



UNIVERSITY OF CAMBRIDGE

BUILDING TECHNICAL PROCESS INNOVATION CAPABILITY: AN INTRA-ORGANISATIONAL PERSPECTIVE

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for the degree of Doctor of Philosophy

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TITLE:

Building technical process innovation capability:
An intra-organisational perspective

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Dedicated to
MY FAMILY
with gratitude and love.

*“[They] taught me the wisdom of choice:
To try and fail is at least to learn; to fail to try is
to suffer the inestimable loss of what might have been.”*

—Barnard (1938, p. v)

BUILDING TECHNICAL PROCESS INNOVATION CAPABILITY: AN INTRA-ORGANISATIONAL PERSPECTIVE

PHILIPP G. EGGER

ABSTRACT

This dissertation is concerned with the strategic management of process innovations. It explores and describes in what way the technical process innovation capability is built and maintained by R&D and production departments at a world leading motor vehicle manufacturer.

It is widely accepted that new or significantly improved production methods are a main driver of competitive advantage for innovative manufacturers and enable both effectiveness and efficiency gains. However, the strategic management of process innovations has been subjected to little research and remains not well understood. This research set out to develop a descriptive model—outlining the used activities, mechanisms and controls to undertake technical process innovation projects as well as the applied strategies, practices or tactics to institutionalise the knowledge and skills—which illustrates the strategic management of process innovations.

An IDEFo (Integration DEFinition language o) function model was ‘constructed’ from 15 examples of current or recent technical process innovations within the Bayerische Motoren Werke Aktiengesellschaft (BMW AG). This single-company multiple-case design utilised data sources such as semi-structured interviews, written documents and direct observations and made use of an inductive thematic (coding) analysis.

Emerging from the evidence, this research reveals that cumulative learning through a closed-loop control and an appropriate interplay of co-ordination and learning mechanisms is essential for building and maintaining a technical process innovation capability. Furthermore, there is evidence to indicate that a formal system of reflection and context-specific co-ordination mechanisms facilitate the incorporation of lessons learned and project related experiences into organisational process assets.

The main outcome of this research has been the synthesis of elements contributing to the formation of a firm’s technical process innovation capability by means of a graphical concept map. However, due to the breadth of the investigated innovation stage-gate model which starts with a stimulus for innovation and proceeds through various stages of design and industrialisation to an innovation introduced into practice, some areas would benefit from further work.

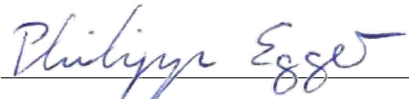
A possible direction to strengthen the empirical evidence is not only to replicate this research within and outside the automotive industry but also to focus on elements of the graphical concept map and to explain and understand their interaction in greater detail.

PREFACE

DECLARATION OF ORIGINALITY: Except for commonly understood and accepted ideas, or where specific reference is made, the work reported in this dissertation is my own and includes nothing which is the outcome of work done in collaboration. No part of the dissertation has been previously submitted to any university for any degree, diploma or other qualification.

STATEMENT OF LENGTH: This dissertation consists of approximately 60,000 words, and therefore does not exceed the 65,000 word limit prescribed by the Degree Committee of the Department of Engineering.

Cambridge, September 2015


Philipp G. Egger

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INTRODUCTION

*No great discovery was ever made
without a bold guess.*

—Isaac Newton

Chapter XI: 'Scientists'
(Beveridge, 1950, p. 145)

THE MAIN OBJECTIVE OF THIS INTRODUCTION CHAPTER IS TO PROVIDE BACKGROUND INFORMATION REGARDING THE ADDRESSED PROBLEM AREA AND TO ARTICULATE THE RESEARCH MOTIVE AND GOAL.

1.1 OVERVIEW

This introduction chapter aligns the academic perspective with the industrial perspective concerning the strategic management of process innovations and highlights a promising research opportunity. In order to accomplish these major tasks, the following three subjects are outlined in more detail: (1) *Research Topic and Problem*, (2) *Research Motive and Goal* and (3) *Structure of the Dissertation*. According to the first, the theoretical and practical relevance of this research is described. The second states the underlying aim for undertaking this research and introduces the major research question. Finally, the third provides an outline of the dissertation with a rough description of each chapter's main objective. Thus, the chapter establishes the importance of the research topic and describes the principal purpose of this dissertation.

1.2 RESEARCH TOPIC AND PROBLEM

Manufacturing employment in developed countries has been decreasing over the last 50 years, though that decline has been mitigated by growing manufacturing-related services employment (UNIDO, 2013, p. 14). Notwithstanding this structural change, manufacturing remains an engine of economic growth and hence plays a key role in the recovery from the global financial and economic crisis that broke out in 2008. In order to strengthen the manufacturing sector, *innovation* is commonly the policy-of-choice (OECD, 2015, p. 34). Perhaps it was no coincidence that, in recent years, policies to disseminate innovation re-entered the stage of intense national debates between members from academia and industry.

In 2010 the German Federal Government announced the *High-Tech Strategy 2020* comprising the strategic initiative *Industry 4.0* (BMBF, 2010, 2014). The corresponding working group¹ formulated implementation recommendations and put forward a research agenda with emphasis on cyber-physical systems which constitute ‘smart factories’ and employ a new approach to manufacturing (Acatech, 2013, pp. 5-7). Acknowledged driving forces for this development are, among others, the servitisation of manufacturing as well as disruptive technologies² such as the Internet of Things (IoT), cloud technology and advanced robotics (Abele and Reinhart, 2011; MGI, 2012, 2013; Pilat et al., 2006; VDMA, 2014). According to Wheelwright and Clark (1992, p. 73), “[...] core products and processes that differ fundamentally from previous generations [...] often incorporate revolutionary new technologies or materials, they usually require revolutionary manufacturing processes”. However, in order to unlock the full potential of technical process innovations, a comprehensive set of new knowledge and skills is necessary (Drucker, 1985, 1990).

Reichstein and Salter (2006, p. 653) outline that “[d]espite its widely acknowledged economic importance, process innovation has received much less attention than product innovation in the literature on the sources and determinants of technological change”. Systematic literature reviews such as Frishammar et al. (2012); Hollen et al. (2013); Keupp et al. (2012); Lengnick-Hall (1992); Wolfe (1994) corroborate that only few studies have focused on the strategic management of process innovations. Notwithstanding substantial theoretical foundations in the domain of strategic management such as the resource-based view (Wernerfelt, 1984), organisational routines (Feldman and Pentland, 2003), dynamic capabilities (Teece et al., 1997), absorptive capacity (Cohen and Levinthal, 1990) and co-ordination mechanisms (Mintzberg, 1979b), little work has been done on operationalising and interlinking these concepts and likewise adopting technical process innovations as the appropriate unit(s) of analysis. In other words:

The discipline of innovation management is however not an old one, and there are still areas that are not yet widely explored and where good theories are still lacking. Management of process innovation can be included in this group. (Lager, 2011, p. 1)

Previous work, mostly quantitative in nature, has usually neglected or underrated a thorough and coherent description of the operational practice firms adopt in building and maintaining their capability to carry out technical process innovations into practice. In consequence, deeper understanding of the strategic management of process innovations is deficient and incomplete; moreover, the scarcity of a descriptive model is regrettable because it is the sort of guidance practitioners appear to be requiring if they are to support the dissemination of technical process innovations.

¹ A detailed description of the ‘National Innovation System’ in Germany can be found in Allen (2010).

² The notion *disruptive technology* was coined by Bower and Christensen (1995); Christensen (1997) meaning the introduction of a technology with a very different set of attributes/values that generally enables the emergence of new applications/markets. Influential works in order to explain the diffusion of innovations are Moore (1998); Rogers (1962).

1.3 RESEARCH MOTIVE AND GOAL

The main motivation for this research is the desire to extend the innovation literature concerning the strategic management of process innovations. This may have some practical benefits for managers of technical process innovations and for organisations that are committed to improving their productivity as well as their ability to adapt quickly to changing business environments. Thorough research has been carried out in the domain of strategic management, but a description how innovative manufacturers build and maintain their technical process innovation capability is largely absent. Hence, there is no appropriate basis for systematically structuring the associated antecedents and/or 'success factors' of process innovations from existing research (Aravind et al., 2014; Frishammar et al., 2012; Lawson and Samson, 2001; Piening and Salge, 2015; Ramm et al., 2012; Terziovski, 2007).

The main goal is to suggest a synthesis of elements contributing to the formation of a firm's technical process innovation capability by means of a graphical concept map. Therefore, this research will have both exploratory and descriptive purposes, and will address the following major research question:

- *In what way does a world leading motor vehicle manufacturer build and maintain its technical process innovation capability?*

Acknowledging Lewin's (1945, p. 129) statement that "nothing is as practical as a good theory", the present research is an attempt to bridge the gap between the scholars who have developed the theoretical foundations and the profession of managers who have to apply them in an industrial context.

1.4 STRUCTURE OF THE DISSERTATION

After the introduction chapter, the structure of this dissertation is as follows:

CHAPTER 2—LITERATURE REVIEW: The main objective of the literature review chapter is to position the research itself and to illuminate the foundations upon which the present research is based. The structure of this chapter is threefold. First, basic categorical taxonomies with greatest relevance to the present research are outlined. Second, substantial theoretical foundations such as the resource-based view, organisational routines, dynamic capabilities, absorptive capacity and co-ordination mechanisms are reviewed. Third, promising practical approaches such as engineering design models, project management models and process reference models are examined.

CHAPTER 3—METHODOLOGY: The main objective of the methodology chapter is to describe how the present research was done and what assumptions and decisions were involved. The structure of this chapter is threefold. First, the author's basic perceptions of research philosophy, research paradigm and research strategy which have greatest relevance to the applied single-company multiple case design are considered. Second, core elements of obtaining and processing the required data are expanded in more detail. Third, the used inductive thematic (coding) analysis is described and justified.

CHAPTER 4—RESULTS: The main objective of the results chapter is to 'construct' a complete picture and to provide a detailed account for building and maintaining a technical process innovation capability. This chapter is primarily composed of a thorough and coherent collection of hierarchically arranged IDEFo diagrams and associated narratives. This descriptive model—outlining the used activities, mechanisms and controls to undertake technical process innovation projects as well as the applied strategies, practices or tactics to institutionalise the knowledge and skills—illustrates the strategic management of process innovations.

CHAPTER 5—DISCUSSION: The main objective of the discussion chapter is to integrate and interpret the insights from the detailed account to answer the stated major research question. The structure of this chapter is threefold. First, the main findings emerging from the evidence are summarised and mapped to existing research. Second, the contributions to knowledge are noted and potential implications for managers of technical process innovations are highlighted. Third, the shortcomings and limitations of the present research are outlined and possible directions for future research concerning the strategic management of process innovations are recommended.

1.5 SUMMARY

This chapter began by establishing the research topic and problem. Subsequently, it articulated the research motive and goal. Then it outlined the structure of the dissertation and provided a rough description of each chapter's main objective. The next chapter will offer an investigation of the literature concerning both, the conceptualisation and contextualisation of a firm's technical process innovation capability.

