>In RaDe, the product design modifications that affect the SM process should be limited, as product-specific changes in SM increase the product development time and costs.</p> <p>Integration of the SM-related objectives, performance measures, product design guidelines, targets and metrics as well as the CMMI scale are utilised to assess the SM maturity for RaDe.</p> <p>The developed framework ensures that the product design is aligned with the existing capability of the SM, supporting the core idea of RaDe.</p>
4. How can the supply capability creation be systematically handled as a process?	<p>SCC process describes the main SCC activities and milestone criteria in preparing the supply process for the new products. SCC roles, responsibilities, metrics and targets are also specified.</p> <p>The systematic SCCC/SCC process is integrated into the NPD process.</p> <p>The SCC process assists the SM by determining the right materials and qualified suppliers at the right moment during the NPD, thus limiting delays and maintaining an optimal stock value to achieve successful product ramp-ups and operational supply process.</p>

The holistic results of this study – representing the mature supply management as an enabler for rapid product development and product portfolio renewal – are illustrated in Figure 10. SM and PPM are aligned through the coordination of the list of recommended products, buy-items and suppliers. Mature SM provides the product design guidelines, targets and metrics to the RaDe team. The products developed

through RaDe comply with the product portfolio management targets and KPIs. RaDe activities start by selecting the RaDe as the product development model, new product analysis and decision-making follows and then the project execution. During the RaDe project, the supply capability creation is prepared and completed. Consecutively, RaDe results in product portfolio renewal and allow fast product ramp-up.

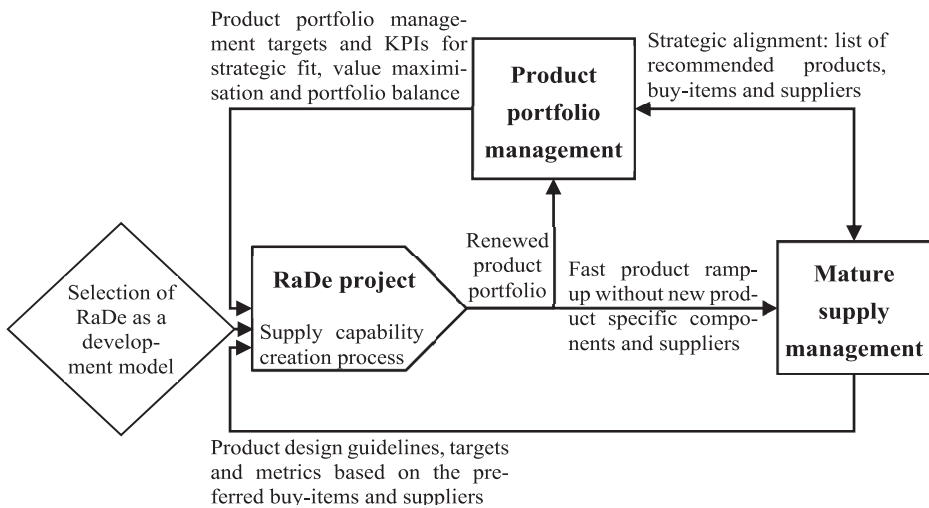


Fig. 10. Mature supply management as an enabler for rapid product development and product portfolio renewal.

RaDe is a type of incremental product development that complements the existing NPD process of companies. In RaDe, new sales items are created by rapidly re-designing or upgrading existing products, simultaneously avoiding new product-specific technology investments, new materials and suppliers. The study of RaDe enablers has recognised the significance of mature SM and PPM for rapid and efficient product development and ramp-up. RaDe enables a quick product portfolio renewal but also presents risks of product portfolio explosion. Therefore, PPM has become increasingly crucial for avoiding product proliferation and cannibalisation. PPM affects the product development process and the supply chain processes by analysing and deciding which new products are to be developed, which existing products are to be still maintained, and which should be removed. Notably for RaDe, PPM is crucial to restrain product portfolio explosion caused by a growing amount

of rapid, small-scale development projects. RaDe projects enable product portfolio renewal within the perimeter of PPM.

In the case of RaDe, the time pressure requires an anticipation of the supply chain constraints at the early stages of the project. As a part of supply chain process, SM can be described as a strategic process defining the company's supply strategies, involving preferred suppliers and recommended materials. Aligning the strategic intent of SM with PPM supports RaDe projects, as product-specific changes must be limited, thus creating new SM capability should be minimised to enable a fast response towards customers. This strategic alignment results in the synchronisation between the list of the recommended products defined by the PPM process and the list of recommended buy-items and suppliers determined by the SM process. The anticipation of SM constraints for NPD and RaDe projects is further analysed through the study of the DfX product design concept and the specific DfSM sub-discipline. DfSM enables conveying the SM activities' knowledge to the product designers (e.g. which suppliers and material to use), as the product design decisions can simplify the complexity of SM operations. An SM evaluation framework is established to question how and ensure that the product design is aligned with the existing SM process capabilities, hence supporting the core idea of RaDe. Furthermore, the rapid delivery of the product is also influenced by the capability of the company to deliver the developed products to the customer. This capability is created through the SCCC and specifically in this research the SCC. Although in case of RaDe the creation of new SM capabilities must be restricted, SCC is also necessary for RaDe projects. The SCC process is then adjusted to fit with the fast and short RaDe projects. The SCC strengthens RaDe as the activities and decisions that affect the SM are recognised and agreed in a timely manner along the RaDe project, and hence supports rapid and smooth ramp-ups on the SM side.

In the present research, the mature SM encompasses four different key topics to be developed in organisations to enhance the rapid product development projects and the product portfolio renewal:

- The SM objectives definition
- The alignment of the list of recommended products, buy-items and suppliers
- The creation of the product design guidelines, targets and metrics from SM the perspective
- The establishment of the SCC process

4 Discussion

4.1 Scientific implications

The present study identifies four essential topics related to mature SM, which allow enhanced RaDe projects and efficient product portfolio renewal. The scientific implications of the individual original studies are summarised in Table 12.

Table 12. Scientific implications of each publication.

Title of the original study	Scientific implications
1. Challenges and Enablers for rapid product development	<p>Identification of the RaDe challenges</p> <p>Definition of the RaDe enablers based on the challenges:</p> <ul style="list-style-type: none"> - Primary understanding of RaDe concept - RaDe targets and KPIs - RaDe governance model and team setups - RaDe processes and tools - Data availability and reporting - DfX product design guidelines
2. Strategic alignment of product portfolio management and supplier management	<p>Identification and analysis of the link between PPM and SM.</p> <p>PPM and SM are connected through the buy-items of the technical product portfolio.</p> <p>Creation of a framework to strategically align PPM and SM based on the three basic performance objectives of PPM and SM.</p>
3. Mature supply management as a critical precondition for rapid product development	<p>The RaDe products must be aligned with the SM process to avoid the need for later adaptation and allow new products to be ramped up shortly.</p> <p>Creation of an SM maturity framework to assess the SM readiness for RaDe.</p> <p>The framework is based on the SM objectives, performance measures and the related DfSM product design guidelines and metrics.</p>
4. Supply capability creation process: Key milestone criteria and activities	<p>Creation of SCC process within the NPD process.</p> <p>The process describes the main SCC activities and milestone criteria in preparing the supply process for new products.</p> <p>Qualified and contracted suppliers and materials are established at the right moment along the NPD process.</p>

Regarding the order fulfilment strategy, RaDe complies with engineering-to-order in which added modifications or customisations are made from a standard product range (Porter et al. 1999, Hill 2000, Wikner & Rudberg 2005, Gosling & Naim

2009). As rapid development is meant for small-scale product development based on existing product designs, it does not conform to the description of ETO where completely new designs are developed (Rudberg & Wikner 2004, Gosling & Naim 2009). Related to the multi-project strategy and depending on companies' approaches, rapid product development can possibly comply with the three different types of incremental design: rapid design transfer, sequential design transfer and design modification (Nobeoka & Cusumano 1997). However, this study provides the added perspective of PPM and SM by analysing how they can enable efficient RaDe projects.