LITERATURE REVIEW

*If I have seen further it is by
standing on the shoulders of giants.*

—Isaac Newton

Letter to Robert Hooke, 5 February 1676
(Knowles, 1999, p. 543, no. 9)

THE MAIN OBJECTIVE OF THIS LITERATURE REVIEW CHAPTER IS TO POSITION THE RESEARCH ITSELF AND TO ILLUMINATE THE FOUNDATIONS UPON WHICH THE PRESENT RESEARCH IS BASED.

2.1 OVERVIEW

This literature review chapter conceptualises and contextualises the present research (McKercher et al., 2007, p. 463). In order to accomplish these major tasks, the following three subjects are investigated in more detail: (1) relevant *Categorical Taxonomies*, (2) substantial *Theoretical Foundations* and (3) promising *Practical Approaches*. According to the first, notions and definitions of basic categorical taxonomies with greatest relevance to the present research are stated and the study is placed in the domain of strategic management (Denzin, 1970; Parsons and Shils, 1951). The second reviews substantial theoretical foundations which introduced a new orientation or point of view into the domain of strategic management and defined the shape and content of related theories (Denzin, 1970, pp. 35-36). Finally, the third examines promising practical approaches which are widely recognised and used industry standards. Thus, the chapter positions the research itself and illuminates the foundations upon which the present research is based.

2.2 CATEGORICAL TAXONOMIES

This section outlines basic categorical taxonomies with greatest relevance to the present research such as *Business Model Archetype*, *Technical Process*, *Process Innovation* and *Innovation Capability* by stating their notions and definitions (Denzin, 1970; Parsons and Shils, 1951). In addition, the study is placed in a broader context through its underlying *Rationale for the Present Research*.

2.2.1 Business Model Archetype

Empirical research conducted by the MIT Sloan School of Management emphasises that the stock market especially values business models focusing on innovation and intellectual property (Lai et al., 2006; Malone et al., 2006; Weill et al., 2004, 2011). In the context of the present research the notion of *innovation* draws on the following multidisciplinary definition: “Innovation is the multi-stage process whereby organizations transform ideas into new/improved products, service[s] or processes, in order to advance, compete and differentiate themselves successfully in their marketplace” (Baregheh et al., 2009, p. 1334). The underlying typological definition of *business model* consists of the following two dimensions: (1) what types of rights are being sold and (2) what types of assets are involved (Malone et al., 2006; Weill et al., 2004). As a result, 16 distinctive business model archetypes were derived (see Table 1). One of the most common business models comprises selling the ownership of significantly transformed physical assets to buyers—manufacturer (Malone et al., 2006, p. 9). Well-known representatives of this archetype can be found in the automotive industry with motor vehicle manufacturers such as BMW AG or Dr. Ing. h.c. F. Porsche AG. Regarding the total stock market returns (i.e. changes in stock price plus dividends), innovative manufacturers are among the top performers and hence highly valued by investors (Weill et al., 2011, p. 18).

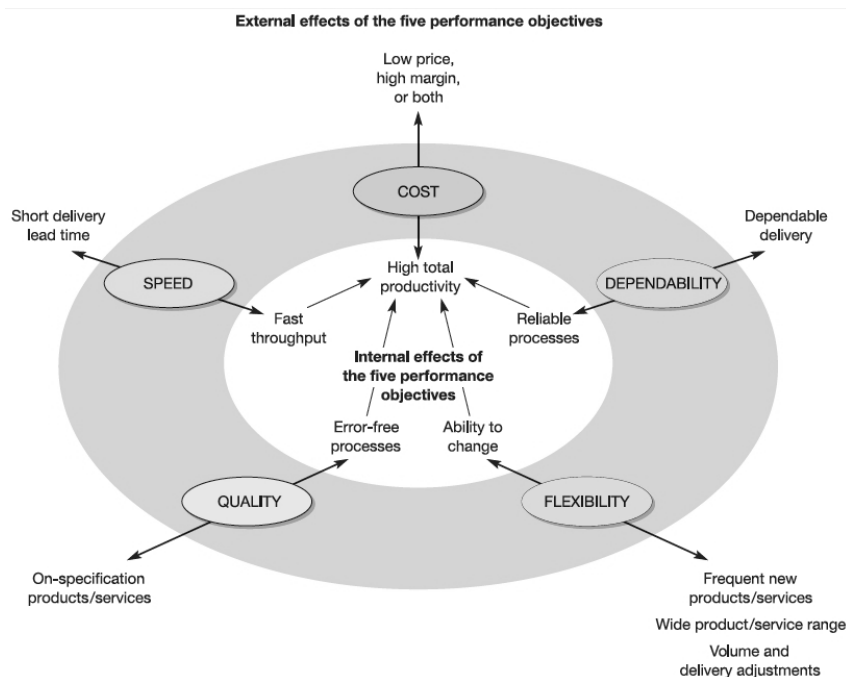
Table 1: The MIT business model archetypes

Asset Rights	Asset Types			
	Financial	Physical	Intangible	Human
<i>Creator</i> (ownership of asset with significant transformation)	Entrepreneur	Manufacturer	Inventor	Human Creator*
<i>Distributor</i> (ownership of asset with limited transformation)	Financial Trader	Wholesaler/ Retailer	IP Trader	Human Distributor*
<i>Landlord</i> (use of asset)	Financial Landlord	Physical Landlord	IP Landlord	Contractor
<i>Broker</i> (matching of buyer and seller)	Financial Broker	Physical Broker	IP Broker	HR Broker

Note: * Not a legal business model. They are included here for logical completeness.

Source: Adapted from Weill et al. (2004, p. 31, figures 1-2)

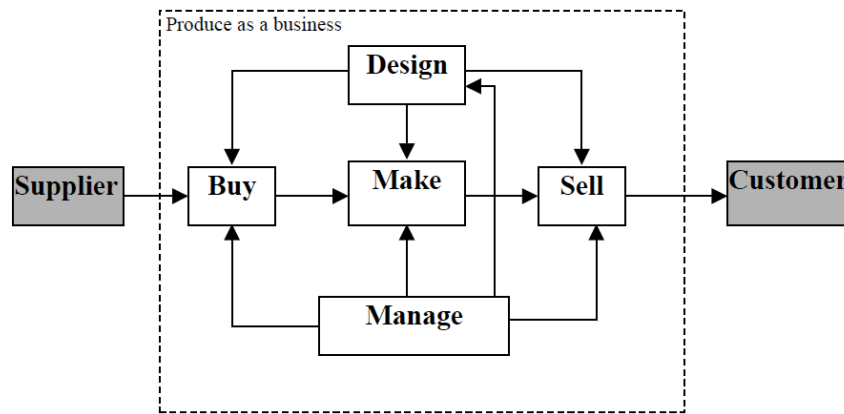
The business model archetype has a determining influence on business activities and *strategic management* links the relevant entities: “The field of strategic management deals with the major intended and emergent initiatives taken by general managers on behalf of owners, involving utilization of resources, to enhance the performance of firms in their external environments” (Nag et al., 2007, p. 944). Absolutely essential is the translation of a developed strategy into competitive priorities (Kaplan and Norton, 2008; Neely et al., 1995, 2000; Skinner, 1969; Wheelwright, 1984). Operations management contributes to competitiveness by addressing the following five interdependent performance objectives: (1) cost, (2) dependability, (3) flexibility, (4) quality and (5) speed (see Figure 1). These operations performance objectives need to be considered by manufacturers when they align their business activities in order to create physical assets (i.e. durable and non-durable items).



Source: Adopted from Slack et al. (2013, p. 58, figure 2.10)

Figure 1: The five operations performance objectives

The MIT process handbook provides a coherent and theoretically based structure for representing and codifying business activities (Malone et al., 1999, 2003). A necessary feature is the use of the specialisation hierarchy in form of a ‘family tree’ with more and more specialised activities (Herman and Malone, 2003, p. 246). At its top-level, five basic activities—(1) buy, (2) make, (3) sell, (4) design and (5) manage—condense what occurs in most businesses (see Figure 2). The notions of *manufacturing* and *production* are often conflated and used interchangeably but both are in general perceived as a subset of the *make* activity. This research adopts an intra-organisational perspective to gain further insights into the business activities of innovative manufacturers.



Source: Adopted from [Herman and Malone \(2003, p. 237, figure 8.10\)](#)

Figure 2: The MIT business activity model

2.2.2 Technical Process

Drawing on the theory of technical systems, a technical process can be seen as the ‘transmission belt’ between technology and the transformation system ([Eder, 2008, 2011](#); [Ehrlenspiel, 1994](#); [Hubka, 1973](#); [Hubka and Eder, 1988](#)). The manufacturing technology which transforms physical assets by applying scientific knowledge is considered as the core of production ([Britannica, 2015](#); [Lowe, 1995](#); [Starr, 1966](#)). According to this, a *technical process* (often referred to as *manufacturing process* or *production process*; see Table 2) embodies the suitable technology within the manufacturing system to accomplish a desired transformation as the following two definitions outline:

[1] The *manufacturing processes* are collected together to form a *manufacturing system* (MS). The manufacturing system is a complex arrangement of physical elements characterized by measurable parameters. [...] The production system includes the manufacturing system plus all other functional areas of the plant for information, design, analysis, and control. ([Black and Kohser, 2013, p. 3](#), emphasis in original)

[2] A Manufacturing System consists of the arrangement and operation of machines, tools, material, people and information to produce a value-added physical, informational or service product whose success and cost is characterized by measurable parameters. The Production System consists of all the elements and functions that support the manufacturing system. ([Cochran, 1999, p. 5](#))

Hence a manufacturer’s *make* activity represents a socio-technical transformation system usually involving operators and technical systems (i. e. machinery or engineering artefacts) to convert raw materials to a finished product (see Figure 3).