The first original study – *Challenges and Enablers for rapid product development* – clarifies the challenges and enablers in the implementation of RaDe projects. The previous research focus has been on milestone-driven product development model; however, this model may not be suitable for every product development need and multiple approaches should be utilised for managing different product development types (Becker 2006, Ward 2007, Cooper 2008). The first original study results are in accordance with the current literature specifying that to achieve fast product offering, a distinctive structure and management in comparison to traditional NPD model is necessary (Tushman & O'Reilly 1996, Birkinshaw & Gibson 2004). The findings strengthen and support the existing literature on the topic (Cooper 2008, Hänninen *et al.* 2014, Niskanen *et al.* 2015, Vigna *et al.* 2015, Kaikkonen *et al.* 2018). This study emphasises how in RaDe projects, the supply chain processes should not be modified to allow immediate product ramp-up. The scope of changes is restricted so that no capabilities should be created (such as the need to select new suppliers) which provides a new contribution and is consistent with previous findings (Niskanen *et al.* 2015).

The second original study – *Strategic alignment of product portfolio management and supplier management* – proposes a framework for aligning PPM and SM strategically. The current literature acknowledges that supply chains should be aligned with the company's products and product portfolio (Fisher 1997, Lee 2002, Langenberg *et al.* 2012), but fails to provide an adequate PPM-SM link. The present publication provides an additional and specific contribution by identifying, recognising and analysing the PPM-SM link and alignment. A framework for aligning PPM and SM strategically is introduced in this study. The framework is created through the three-PPM basic performance objectives - strategic fit, value maximisation and portfolio balance. The results provide a support and additional contribution to the previously identified importance of PPM (Cooper *et al.* 1999, Mikkola 2001, Miguel 2008, Barczak *et al.* 2009, Oh *et al.* 2012, Tolonen *et al.* 2015a). The

SM can be considered as a portfolio of suppliers and buy-items because of the description and the focus of SM highlighted in the literature (Kraljic 1983, Goffin *et al.* 1997, Chan *et al.* 2008, Morssinkhof *et al.* 2011, Hoffmann *et al.* 2013, Jack & Powers 2015). The strategic PPM-SM alignment, which is based on the three basic performance objectives of both PPM and SM, is established in this study, providing a new contribution.

The third original study – *Mature supply management as a critical precondition for rapid product development* – presents the SM maturity in terms of managing and aligning product design according to SM goals and capabilities, crucial in RaDe projects. The establishment of the SM objectives, performance measures as well as the related DfSM product design guidelines and metrics form the basis of the introduced SM maturity framework. Unlike the existing SM maturity models in the literature (e.g. Barry *et al.* 1996, Paulraj *et al.* 2006), the framework presented in this study specifically assesses and concentrates on the SM readiness for RaDe. Obviously, the different models present some similarities and the aspects of standardisation, design to cost, or supplier base rationalisation (Schiele 2007) are as crucial in the presented framework. The results in this publication correspond with the current literature asserting that the NPD should consider the SM requirements early to enable efficient new product introductions (Sharifi *et al.* 2006, Pulkkinen *et al.* 2012, Brewer & Arnette 2016). As studied in article I, the lead-time factors in RaDe projects do not allow wasting time in the development of the receiving business processes including SM, which is the focus of this paper. The RaDe products must be aligned with the SM process to avoid the need for adaptation and allow new products to be ramped up shortly. Consequently, in line with previous studies, the DfX and DfSM issues become more critical (Gatenby and Foo 1990, Holt & Barnes 2010, Lehto *et al.* 2011, Barbosa & Carvalho 2013) and are adapted in the introduced SM maturity framework.

The fourth original study – *Supply capability creation process: Key milestone criteria and activities* – introduce an SCC process within the NPD process. Few studies have previously addressed the coordination of supply chain processes and NPD (e.g. Hillebrand & Biemans 2004, Carrillo & Franza 2006, Van Hoek & Chapman 2007, Hilletoft *et al.* 2010, Pero *et al.* 2010, Marsillac & Roh 2014) and more specifically the SM role in NPD (Luzzini *et al.* 2015). However, the necessity to further study the integration of NPD and supply chain process has been identified (Van Hoek & Chapman 2007). The SCC process presented in this study aims at preparing the operational supply process during the NPD, without directly focusing

on supplier involvement nor influencing the product design, and hence provides a new contribution to the topic (cf. Wynstra *et al.* 1999, Behncke *et al.* 2014).