Table 2: Selected definitions of technical process

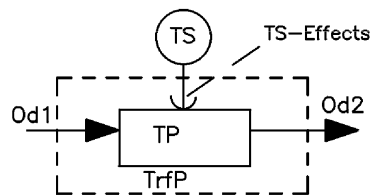
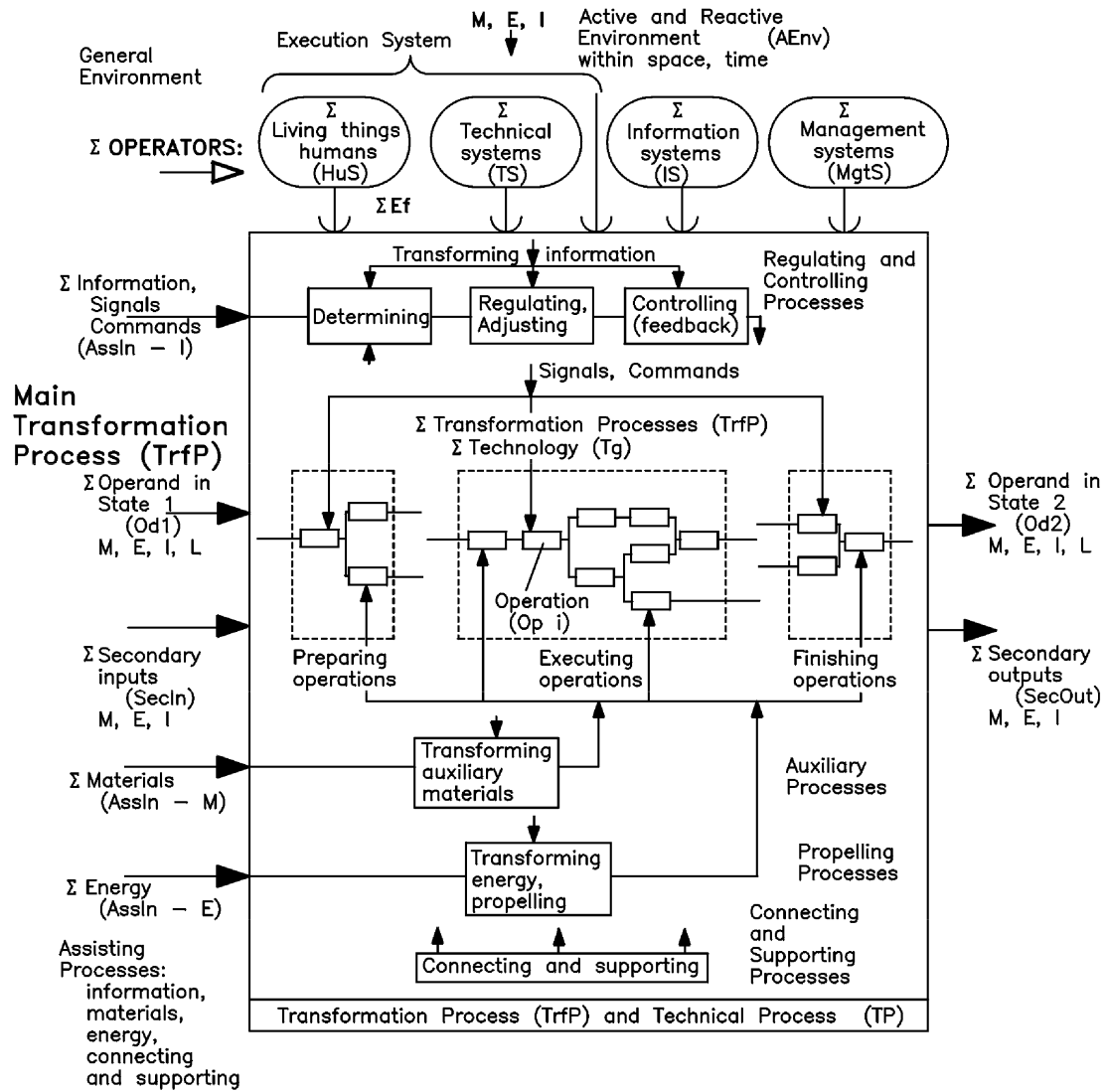
<i>Study</i>	<i>Definition</i>
Starr (1966, p. 28, emphasis in original)	"[...] the core of production is the <i>technology</i> of transformations. Any production process can be viewed as an input-output system. In other words, there is a set of resources which we call inputs. A transformation process operates on this set and releases it in a modified form which we call outputs."
Utterback and Abernathy (1975, p. 641)	"A production process is the system of process equipment, work force, task specifications, material inputs, work and information flows, etc. that are employed to produce a product or service".
Ohno (1988, p. 130, emphasis in original)	" <i>Work flow</i> means that value is added to the product in each process while the product flows along."
Shingo (1989, pp. 3-4, emphasis in original)	"Production is a network of processes and operations. [...] When we look at <i>process</i> , we see a flow of material in time and space; its transformation from raw material to semi-processed component to finished product. When we look at <i>operations</i> , [...] we see the work performed to accomplish this transformation—the interaction and flow of equipment and operators in time and space."
Harrington (1991, p. 9)	"Any activity or group of activities that takes an input, adds value to it, and provides an output to an internal or external customer. Processes use an organization's resources to provide definitive results."
Davenport (1993, p. 5)	"A process is [...] a specific ordering of work activities across time and place, with a beginning, an end, and clearly identified inputs and outputs: a structure for action."
Johansson et al. (1993, p. 57)	"A process is a set of linked activities that take an input and transform it to create an output. Ideally, the transformation that occurs in the process should add value to the input and create an output that is more useful and effective to the recipient either upstream or downstream."
Earl (1994, p. 13)	"Essentially a lateral or horizontal organizational form (except in the case of management processes), process encapsulates the interdependence of tasks, roles, people, departments, functions etc. that is required to provide a customer (internal or external) with a product or service."

Continued on next page

<i>Study</i>	<i>Definition</i>
Manganelli and Klein (1994, p. 8)	"A process [...] is an interrelated series of activities that convert business inputs into business outputs. Processes are composed of three primary types of activities: value-adding activities [...]; hand-of activities [...]; and control activities [...]."
Hammer and Champy (1995, p. 35)	"We define a [...] process as a collection of activities that takes one or more kinds of input and creates an output that is of value to the customer."
Lowe (1995, p. 9)	"A technology is the structured application of scientific principles and practical knowledge to physical entities and systems"
Rummler and Brache (1995, p. 45)	"A business process is a series of steps designed to produce a product or service. Some processes [...] may be contained wholly within a function. However, most processes [...] are cross-functional, spanning the 'white space' between the boxes on the organization chart."
Womack and Jones (1996, p. 309, emphasis in original)	"The <i>value stream</i> is the set of all the specific actions required to bring a specific product [...] through the three critical management tasks of any business: the <i>problem-solving task</i> running from concept through detailed design and engineering to production launch, the <i>information management task</i> running from order-taking through detailed scheduling to delivery, and the <i>physical transformation task</i> proceeding from raw materials to a finished product in the hands of the customer."
Ashby (2005b, p. 176, emphasis in original)	"A <i>process</i> is a method of shaping, joining, or finishing [i.e. surface treatment] a material."
ISO (2005, p. 11, § 3.4.1)	"Set of interrelated or interacting activities which transforms inputs into outputs."
Black and Kohser (2013, p. 6, emphasis in original)	"A <i>manufacturing process</i> converts unfinished materials to finished products, often using machines or machine tools."

Note: The definitions listed are representative rather than exhaustive.

From a technical perspective product and process can be seen as two pivotal concepts which heavily interact in any production and breakthrough products usually require new manufacturing processes (Abruzzi, 1966; Wheelwright and Clark, 1992). A considerable number of manufacturing textbooks and web-based references deal with the fundamentals of manufacturing processes (ASM, 2014; Black and Kohser, 2013; Groover, 2013; Kalpakjian and Schmid, 2008, 2014; Schey, 2000; SME, 2014). The large amount of established manufacturing processes can be classified under three broad process families: (1) shaping, (2) joining and (3) finishing (see Figure 4). It is essential "[...] to choose the right process-route at an early stage in the design before the cost-penalty of making

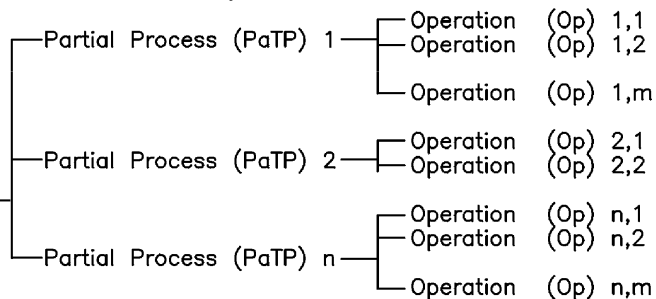


Operations in a technical process (TP) are a sub-set of the operations in a transformation process.

Technical Process (TP)

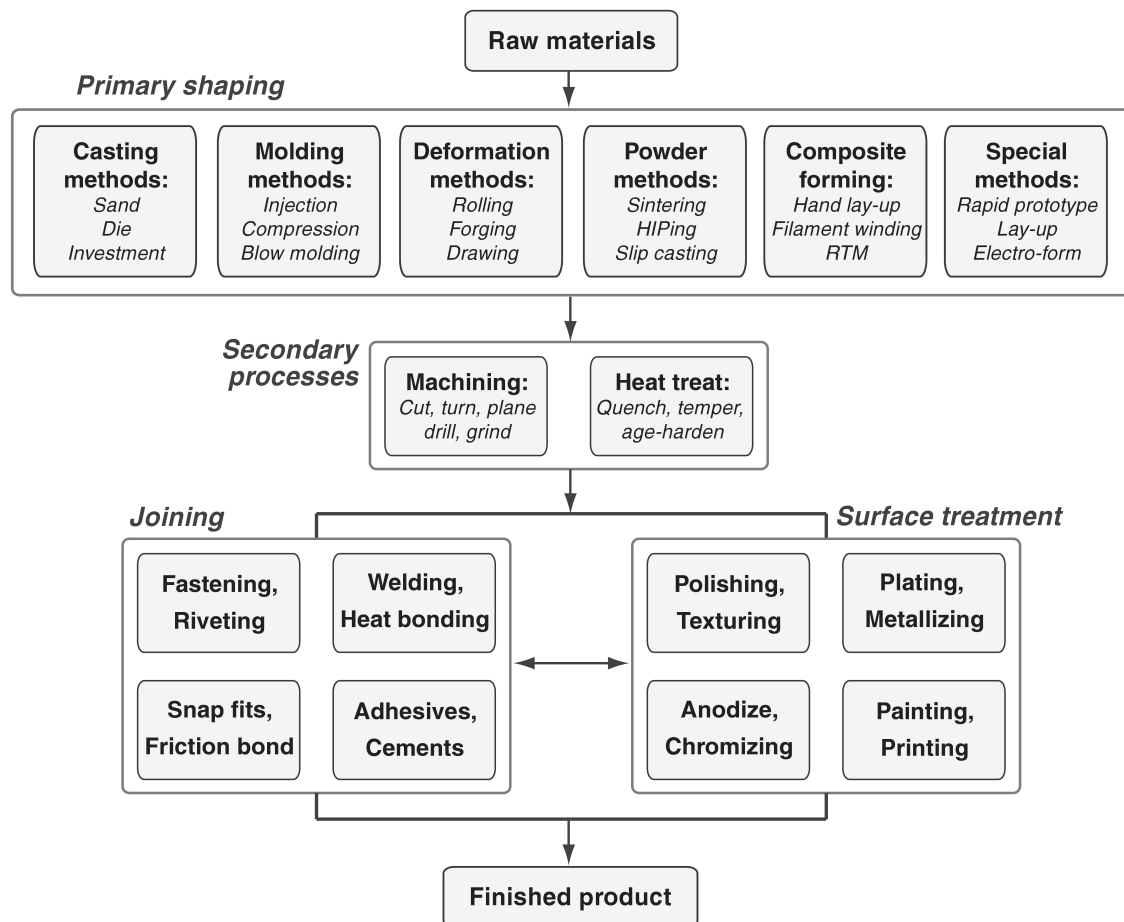
Transformation of Operand

Each operation needs various effects exerted onto the operand by one or more of the operators, resulting in an intermediate (or final) state of the operand. Each operation or partial process can therefore be modeled as a transformation system.