In summary, the fundamental theoretical contribution of the present study is to provide new insights of SM maturity, which enables effective and efficient rapid product development projects and product portfolio renewal. This model includes 1) the definition of the SM objectives, 2) the alignment between the recommended products, buy-items and suppliers, 3) the formulation of the product design guidelines, targets and metrics from the SM perspective and 4) the creation of the SCC process.

4.2 Managerial implications

This research provides a model that can help business managers in the planning and implementation activities related to RaDe, PPM and SM. The novelty of the presented SM maturity lies in the description of the role and significance of SM in successful RaDe implementation and product portfolio renewal. Companies may not have considered the presented aspects in the extent of the study findings.

When the current product portfolio of a company cannot satisfy a strategic and economic business needs, RaDe model can be considered to provide a solution to renew the product portfolio by developing a requested new product within a short timeframe. Practitioners should realise that RaDe aims at redesigning existing products to create new sales items that complement the product portfolio. However, the scope of RaDe projects should be determined so that the product changes do not lead to radical innovations, new supply chain models or processes. Additional to short development lead-time, other aspects such as cost, quality and performance should be addressed. The findings related to the RaDe challenges and enablers can support business managers in understanding and initiating the presented alternative product development model, which supplements the traditional NPD. Managers can benefit from the understanding of the importance of systematised PPM and advanced SM for smooth RaDe and ramp-ups as well as for preventing product portfolio proliferation caused by RaDe. It is important to note that creating a frame to maximise the fit of the new product with the existing supply chain processes (including the SM process) is a prerequisite of RaDe.

As a support for RaDe projects, companies should realise the need to align their PPM and SM strategies. This study assists practitioners in connecting and synchronising PPM and SM by utilising the product portfolio structure. Simplifying the

technical product portfolio can potentially streamline the supplier base, which results in better-focused and simplified supplier relations and structure. Conversely, rationalising the number of suppliers will facilitate the PPM. Companies can utilise the proposed PPM and SM alignment to agree and create the list of recommended products and related buy-items with the corresponding list of recommended suppliers. An optimised product portfolio size, buy-items quantity and supplier base will likely result in improved business performance due to improved focus on profitable, strategic and balanced product portfolio and supplier base. Additionally, an optimised product portfolio and supplier base will facilitate RaDe activities and decision-making related for instance to the product design and supplier selection.

Further related to the anticipation of SM constraints, the research results highlight to practitioners the significance of mature SM process regarding the RaDe success. Aligning the product design with the current SM capabilities and avoiding introducing new competencies, materials or suppliers are essential aspects to ensure smooth RaDe projects. Companies can implement the proposed SM maturity framework to analyse and improve the readiness of their SM process and related DfSM product design concept for RaDe. SM people can utilise the integration of the SM objectives, performance measures, DfSM product design guidelines and metrics to develop this type of framework and strengthen their RaDe and NPD process.

Finally, the company abilities, in relation to aspects such as supplying, manufacturing or shipping the developed products to the customer, play a significant role in the smooth and rapid delivery of the products. Firms can utilise the presented SCC process to prepare the supply capability systematically within the NPD process. This is critical for commercialising the new products within the intended time. SM and NPD organisation can benefit from this kind of process as it improves the product ramp-ups success based on the NPD and SCC processes. The main SCC activities, which the companies should address, include the systematic qualification and contracting of the required suppliers and materials at the right moment of the product development. Nominated SCC process owner is an integral part of the product development team and involves the SM operational members at the right moment to prepare the supply process for the new products ramp-ups. The SCC process should be adjusted according to the company size, its supply chain model, the product features and the type of product development. In case of RaDe, the SCC process is adjusted to conform to those kinds of development projects, which do not include phases and gates.

The managerial implications can be summarised into the following enablers and steps: 1) Align the strategic targets and KPIs of the product portfolio management and supply management, 2) describe and deploy mature supply management process according to the agreed targets, 3) describe and deploy product portfolio management according to the agreed targets, 4) create the DfSM product design guidelines, targets and KPIs as well as instruct them to the NPD teams, 5) describe and deploy SCCC process as a part of the NPD process and finally, 6) describe, educate and deploy RaDe to create new requested products based on minor technical changes of existing products. The present research emphasises how the role of mature supply management – in terms of SM strategy, alignment of recommended products, buy-items and suppliers, product design guidelines from SM viewpoint and SCC – is significant to allow successful rapid product development and product portfolio renewal.