Source: Adopted from Eder (2008, p. 24, figure 6)

Figure 3: The conceptualisation of a socio-technical transformation system



Source: Adopted from [Ashby et al. \(2007, p. 18, figure 2.4\)](#)

Figure 4: The classification of manufacturing processes

changes becomes large” ([Ashby et al., 2007, p. 18](#)). However, the proposed function, material and shape of the part or component as well as economic measures limit the choice of suitable manufacturing processes ([Abruzzi, 1966](#); [Ashby, 2005c](#); [Swift and Booker, 2013](#)). Software tools like the *Cambridge Engineering Selector* with comprehensive databases of materials and process records help to identify the best match between design requirements and process attributes ([Granta, 2014](#)). Another promising approach to resolve existing constraints and to increase cost-effectiveness is to design for manufacturability ([Bakerjian and Mitchell, 1992](#); [Boothroyd et al., 1994](#); [Bralla, 1998](#)). In summary, a manufacturer needs to innovate its socio-technical transformation system when technical processes required to produce breakthrough products are either unavailable or immature.

2.2.3 Process Innovation

The development of new or significantly improved production methods is fundamental for manufacturers' economic wealth. Intellectual progenitors of this interdependency are the Scottish philosopher and economist Adam [Smith](#) (1723*-1790[†]; *An Inquiry into the Nature and Causes of the Wealth of Nations*), the English mathematician, inventor and economist Charles [Babbage](#) (1791*-1871[†]; *On the Economy of Machinery and Manufactures*), the American engineer and management theorist Frederick Winslow [Taylor](#) (1856*-1915[†]; *The Principles of Scientific Management*) and the Austrian economist Joseph Alois [Schumpeter](#) (1883*-1950[†]; *The Theory of Economic Development*). The empirical justification that productivity increase through technological development plays a key role in economic growth was done independently in the mid-1950s by the American economists [Abramovitz](#) (1956) and [Solow](#) (1956, 1957). Moreover, Robert Merton Solow's *Contribution to the Theory of Economic Growth* was awarded with the Nobel Prize in Economics in 1987. The award ceremony speech highlights:

If, by research and development, new production methods are generated, then the economic growth can continue according to professor Solow's model for economic growth even in the long run. The conclusion is then that in the long run, technological development is the major factor behind economic growth. ([The-Nobel-Foundation, 1987](#), excerpt)

As a consequence, innovative manufacturers attach importance to their socio-technical transformation system and invest in the development of new or significantly improved production methods to gain competitive advantage.

A *process innovation* (see Table 3) is complete only after it is carried out into practice ([Fagerberg et al., 2005](#); [Knight, 1967](#)). For example, the introduction of a moving assembly line by Henry Ford in the Highland Park Plant at Detroit is recognised as the first true application of full-scale mass production techniques and acknowledged for its pioneering contribution to technological advance ([Freeman and Louçã, 2001](#), p. 273). The associated just-in-time (JIT) production methods were developed and refined to a great degree by Ernest Kanzler, one of Henry Ford's managers ([Holweg, 2007](#); [Petersen, 2002](#); [Schonberger, 2007](#)). For this reason, the automotive industry affords an exceptional opportunity to study the design and development of socio-technical transformation systems ([Abernathy, 1978](#); [Cho and Ohba, 1999](#); [Fujimoto, 1999](#); [Liker, 2004](#); [Ohno, 1988](#); [Shingo, 1989](#); [Spear, 1999](#); [Spear and Bowen, 1999](#); [Sugimori et al., 1977](#); [Womack et al., 1990](#)). In order to avoid the so-called *productivity dilemma* it is generally suggested that manufacturers balance their focus on both productivity improvements and innovation ([Abernathy, 1978](#); [Adler et al., 2009](#)). In summary, to put new or significantly improved production methods in operation a combination of several different types of resources and capabilities is necessary.

Table 3: Selected definitions of process innovation

<i>Study</i>	<i>Definition</i>
Schumpeter (1934, p. 66)	"The introduction of a new method of production, that is one not yet tested by experience in the branch of manufacture concerned, which need by no means be founded upon a discovery scientifically new, and can also exist in a new way of handling a commodity commercially."
Blaug (1963, p. 13)	"A process-innovation is defined as any adopted improvement in technique which reduces average costs per unit of output despite the fact that input prices remain unchanged."
Knight (1967, p. 482, emphasis in original)	" <i>Production-process innovations.</i> —These are the introduction of new elements in the organization's task, decision, and information system or its physical production or service operations, the advances in the technology of the company."
Rosenberg (1982, p. 4)	"Process innovations typically involve new machinery or equipment in which they are embodied; this machinery or equipment constitutes a product innovation from the point of view of the firm that produces it."
Tushman and Nadler (1986, pp. 76-77)	"[...] a change in the way a product is made or the service provided. [...] Process innovations change the way products and services are made or delivered. Process innovations may be invisible to the user except through changes in the cost or quality of the product."
Collins et al. (1988, p. 512)	"We define process innovation as any operations technology that is new to the adopting organization."
Damanpour (1991, p. 561)	"[...] process innovations are new elements introduced into an organization's production or service operations—input materials, task specifications, work and information flow mechanisms, and equipment used to produce a product or render a service."
Ettlie and Reza (1992, p. 796)	"Process innovation is defined generally as changes in throughput technology for an organization or operating unit, such as a plant, that are new to an industry."
Gopalakrishnan and Damanpour (1997, p. 18)	"Process innovations are defined as tools, devices, and knowledge in throughput technology that mediate between inputs and outputs and are new to an industry, organization, or sub-unit."

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<i>Study</i>	<i>Definition</i>
Pisano (1997, p. 34)	"[...] process development projects are defined as attempts to create new process architectures, rather than to achieve incremental improvements in an existing technology. Thus a process development project is likely to be associated with the launch of a major new product or the introduction of a next-generation process for an existing product."
Papinniemi (1999, p. 96, emphasis in original)	" <i>Process Innovation</i> means performing a work activity in a radically new way."
Edquist et al. (2001, p. 14, emphasis in original)	" <i>Process innovations</i> are new ways of producing goods and services; it is a matter of <i>how</i> existing products are produced."
Afuah (2003, p. 371, emphasis in original)	" <i>Process innovation</i> . Use of new methods, techniques, materials, task specification, or equipment in an organization's manufacturing or service operations to offer a lower cost or better quality product."
OECD (2005, p. 49, clause 163, emphasis in original)	"A <i>process innovation</i> is the implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software."
Reichstein and Salter (2006, p. 653)	"Process innovation can be defined as new elements introduced into an organization's production or service operations—input materials, task specifications, work and information flow mechanisms, and equipment used to produce a product or render a service—with the aim of achieving lower costs and/or higher product quality."
Tidd and Bessant (2009, p. 21)	"'Process innovation'—changes in the ways in which they [products or services] are created and delivered."
Ahmed and Shepherd (2010, p. 8)	"Process innovation refers to the change in the conduct of a firm's organisational activities."
Frishammar et al. (2012, p. 519)	"[...] process innovation, which involves innovation in the production processes and component technologies that are used to produce the firm's products."

Note: The definitions listed are representative rather than exhaustive.

2.2.4 Innovation Capability

Learning by firms is seen as a dynamic process which utilises learning mechanisms such as experience accumulation, knowledge articulation and knowledge codification (Malerba, 1992; Zollo and Winter, 2002). In particular cumulative learning on "[...] how to coordinate diverse production skills and integrate multiple streams of technologies" is of great importance to innovative manufacturers (Prahalad and Hamel, 1990, p. 82).

Innovation capability (see Table 4) can be classified as a higher-order capability because it primarily co-ordinates several subsets of capabilities (Collis, 1994; Mills et al., 2003; Prahalad and Hamel, 1990; Winter, 2003). For example, to carry out a technical process innovation, existing mainstream (i. e. production) capabilities need to be co-ordinated with newstream (i. e. technological development) capabilities (Bell and Pavitt, 1992; Lall, 1992; Lawson and Samson, 2001; Pisano, 1997; Zawislak et al., 2012). These capabilities, in turn, co-ordinate exploratory, transformative and exploitative learning routines (Berner and Tushman, 2003; Gupta et al., 2006; Lane et al., 2006; March, 1991; Zahra and George, 2002). Drawing on Mills et al. (2003, p. 984), the recursive relationship between resources and capabilities can be expressed with the following equations:

$$\begin{aligned} \text{Resources} &= \text{Tangible Assets} + \text{Intangible Assets} \\ \text{Activities} &= \text{Resources} + \text{Co-ordination} \\ \text{Capabilities} &= \text{Activities} + \text{Co-ordination} \\ \text{Higher-order Capabilities} &= \text{Capabilities} + \text{Co-ordination} \end{aligned}$$

To unlock the full potential of higher-order capabilities a comprehensive understanding of a firm's resource base is necessary which is not only technical or tangible in nature but also non-technical and intangible (Bowen et al., 1994; Drucker, 1985, 1990; Pisano, 1997; Slack and Lewis, 2011). Therefore, the knowledge set of a manufacturer consists of four dimensions which interact with certain knowledge-creating and knowledge-diffusing activities (Leonard-Barton, 1992a,b, 1995):

There are four dimensions to this knowledge set. Its content is embodied in (1) employee *knowledge and skills* and embedded in (2) *technical systems*. The processes of knowledge creation and control are guided by (3) *managerial systems*. The fourth dimension is (4) *the values and norms* associated with the various types of embodied and embedded knowledge and with the processes of knowledge creation and control. (Leonard-Barton, 1992a, p. 113, emphasis in original)

Learning requires creation and control of both external and internal knowledge for both current and future operations. Therefore, four distinguishing activities are critical to a learning laboratory: (1) problem solving (in current operations); (2) internal knowledge integration (across functions and projects); (3) innovation and experimentation (to build for the future); and (4) integration of external information flows. (Leonard-Barton, 1992b, p. 25)

Several similar classification schemes of knowledge and technology management activities can be found in the literature (Cetindamar et al., 2009; Gregory, 1995; Probst, 1998). Those activities as well as the innovation typology as such influence a firm's innovation capability (Attewell, 1992; Christensen, 1992a,b; Gatignon et al., 2002; Henderson and Clark, 1990; Henderson, 1993). In summary, the adopted resource and capability architecture explains the higher-order capability of innovation and provides insights into its relationship with learning routines.

Table 4: Selected definitions of innovation capability

<i>Study</i>	<i>Definition</i>
Richardson (1972, p. 888, emphasis in original)	"It is convenient to think of industry as carrying out an indefinitely large number of <i>activities</i> , activities related to the discovery and estimation of future wants, to research, development and design, to the execution and co-ordination of processes of physical transformation, the marketing of goods and so on. And we have to recognise that these activities have to be carried out by organisations with appropriate <i>capabilities</i> , or, in other words with appropriate knowledge, experience and skills."
Bell and Pavitt (1992, pp. 260-261)	"[Production capacity] incorporates the resources used to produce industrial goods at given levels of efficiency and given input combinations: equipment (capital-embodied technology), labor skills (operating and managerial know-how and experience), product and input specifications, and organizational systems. Technological capability incorporates the additional and distinct resources needed to generate and manage technical change, including skills, knowledge and experience, and institutional structures and linkages."
Lall (1992, p. 166)	"Once firm-level technological change is understood as a continuous process to absorb or create technical knowledge, determined partly by external inputs and partly by past accumulation of skills and knowledge, it is evident that 'innovation' can be defined much more broadly to cover all types of search and improvement effort."
Lawson and Samson (2001, p. 384)	"An innovation capability is therefore defined as the ability to continuously transform knowledge and ideas into new products, processes and systems for the benefit of the firm and its stakeholders."
Francis and Bessant (2005, p. 171)	"[...] enterprises that are better able to manage innovation than others and demonstrate a record of successfully exploiting new ideas can be said to possess, at least for a period of time, a superior 'innovation capability'".
Assink (2006, p. 219)	"The internal driving energy to generate and explore radical new ideas and concepts, to experiment with solutions for potential opportunity patterns detected in the market's white space and to develop them into marketable and effective innovations, leveraging internal and external resources and competencies."