4.3 Reliability and validity

Product development related research must be tightly motivated by the industrial practice needs, as product development knowledge is barely significant if disconnected from the real business context (Krishnan & Ulrich 2001). The topics studied in this study have emerged from the industry and motivated by the needs of the companies. The whole research has been designed and conducted in collaboration with companies. The present research is qualitative in nature and utilises the experiences of practitioners in the industry. The research quality is important during the designing, conducting and reporting of scientific research (Bryman & Bell 2007). The nature of qualitative research requires specific criteria for evaluating the reliability and validity. The four criteria include the *trustworthiness* of the results, the *validity* of the results in different environments, the *repeatability* of the observations and the *influence* of researcher's own capability on the results (Bryman & Bell 2007).

Trustworthiness can be defined as whether the result of the study is obtained in a way that the outcomes closely resemble the reality. The empirical part of this study is based on semi-structured group interviews. They provide accurate results as all the informants can together discuss each question, oppose views and thus improve the answers' reliability. Naturally, there is a possibility that some of the attendees would try to dominate the group interview, which is however alleviated by the active participation of the researcher to involve all the participants. In addi-

tion, several semi-structured interviews facilitated the interactions between the researcher and informants as well as provided opportunities for the interviewees to comment the issues under study. As individual interviews could also further lighten up the results additional clarifications were requested from the informants after the interviews. To obtain an exhaustive current state analysis, eleven case companies were involved in the research. Adequate numbers of informants and various organisational functions (included product management, product development, supply chain management, supply management) participated in the study. The collected data were recorded, transcribed and stored to ensure thorough data analysis. In addition, the company documentation was utilised to complement the interview findings. The informants, who were encouraged to be honest, reviewed and commented the data, data analysis and the research reports. The analysis logic and results were also confirmed by other researchers to reduce the researcher bias. The theoretical background, the empirical analysis, the research findings and the interpretations are interconnected with one another to improve the trustworthiness of the results. Hence, the results can be seen to be trustworthy in the studied context and environment. However, the implementation of the SM maturity for RaDe will require further empirical research and implementation to guarantee further the credibility of the results.

The qualitative research should be evaluated according to the applicability and *validity* of the results in another environment (Yin 2003, Bryman & Bell 2007). The original target of this study was to study the SM maturity supporting RaDe so that it can suit various types of businesses. The eleven analysed companies were selected to represent different business types, markets, products and organisational sizes. However, the limitations of this study include the analysis of a limited number of companies in different aspects of the proposed model. This study focuses on analysing the current process settings and does not measure the performance even if performance is indicated by the findings. The studied issues may be most relevant for product development intensive large and medium-sized companies and more conforming to tangible products. The consistency of the findings might vary if a larger number and different types of organisations from various industries would be included. A similar research on intangible products might deviate from the current findings. Additionally, the inductive approach to qualitative data is not the strongest approach for generalisation, and quantitative data may provide additional value. However, throughout the research and individual studies I–IV, numerous data sources including interviews, companies' internal documents and meeting notes were applied to verify the findings and ensure the validity of the research.

Furthermore, three articles included in this study have been subjected to a double-blind review process, including a critical judgement of the scientific community.

Another criterion for evaluating the reliability and validity is the *repeatability*, which evaluates the capability of the research logic to provide the same results and conclusions regardless the researcher and circumstances (Yin 2003). The repeatability is addressed in several manners along the research process, for instance by utilising standardised methods for collecting data, utilising product and SCM experts as informants, recording and transcribing the interviews, storing and archiving the research data as well as handling the data anonymously (Yin 2003). Each original study I-IV can be repeated in a different context, but the results are likely to be somewhat different. This is due to various factors such as the temporal and social context of the research. Repeating the same research methods even by the same researchers may produce different results due to possible enhancements in the studied companies (Saunders *et al.* 2009); thus, providing the same results by different researchers may not be feasible.