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<i>Study</i>	<i>Definition</i>
Zawislak et al. (2012, p. 23)	"Innovation capability is the ability to absorb, adapt and transform a given technology into specific operational, managerial and transactional routines that can lead a firm to Schumpeterian profits, i. e., innovation. By doing so, a firm can perpetuate itself overtime."
Frishammar et al. (2012, p. 519)	"[...] process innovation capability is defined as a firm's ability to acquire, assimilate, transform, and exploit technically related resources, procedures, and knowledge for process innovation purposes, such as engineering know how."

Note: The definitions listed are representative rather than exhaustive.

2.2.5 *Rationale for the Present Research*

In this subsection the study is placed in a broader context and the outlined categorical taxonomies are tied together into a central research phenomenon being investigated. For this reason, the *Research Topic and Problem* as well as the *Research Purpose and Question* are presented (Blaikie, 2010, pp. 16-17).

Research Topic and Problem

Process innovations are widely acknowledged for their economic importance but their management is still not sufficiently explored (Hatch and Mowery, 1998; Hollen et al., 2013; Lager, 2011; Piening and Salge, 2015; Reichstein and Salter, 2006). Systematic literature reviews reveal that, in contrast to product innovation, few studies have focused on the strategic management of process innovations (Frishammar et al., 2012; Hollen et al., 2013; Keupp et al., 2012; Lengnick-Hall, 1992; Wolfe, 1994). For example, drawing on Keupp et al. (2012), only 11 from 342 reviewed articles, published in seven journals¹ from 1992 to 2010, examine process innovations within a strategic context. While some of these studies tend to apply the outcome approach where insights into capability building are only a by-product (Bernstein and Kök, 2009; Carrillo and Gaimon, 2000; Chang and Harrington, 2000; Christmann, 2000; Leiblein and Madsen, 2009; Schroeder et al., 2002), others make use of the process approach in order to illuminate the 'black box' directly (Choo et al., 2007; Ettlie and Reza, 1992; Maritan and Brush, 2003; Pisano, 1994; Tyre and Hauptman, 1992). Unfortunately, most of them are quantitative in nature and have neglected or underrated a thorough and coherent description of the operational practice how manufacturers build and maintain their technical process innovation

¹ (1) *Academy of Management Journal*, (2) *Academy of Management Review*, (3) *Administrative Science Quarterly*, (4) *Journal of Management*, (5) *Management Science*, (6) *Organization Science* and (7) *Strategic Management Journal*.

capability. Moreover, previous work rarely operationalises and interlinks substantial theoretical foundations in the domain of strategic management such as the resource-based view (Wernerfelt, 1984), organisational routines (Feldman and Pentland, 2003), dynamic capabilities (Teece et al., 1997), absorptive capacity (Cohen and Levinthal, 1990) and co-ordination mechanisms (Mintzberg, 1979b). For this reason, two recent systematic literature reviews address this issue and hence call for further research:

[1] The literature provides detailed insights into the possibilities to foster process innovation [...]. However, less attention has been devoted to explain how process innovation is achieved, developed, implemented, and exploited to reap desired outcomes, which legitimizes the choice of a capability-based perspective. (Frishammar et al., 2012, p. 521)

[2] It is essential to delve deeper into the 'black box' of innovative processes to understand both their content and the forces that drive them [...]. The results of the cluster analysis [...] consistently suggest that this call has been addressed little to date and that relatively few articles focus on the strategic management of process innovations [...]. [...] Thus, a deeper understanding of how firms can strategically manage process innovations would be desirable. (Keupp et al., 2012, p. 377)

Finally, also industrial practitioners suffer from deficient and incomplete understanding of the strategic management of process innovations. O'Donovan et al. (2005, p. 61) outline that even "[c]ompanies with great confidence in their technical abilities often are very dismissive of their understanding of design process planning. They can be world leaders in their respective technologies, yet they may not understand the process through which they have generated them, or through which they will incorporate the technology into a product". Therefore, the scarcity of a descriptive model—outlining the used activities, mechanisms and controls to undertake technical process innovation projects as well as the applied strategies, practices or tactics to institutionalise the knowledge and skills—is regrettable because it is the sort of guidance practitioners appear to be requiring if they are to support the dissemination of technical process innovations.

Research Purpose and Question

In order to enable concrete observations of the central research phenomenon—*technical process innovation capability*—an operational definition which is subject to the norms of consistency, precision and criticalness needs to be elaborated (Denzin, 1970, pp. 40-41). The synthesis of reviewed categorical taxonomies—*manufacturer* (Malone et al., 2006, p. 9), *technical process* (Eder, 2008, p. 24, figure 6), *process* (ISO, 2005, p. 11, § 3.4.1), *process innovation* (OECD, 2005, p. 49, clause 163), *innovation* (Baregheh et al., 2009, p. 1334), *innovation capability* (Lall, 1992, p. 166) and *capability* (OED, 2014)—suggests the following theoretically grounded and practically relevant definition for the present research:

A **TECHNICAL PROCESS INNOVATION CAPABILITY** is the power or ability of manufacturers to explore, transform and exploit in a co-ordinated multi-stage process knowledge and skills into new or significantly improved production methods implemented in a socio-technical transformation system, in order to advance, compete and differentiate themselves successfully in their marketplace.

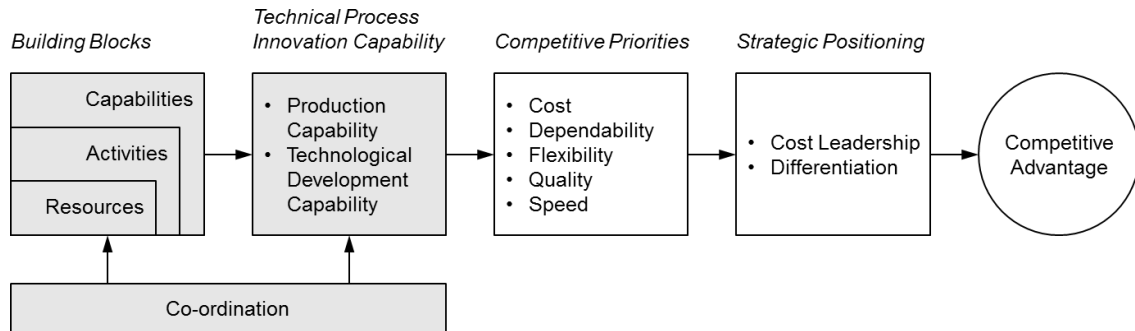


Figure 5: The conceptual framework of the present research

In addition, a conceptual framework depicts the key factors to be investigated (grey coloured, see Figure 5); the graphical representation is based on Brown's (1996, p. 96, figure 8.1) macro process model of an organisation which is often referred to as 'input-process-output-outcome-goal' model (Neely et al., 2007, pp. 146-147). The purpose of this case study-based dissertation is to *explore* and *describe* in what way the *technical process innovation capability* is built and maintained by R&D and production departments at a world leading motor vehicle manufacturer. Drawing on Blaikie (2010, p. 69, emphasis in original): "To *explore* is to attempt to develop an initial, rough description or, possibly, an understanding of some social phenomenon" and "[t]o *describe* is to provide a detailed account, or the precise measurement and reporting, of the characteristics of some [...] phenomenon, including establishing regularities". According to O'Leary (2005, p. 33) and Robson (2011, pp. 58-59), the following set of research questions provides the scope and direction for the present research:

MAJOR RESEARCH QUESTION

- *In what way does a world leading motor vehicle manufacturer build and maintain its technical process innovation capability?*

SUBSIDIARY RESEARCH QUESTIONS

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*
- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

2.3 THEORETICAL FOUNDATIONS

Several concepts introduced a new orientation or point of view into the domain of strategic management and defined the shape and content of related theories (Denzin, 1970, pp. 35-36). For this reason, substantial theoretical foundations such as the *Resource-Based View*, *Organisational Routines*, *Dynamic Capabilities*, *Absorptive Capacity* and *Co-Ordination Mechanisms* are reviewed in this section.

2.3.1 *Resource-Based View*

The following review of the *Resource-Based View* is twofold: the description of the concept itself and the evaluation of implications for the present research.

The Concept of the Resource-Based View

In the late 1950s it was questioned whether the conventional industrial organisation (I/O) view—later prominently elucidated by Porter (1980, 1985)—sufficiently explains a firm's competitive advantage. With the work of Selznick (1957, p. 42, emphasis in original), who studied the character² of organisations and was interested “[...] in the *distinctive competence* or *inadequacy* that an organization has acquired”, the attention turned towards a firm's inside. Moreover, the American-born British economist Edith Tilton Penrose (1914*-1996[†]; *The Theory of the Growth of the Firm*) critically challenged in her seminal work the prevailing reasoning of neoclassical economists and their associated outside view of a firm by saying:

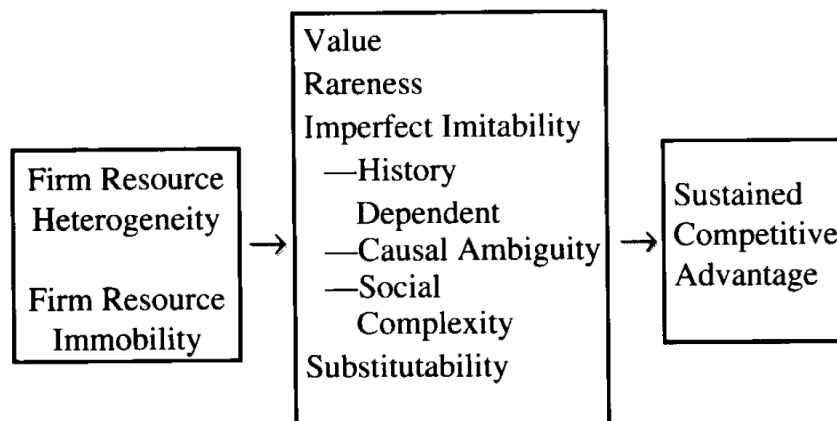
Growth becomes merely an adjustment to the size [of firms] appropriate to given conditions; there is no notion of an *internal* process of *development* leading to cumulative movements in any one direction. [...] It is often presumed that there is a ‘most profitable’ size of firm and that no further explanation than the search for profit is needed of how and why firms reach that size. Such an approach to the explanation of the size of firms will be rejected in this study; it will be argued that size is but a by-product of the process of growth, that there is no ‘optimum’, or even most profitable, size of firm. (Penrose, 1959, pp. 1-2, emphasis in original)

She considered a firm's inside as a pool of *resources* which can render *services* and noted that the unique character of a firm is given in the heterogeneity of the productive services available or potentially available from its resources (Penrose, 1959, pp. 25, 75, 149). This adopted inside view advances the understanding of a firm's competitive advantage.

² Wilkins (1989, pp. xi-xii, preface) also suggests the term *character* rather than *culture* because the latter has been trivialised due to its excessive but somewhat careless use when talking about almost everything organisational; moreover, he stresses the idea that the development of good habits through self-disciplined practice results in organisational character.

Another concept that contributes to the understanding of inter-firm differences in efficiency is labelled as *uncertain imitability* and introduced by Lippman and Rumelt (1982). It comprises two building blocks which impede a competitor replicating one's advantage: (1) causal ambiguity and (2) factor immobility. The former implies that complete homogeneity even through imitation is unattainable due to the difficulty of precisely identifying the factors responsible for performance differentials (Lippman and Rumelt, 1982, p. 418). The latter is defined as "[...] uniqueness combined with enforceable rights to the exclusive use of the unique resource" (Lippman and Rumelt, 1982, p. 420). As a result, the concept of uncertain imitability supplements the idea of resource bundles by suggesting specific characteristics which are needed to sustain a firm's competitive advantage.

Wernerfelt (1984, p. 172) who coined the term *resource-based view* (RBV) categorised resources into tangible and intangible assets and suggested the concept of resource position barriers. He clearly stated: "What a firm wants is to create a situation where its own resource position directly or indirectly makes it more difficult for others to catch up" (Wernerfelt, 1984, p. 173, emphasis in original). Therefore, a firm's privileged asset position mainly depends on how easily assets can be imitated or substituted (Dierickx and Cool, 1989, p. 1504). In order to compile the existing but somewhat fragmented concepts, an integrated framework of core tenets is needed. Since not all resources are equally important for creating a sustained competitive advantage, the *VRIN attributes*—Valuable, Rare, Inimitable and Non-substitutable—of critical resources are proposed by Barney (1986, 1991). Last, but by no means least, the underlying economics of sustained competitive advantage through the lens of the resource-based view are explained in detail by Peteraf (1993, pp. 185-186). The essence of the resource-based view can be synthesised into a framework which supports the analysis whether resources are strategically relevant or not (see Figure 6).



Source: Adopted from Barney (1991, p. 112, figure 2)

Figure 6: The resource-based view framework of a firm

The Implications for the Present Research

Despite critical appraisals, the resource-based view of the firm is still one of the most widely acknowledged theoretical perspectives (Acedo et al., 2006; Armstrong and Shimizu, 2007; Barney et al., 2011; Crook et al., 2008; Kraaijenbrink et al., 2010; Lockett et al., 2009; Newbert, 2007). Moreover, the resource-based view is particularly appropriate to investigate observable organisational phenomena such as technical process innovations (Bates and Flynn, 1995, pp. 235, 238). For example, applying the VRIN attributes to the resource 'physical technology' reveals that it should not be considered as a source of sustained competitive advantage because it is usually imitable by other firms. However, uncertain imitability relies among others on *social complexity* which has the potential to hamper imitative attempts of competitors as follows:

[...] the exploitation of physical technology in a firm often involves the use of socially complex firm resources. Several firms may all possess the same physical technology, but only one of these firms may possess the social relations, culture, traditions, etc. to fully exploit this technology in implementing strategies (Wilkins, 1989). If these complex social resources are not subject to imitation (and assuming they are valuable and rare and no substitutes exist), these firms may obtain a sustained competitive advantage from exploiting their physical technology more completely than other firms, even though competing firms do not vary in terms of the physical technology they possess. (Barney, 1991, pp. 110-111)

A well-known example of this can be found in the automotive industry where manufacturers try to replicate the Toyota Production System (TPS) in order to catch up with Toyota's productivity improvements but due to Toyota's underlying socially complex resource configuration they often end up only with a Toyota-like production system (Spear, 1999; Spear and Bowen, 1999). In consequence, the present research investigates critical (i.e. strategically relevant) resources which form the basis of the proposed conceptual framework (see on page 20).

Innovation by itself is inextricably connected with learning and a firm's stock of knowledge and skills (Cohen and Levinthal, 1989, 1990; Malerba, 1992). The psychological and educational theory distinguishes between the following three learning domains: (1) cognitive domain, (2) affective domain and (3) psychomotor domain (Anderson et al., 2001; Bloom et al., 1956; Dave, 1970; Harrow, 1972; Krathwohl, 2002; Krathwohl et al., 1964; Maclay, 1974; Pintrich, 2002; Simpson, 1966). Focusing on the cognitive domain with its emphasis on intellectual outcomes, the stock of knowledge and skills can be further disaggregated into *factual knowledge*, *conceptual knowledge*, *procedural knowledge* and *meta-cognitive knowledge* (see Table 5). These knowledge components can be used as building blocks for strategically relevant resources such as *technological development knowledge* and *production skills* (Slack and Lewis, 2011, pp. 17-18). In summary, the concept of the resource-based view supports the illumination of technical process innovation capability by shedding light on a firm's stock of knowledge and skills.

Table 5: The different knowledge components

<i>Component</i>	<i>Definition</i>
Factual Knowledge	The basic elements that organisational members must know to be acquainted with a discipline or solve problems in it (e. g. knowledge of terminology; knowledge of specific details and elements).
Conceptual Knowledge	The interrelationships among the basic elements within a larger structure that enable them to function together (e. g. knowledge of classifications and categories; knowledge of principles and generalisations; knowledge of theories, models and structures).
Procedural Knowledge	How to do something; methods of inquiry and criteria for using skills, algorithms, techniques and methods (e. g. knowledge of subject-specific skills and algorithms; knowledge of subject-specific techniques and methods; knowledge of criteria for determining when to use appropriate procedures).
Meta-Cognitive Knowledge	Knowledge of cognition in general as well as awareness and knowledge of one's own cognition (e. g. strategic knowledge; knowledge about cognitive tasks, including appropriate contextual and conditional knowledge; self-knowledge).

Source: Adapted from Krathwohl (2002, p. 214, table 2)

2.3.2 *Organisational Routines*

The following review of *Organisational Routines* is twofold: the description of the concept itself and the evaluation of implications for the present research.

The Concept of Organisational Routines

Early and notable writers who advanced the understanding and importance of organisational routines are Cohen et al. (1996); Cyert and March (1963); March and Simon (1958); Nelson and Winter (1982); Penrose (1959); Stene (1940); Thompson (1967). According to Becker (2004, pp. 644-645), the notion of *routines* refers historically most often to behaviour regularities (i. e. recurrent interaction patterns) as opposed to cognitive regularities (i. e. rules). Routines, or *services*, are essentially activities performed by resources (Penrose, 1959, p. 25). The notion of *organisational routines* draws on the following understanding:

Our general term for all regular and predictable behavioral patterns of firms is “routine.” We use this term to include characteristics of firms that range from well-specified technical routines for producing things, through procedures for hiring and firing, ordering new inventory, or stepping up production of items in high demand, to policies regarding investment, research and development (R&D), or advertising, and business strategies about product diversification and overseas investment. In our evolutionary theory, these routines play the role that genes play in biological evolutionary theory. They are a persistent feature of the organism and determine its possible behavior (though *actual* behavior is determined also by the environment); they are heritable in the sense that tomorrow’s organisms generated from today’s (for example, by building a new plant) have many of the same characteristics, and they are selectable in the sense that organisms with certain routines may do better than others, and, if so, their relative importance in the population (industry) is augmented over time. (Nelson and Winter, 1982, p. 14, emphasis in original)

Therefore, routines reflect the way current things are done in an organisation and three underlying purposes are distinguished: (1) co-ordination/integration, (2) reconfiguration and (3) learning (Teece et al., 1997, p. 518). As a result, drawing on the concept of organisational routines provides insights into the ways a firm utilises its resources rather than merely possessing them.

Organisational routines act as a repository of a firm’s knowledge and skills, a so-called *organisational memory* (Nelson and Winter, 1982, pp. 99-107). The relationship between doing activities and storing the inherent knowledge is explained as follows:

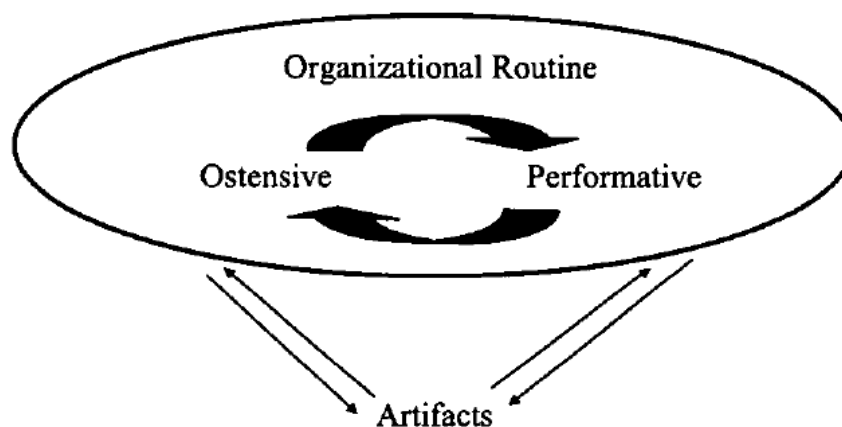
We propose that the routinization of activity in an organization constitutes the most important form of storage of the organization’s specific operational knowledge. Basically, we claim that organizations *remember* by *doing*—although there are some important qualifications and elaborations. The idea that organizations “remember” a routine largely by exercising it is much like the idea that an individual remembers skills by exercising them. The point that remembering is achieved largely through exercise, and could not be assured totally through written records or other formal filing devices, does not deny that firms keep formal memories and that these formal memories play an important role. But there must be much more to organizational memory than formal records. (Nelson and Winter, 1982, p. 99, emphasis in original)

Thus it is particularly *procedural knowledge* which is bound by organisational routines (Becker, 2004, p. 652). In order to conceptualise organisational routines, they can be further disaggregated into *performative* aspects, *ostensive* aspects and *artefacts*; these components cover both interpretations of routines in the literature: behaviour regularities and cognitive regularities (see Table 6). According to Pentland and Feldman (2005, p. 794), the specific relationships between these routine components offer a potential explanation of the way certain capabilities are constructed (see Figure 7). Therefore, organisational routines can be seen as major building blocks of organisational capabilities (Becker, 2004; Dosi et al., 2000; Winter, 2003). Finally, a detailed analysis of routine components and their interactions in a given context can help in understanding the ways a firm utilises its strategically relevant resources in order to build required capabilities.

Table 6: The different routine components

<i>Component</i>	<i>Definition</i>
Performative	The performative aspect of an organisational routine is the enactment and consists of the actual performance/action of the routine by (usually distributed) specific people, at specific times, in specific places (agency) that bring the routine to life.
Ostensive	The ostensive aspect of an organisational routine embodies the abstract idea/pattern (cognitive regularities) of the routine (structure) and is the ideal or schematic form of the routine; this may be codified, for example, as a standard operating procedure which contains significant tacit knowledge.
Artefacts	Artefacts are codified or prescribed physical manifestations of performative and ostensive aspects of organisational routines that enable and constrain them, for example, written rules, manuals, standard operating procedures, templates, databases or general physical settings such as layout of the workplace and the tools used in performing the routine.