Finally, the *influence* of researcher's own capability on the results is an important aspect of qualitative research. Qualitative research might include some subjective risks (Yin 2003). The researchers' interest areas, competencies and previous experiences influence the objectiveness in qualitative research work (Yin 2003). Objectivity represents the degree to which the researchers' own values can influence the results (Bryman & Bell 2007). During the interviews, the objectiveness of the informants can also be questioned. Additionally, the interpretation of the given answers by the researchers may produce divergent observations and results. Various efforts were made to improve the objectivity of each individual study and the present study. To reduce potential research subjectivity, the researcher has strived to organise the semi-structured questionnaires, interviews and data analysis as accurate as possible to increase the objectivity of the researchers and informants. Likewise, the perspectives of several researchers were utilised during the data collection and analyses. The research articles and reports have been written and reviewed in cooperation with other researchers to minimise the influence of a single researcher on the results. Therefore, the negative influence of researcher's own capabilities on the results has been minimised.

4.4 Recommendations for further research

This study presents the mature SM as an enabler for RaDe. The practical adaptation and implementation of this model in organisations could be a logical stage of studying the model further. It would be beneficial to investigate the actual and comprehensive impacts of the proposed model. Expanding the analysis of process settings, the actual analysis of the performance would clarify the performance of RaDe in different condition and times. In addition, further research could consider in more detail the other RaDe enablers and concentrate specifically on the RaDe targets, KPIs, governance model, processes, tools and data availability.

This study focuses on the SM process and its requirements for efficient RaDe projects. However, the SM is not the only critical area in RaDe and further research should be accomplished on the other aspects of the supply chain (such as manufacturing or logistics) as well as on the various receiving business processes (such as care, marketing or sales processes). Besides, as the SCC process presented in this research is more conforming to full-scale NPD, its adaptation for rapid product development projects may require further clarification.

Furthermore, involving additional case companies, other industry sectors and small-sized enterprises would provide new research opportunities. As the introduced SM maturity conforms to rather tangible products, accommodating this model for intangible products would provide new interesting insights.

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Appendices

Appendix 1: Analysis template for connecting PPM and SM (Article II, reprinted with permission of Inderscience Publishers).

	Product Portfolio Management	PPM effects on SM	Alignment	SM effects on PPM	Supplier Management
Strategic targets	Strategic and cost efficient renewal of product portfolio by adding new products to the product portfolio, enhancing and modifying the existing products and removing the non-competitive products. Maximise the value of the Product Portfolio (PP).	PM allows the SM to select and manage the suppliers only related to strategic and profitable products.	The supply strategies are adapted according to the supply risk, impact on profitability, predictability of the demand and life cycle of the items supplied. Enhanced value and focus on the profitable and strategic products and suppliers. The suppliers should also actively manage their own product portfolio and it should somewhat fit the focal company's one.	Supplier performance advantages create value into the PP. Improvement of product quality, reduction of the total cost and the product development time.	Identifying company's total requirements, developing supply strategies, identifying, evaluating and selecting suppliers, and managing and developing those suppliers to realise performance advantages.
	Management of the product portfolio size/product variety. – Focus business (avoidance of product proliferation, minimisation of the number of products/components in the product portfolio)	Minimisation of the number of suppliers due to minimisation of the number of components.	Avoidance of the explosion of the PP and the supplier base. Optimal size of supplier base and product portfolio leading to competitive advantage.	PPM primarily makes use of the current supplier base.	Rationalisation of the supplier base and its continual renewal.
	Product Portfolio balance (in terms of resources, duration, risk, technology).	Promote the supplier base balance.	Coordination between product portfolio balance and supplier base balance. Resources of SM and PPM focus on the same strategic and profitable products and the related suppliers resulting in improved business performance.	Promote the product portfolio balance.	Supplier base balance (in terms of supplier relationship model, supply risks, relationship duration, resources allocation). Balance allocated resources between strategic suppliers and durable arm's length suppliers.
	Strategic fit of the Product Portfolio (alignment with business strategy, investment on R&D, quantity of resources in product development, spending and the number of final products sold and delivered).	Support the strategic fit of the SM and its focus on the strategic items. Restrict the management of suppliers to the strategic products.	Strategic supplier segmentation into durable arm's length suppliers to strategic model. Improving the focus of PPM and SM on the strategic items/components supplied by the strategic suppliers and strengthening the cross-functional relations between PPM and SM. The benefits may be a reduced inventory, improved quality, accelerated product development, competitiveness improvement, minimisation of PP risk and economies of scale realised by strategic suppliers.	Support the strategic fit of the PPM and its focus on the strategic items.	Strategic fit of the supplier base (in terms of flexibility, reliability, punctuality, innovation, sustainability, cost efficiency and profitability). Preferred strategic supplier program and integration development. Simultaneously strive to be and remain the preferred customers of the suppliers in order to benefit the most from them (innovation, new technology, relation-specific investment)
	Defined product portfolio management ownership and governance model in order to manage the entire group of all sub-portfolios and products over the life cycle (nominated product/product portfolio/sub portfolio owners).	Products owners and sub portfolio owners are connected to the related supplier managers and collaborate with each other.	Connection and collaboration between the product owners, the sub portfolio owners and the supplier managers. This cross functional integration may result in increased product quality, reliability and improved PP profitability. Senior management defines, aligns and communicates the targets setting and incentives given to the PPM and SM stakeholders as well as their own roles and how they should cooperate.	Supplier managers are connected to the related product owners and sub portfolio owners and collaborate with each other.	Defined supplier management ownership and governance model in order to manage the entire supplier base (nominated supplier owners/managers).
Business process targets	Fit the PP with the company's strategy.	SM only focus on the supply related to the strategic products.	Alignment between PPM and SM which fit the company's strategy.	Focus of the PPM and the suppliers fitting the company's strategy.	Select and manage the suppliers which fit the company's strategy.
	Balance, renew and avoid the explosion of the PP.	Avoid the supplier proliferation.	Avoid the explosion of the PP and the supplier base.	Avoid the product proliferation.	Balance, renew and optimise the size of the supplier base.
	Maximise the value of the PP.	Support in the management of competitive suppliers.	Value maximisation of the PP and the supplier base.	Support in the profitability of the PP.	Realise overall performance and competitive advantages through the suppliers.

	Product Portfolio Management	PPM effects on SM	Alignment	SM effects on PPM	Supplier Management
Design rules	Use of preferred/strategic components and removal of the obsolete ones.	Avoid the supplier proliferation and allow to focus on the strategic ones. Development of better relationships with the strategic suppliers leading to a decreased order lead-time due to fewer supplied components.	The PPM and SM design rules fit with each other. The PPM does not aim to add more unprofitable /non-strategic products into the PP as it is counterproductive for the SM to manage the related components and suppliers of those products. The target is to focus on the strategic and profitable products and the related suppliers.	Limit the increase of the component portfolio. Adding new components is motivated by an added value for the product and the PP. The PP may become more profitable and less complex.	Use of the preferred/strategic suppliers (and the related preferred components) and optimisation of the number of suppliers per components.
	Minimise the number of different components and assemblies (Minimum number of elements in each product structure level).				
	Use of company's strategic technologies.	Management of suppliers only related to strategic technologies	Optimising the components commonality across the PP is important in the alignment of PPM and SM but it should be done without sacrificing product distinctiveness. Products in a same product family should be very distinctive (to avoid cannibalisation) but share as many parts as possible.	Simplification of PP/PPM through the use of fewer unique parts resulting from product modularity and standardisation.	In case of high product variety, maximisation of modular product design between different products. Standardisation across the PP of the components/modules and balance with the differentiation modules. Optimal use of commonly available materials.
	Totally new items should bring more overall value to the PP (cannibalisation avoidance)	Avoid the increase of new unprofitable products (and the associated components and suppliers) to be managed by the SM.			
	New item should replace one or several items from the commercial PP or technical PP.		Modular product design improves the use of same components across product families which may facilitate the product update and design, increase the product variety from a smaller set of components and leverage the purchasing power through economies of scale.		
	New item based on new technical items should create more value to the technical PP.				
Product design targets and metrics	Share of preferred/strategic components	PPM and SM product design targets and metrics fundamentally support each other.			Number of components bought per number of suppliers managed
	Share of obsolete/non-strategic/low profit components				Share of the use of commonly available materials
	Share of strategic technology				Share of standard/differentiation components and modules
	Cannibalisation rate in relation to the total profit increase				Degree of component commonality versus degree of products distinctiveness
	Average number of replaced items in the commercial or technical PP when existing sellable or technical items are introduced (above or equal 1)				Share of preferred components/suppliers
					Degree of product modularity

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