Source: Compiled from [Feldman and Pentland \(2003\)](#); [Pentland and Feldman \(2005, 2008\)](#)



Source: Adopted from [Pentland and Feldman \(2005, p. 795, figure 1\)](#)

Figure 7: The conceptualisation of organisational routines

The Implications for the Present Research

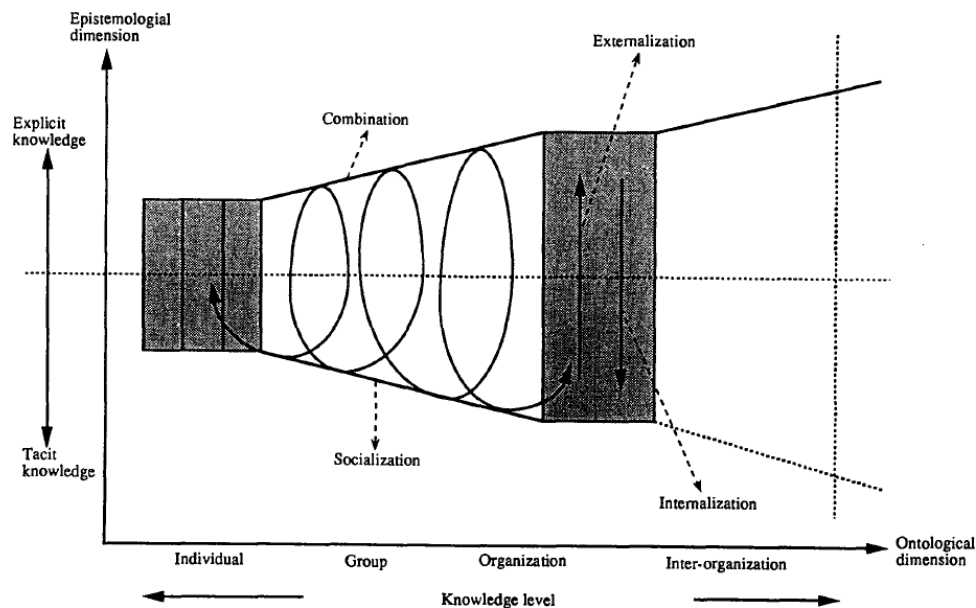
Innovation and routinisation are not in opposition. Innovation in firm's activities is, in large parts, based on new combinations (i. e. reconfiguration) of existing and reliable routines with well-understood scopes (Nelson and Winter, 1982; Schumpeter, 1934). In order to deploy a firm's existing stock of knowledge and skills, sufficient understanding of both *tacit* versus *explicit* knowledge and *individual* versus *collective* knowledge is needed (Alavi and Leidner, 2001; Nonaka, 1994; Pentland, 1995; Polanyi, 1958, 1967). The highly interdependent and intertwined knowledge creation modes involved (see Figure 8) are defined as follows:

The socialization mode refers to conversion of tacit knowledge to new tacit knowledge through social interactions and shared experience among organizational members (e. g., apprenticeship). The combination mode refers to the creation of new explicit knowledge by merging, categorizing, reclassifying, and synthesizing existing explicit knowledge (e. g., literature survey reports). The other two modes involve interactions and conversions between tacit and explicit knowledge. Externalization refers to converting tacit knowledge to new explicit knowledge (e. g., articulation of best practices or lessons learned). Internalization refers to creation of new tacit knowledge from explicit knowledge (e. g., the learning and understanding that results from reading or discussion). (Alavi and Leidner, 2001, p. 116)

Therefore, knowledge creation modes are often embedded in innovation relevant activities. In consequence, the present research investigates critical (i. e. strategically relevant) sets of activities such as production and technological development which are then considered as connecting elements in the proposed conceptual framework (see on page 20).

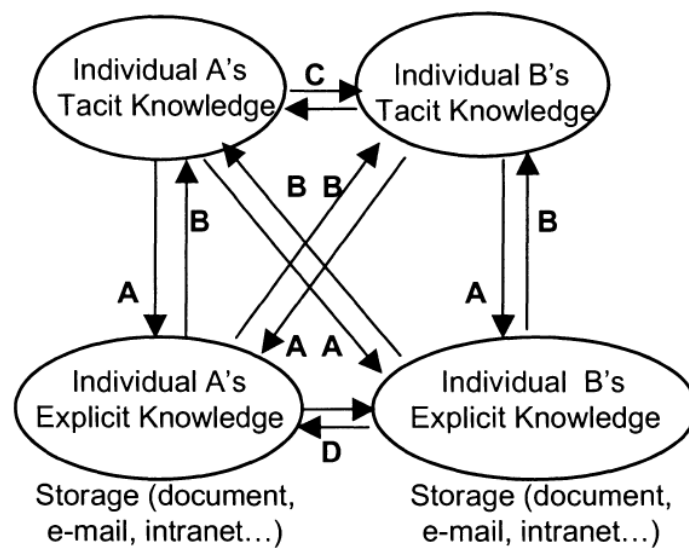
Activities analysed in the present research utilise strategically relevant resources such as technological development knowledge and production skills. Since routines are seen as important building blocks of capabilities, it is argued that observing activities equals observing 'capabilities in use' (Helfat et al., 2007, p. 31). For this reason, the following classification of 'capabilities in use' is compiled from Fujimoto's evolutionary framework for manufacturing:

1. "*Routinized manufacturing capability*. A set of organizational routines that affect the level of manufacturing performance at a given time in a steady state of repetitive production, development, and transactions" (Fujimoto, 1999, p. 17, emphasis in original).
2. "*Routinized learning capability*. A set of organizational routines that affect the pace of continuous or repetitive performance improvements, as well as recoveries from system disruptions or deterioration" (Fujimoto, 1999, p. 17, emphasis in original).
 - a) "*Routines for problem identification*. Stable practices that reveal and help visualize problems, diffuse problem information to problem solvers, and keep individuals conscious of problems" (Fujimoto, 1999, p. 19, emphasis in original).
 - b) "*Routines for problem solving*. The ability to search, simulate, and evaluate alternatives; to coordinate knowledge, skills, responsibility, and authority for solving problems; and to diffuse such tools throughout an organisation" (Fujimoto, 1999, p. 19, emphasis in original).



(a) Spiral of organisational knowledge creation

Source: Adopted from Nonaka (1994, p. 20, figure 2)



Legend: Each arrow represents a form of knowledge creation.
 A—Externalization; B—Internalization; C—Socialization;
 D—Combination

(b) Knowledge creation modes

Source: Adopted from Alavi and Leidner (2001, p. 117, figure 1)

Figure 8: The conceptualisation of knowledge creation

- c) “*Routines for solution retention*. The ability to formalize and institutionalize new solutions in standard operating procedures, thereby providing stability for individuals who internalize the solutions” (Fujimoto, 1999, p. 19, emphasis in original).
- 3. “*Evolutionary learning capability*. A nonroutine ability that affects creation of the above routine capabilities themselves through irregular processes of multi-path system emergence [e. g. random trials, rational calculation, environmental constraints, entrepreneurial vision and knowledge transfer]” (Fujimoto, 1999, p. 17, emphasis in original).
 - a) “*Intentional Learning Capability*. A firm is able to search alternative organizational routines more effectively than competitors in advance of actual trials or establishment of routines. This may include calculating potentially effective trials rationally or using an entrepreneur’s intuitive ability to envision effective trials. In any case, creation of causal knowledge precedes routinization” (Fujimoto, 1999, p. 22, emphasis in original).
 - b) “*Opportunistic (i. e., ex-post) Learning Capability*. What if a new routine [were] created for a noncompetitive reason but turns out to increase competitive performance? A firm with an ability to reinterpret past trials or existing routines can still create specific advantages for itself because it grasps the competitive consequences of such emergent routines, shapes a routine to exploit its full potential, and then institutionalizes and retains the routine more effectively than its rivals. Thus, routinization precedes competitive insights in this mode” (Fujimoto, 1999, p. 22, emphasis in original).

These intra-organisational activities or ‘capabilities in use’ can be further disaggregated into observable context-specific routine components (i. e. performative aspects, ostensive aspects and artefacts). In summary, the concept of organisational routines enables a view beneath the surface of technical process innovation capability by analysing a firm’s knowledge and skills reservoir through its activities.

2.3.3 *Dynamic Capabilities*

The following review of *Dynamic Capabilities* is twofold: the description of the concept itself and the evaluation of implications for the present research.

The Concept of Dynamic Capabilities

During the 1990s the resource-based view gradually changed into a capability-based view of the firm. Prahalad and Hamel (1990, p. 81) claim that “[t]he real sources of advantage are to be found in management’s ability to consolidate corporatewide technologies and production skills into competencies that empower individual businesses to adapt quickly to changing opportunities”. The distinction of resources and capabilities is then explicitly drawn by Amit and Schoemaker (1993) with the following two definitions:

[1] The firm's *Resources* will be defined as stocks of available factors that are owned or controlled by the firm. *Resources* are converted into final products or services by using a wide range of other firm assets and bonding mechanisms such as technology [...].

[2] *Capabilities*, in contrast, refer to a firm's capacity to deploy *Resources*, usually in combination, using organizational processes, to effect a desired end. They are information-based, tangible or intangible processes that are firm-specific and are developed over time through complex interactions among the firm's *Resources*. (Amit and Schoemaker, 1993, p. 35, emphasis in original)

Therefore, a firm's stock of knowledge and skills represents available resource bundles, whereas *knowledge* by itself can also be interpreted as "[...] the capacity for effective action", for example, to respond to a firm's volatile environment (Senge et al., 1999, p. 78). As a result, the adopted capability-based view offers a link to the industrial organisation (I/O) view.

The concept of *dynamic capabilities* which is sometimes explained as a 'spin-off perspective' or an 'evolutionary extension' refines and connects existing notions (Barney et al., 2011; Barreto, 2010). Iansiti and Clark (1994, p. 559) derived the initial concept from their empirical study of the development of new products and processes in a turbulent environment. Dynamic capabilities provide the bridge between the inside view of a firm (i. e. exploitation of firm-specific resources) and the outside view of a firm (i. e. strategic positioning within an industry through cost leadership or differentiation) as follows:

The term 'dynamic' refers to the capacity to renew competences so as to achieve congruence with the changing business environment; certain innovative responses are required when time-to-market and timing are critical, the rate of technological change is rapid, and the nature of future competition and markets difficult to determine. The term 'capabilities' emphasizes the key role of strategic management in appropriately adapting, integrating, and reconfiguring internal and external organizational skills, resources, and functional competences to match the requirements of a changing environment. (Teece et al., 1997, p. 515)

An impressive body of subsequent work extends the understanding of dynamic capabilities (Barreto, 2010; Dosi et al., 2000; Eisenhardt and Martin, 2000; Helfat and Peteraf, 2003; Helfat et al., 2007; Makadok, 2001; Miller, 2003; Teece, 2007; Wang and Ahmed, 2007; Winter, 2003; Zahra et al., 2006; Zollo and Winter, 2002; Zott, 2003). The present research draws on the argument from Eisenhardt and Martin (2000, p. 1105) that dynamic capabilities are identifiable and specific processes, they define them as:

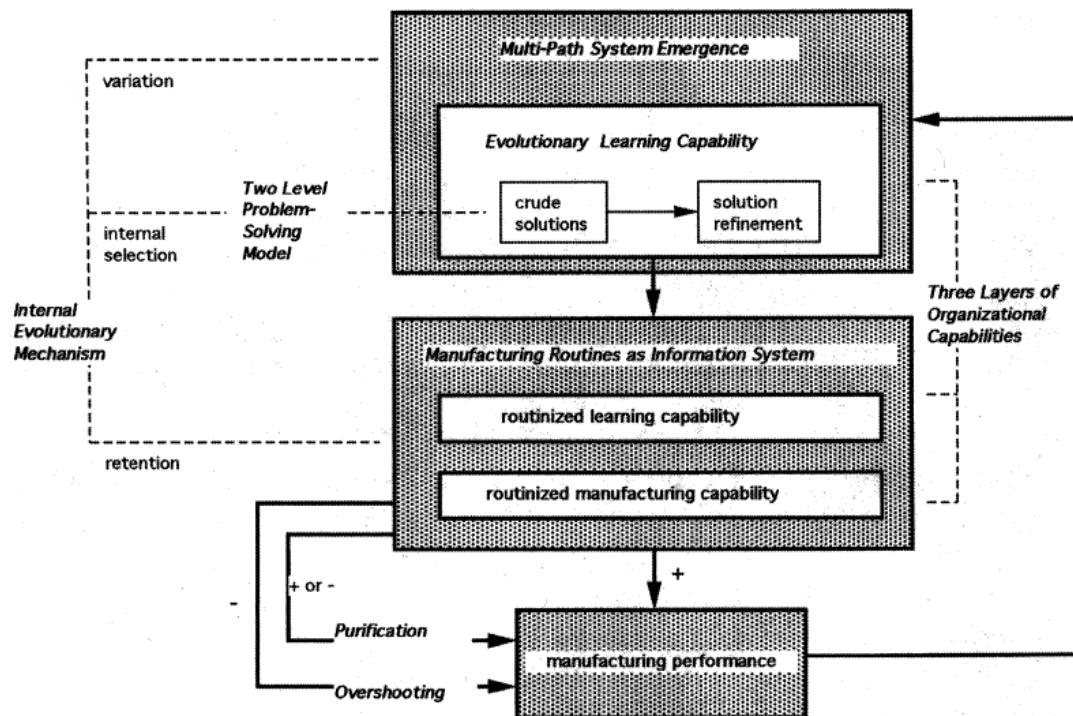
The firm's processes that use resources—specifically the processes to integrate, reconfigure, gain and release resources—to match and even create market change. Dynamic capabilities thus are the organizational and strategic routines by which firms achieve new resource configurations as markets emerge, collide, split, evolve, and die. (Eisenhardt and Martin, 2000, p. 1107)

This practicable conceptualisation of dynamic capabilities enables a firm to purposefully strengthen its strategically relevant capabilities in order to respond to external opportunities or threats.

The Implications for the Present Research

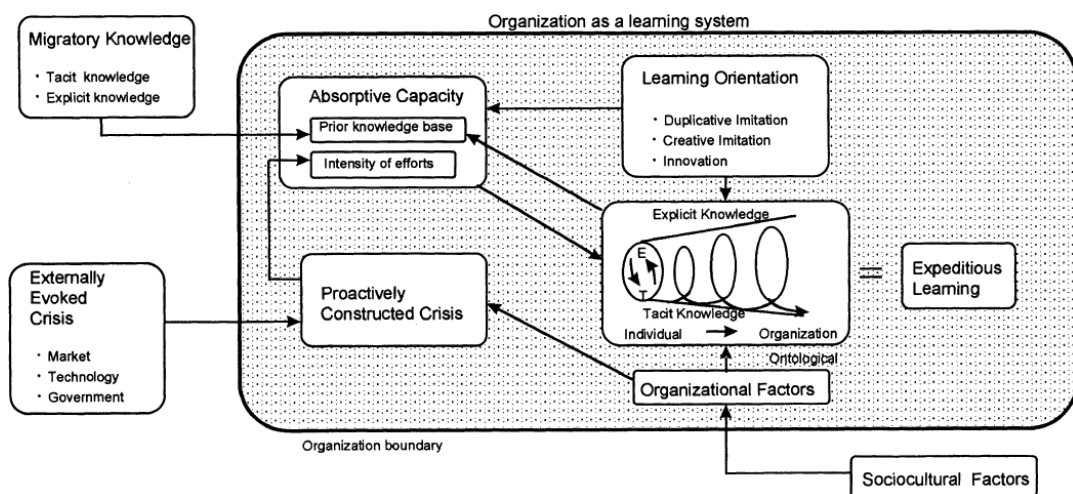
To create economic rent, a firm must be more effective than its competitors in two noticeable mechanisms: (1) resource picking and (2) capability building (Makadok, 2001, p. 387). While the former—selecting resources—can be supported by applying the VRIN attributes (see on page 22), the latter—deploying resources—involves learning mechanisms such as experience accumulation, knowledge articulation and knowledge codification (Barney, 1991; Makadok, 2001; Zollo and Winter, 2002). The technical process innovation capability—a higher-order capability—co-ordinates existing mainstream (i.e. production) capabilities with newstream (i.e. technological development) capabilities (Bell and Pavitt, 1992; Lall, 1992; Lawson and Samson, 2001; Pisano, 1997; Zawislak et al., 2012). In the context of the present research, the co-ordination of production is seen as a firm's static capability which regulates ongoing operational activities, whereas technological development is classified as a prototypical dynamic capability (Cetindamar et al., 2009; Eisenhardt and Martin, 2000; Helfat, 1997; Iansiti and Clark, 1994; Lawson and Samson, 2001; Lee and Kelley, 2008; McKelvie and Davidsson, 2009; O'Connor, 2008; Zott, 2003). In consequence, the present research investigates both subsets of capabilities which can also be assigned to the proposed conceptual framework (see on page 20) but with particular emphasis on building dynamic capabilities since they have the potential to change a firm's resource configuration.

Dynamic capabilities by themselves evolve via learning routines and thus can be internally architected and constructed (Eisenhardt and Martin, 2000; Makadok, 2001; Wang and Ahmed, 2007). Empirical studies of motor vehicle manufacturers illustrate different capability building frameworks (see Figure 9). Toyota's framework, for example, stresses the interplay of routinised manufacturing and learning capabilities with an evolutionary learning capability (Fujimoto, 1999, p. 272). Hyundai's framework, on the other hand, emphasises how migratory knowledge raises the prior knowledge base and proactively constructed crises intensify the learning efforts (Kim, 1998, p. 517). Both frameworks make use of the process approach (in contrast to applying the outcome approach) in order to investigate dynamic capabilities which is adopted by the present research (Helfat et al., 2007, p. 37). In summary, the concept of dynamic capabilities furthers the understanding of technical process innovation capability by highlighting the importance of learning routines with which a firm can reconfigure its resource base.



(a) Toyota Motor Corporation

Source: Adopted from Fujimoto (1999, p. 273, figure 8.1)



(b) Hyundai Motor Company

Source: Adopted from Kim (1998, p. 509, figure 2)

Figure 9: Selected capability building frameworks

2.3.4 *Absorptive Capacity*

The following review of *Absorptive Capacity* is twofold: the description of the concept itself and the evaluation of implications for the present research.

The Concept of Absorptive Capacity

A dynamic capability with particular emphasis on reconfiguration and deployment of a firm's stock of knowledge and skills is known as absorptive capacity (Lane et al., 2006; Zahra and George, 2002). Initial observations of this organisational phenomenon can be found in Allen (1970, 1977); Evenson and Kislev (1975); Mowery (1983); Tilton (1971). However, Cohen and Levinthal (1989, 1990, 1994) coined the term *absorptive capacity* to describe a firm's ability to evaluate and utilise new or outside knowledge and skills. A growing body of research refines and operationalises this construct further (Dyer and Singh, 1998; Kim, 1998; Koza and Lewin, 1998; Lane and Lubatkin, 1998; Lane et al., 2006; Mowery et al., 1996; Roberts et al., 2012; Szulanski, 1996; Todorova and Durisin, 2007; van den Bosch et al., 1999; Zahra and George, 2002). For example, Lane et al. (2006, pp. 855-856) adopt a learning process-oriented perspective and highlight in their definition three distinct sets of organisational routines as follows:

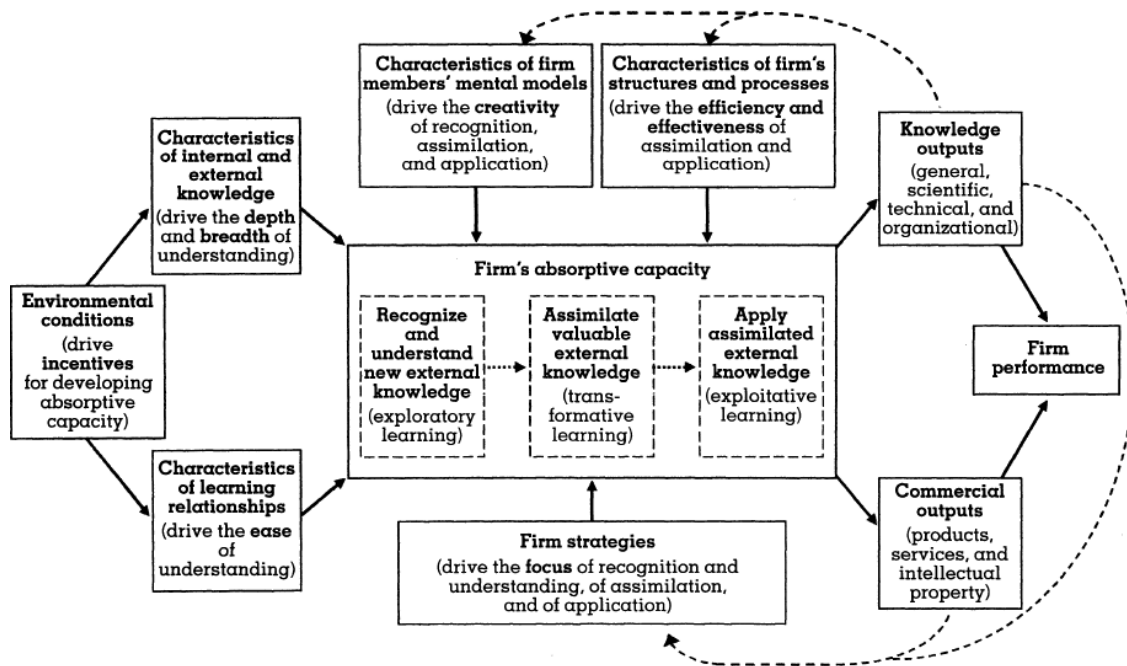
Absorptive capacity is a firm's ability to utilize externally held knowledge through three sequential processes: (1) recognizing and understanding potentially valuable new knowledge outside the firm through exploratory learning, (2) assimilating valuable new knowledge through transformative learning, and (3) using the assimilated knowledge to create new knowledge and commercial outputs through exploitative learning. (Lane et al., 2006, p. 856)

This definition positions the absorptive capacity routines (i. e. identify, assimilate and apply new or outside knowledge and skills) within an extended exploration/exploitation learning framework (Roberts et al., 2012, p. 629). As a result, the concept of absorptive capacity exemplifies learning routines with which a firm can reconfigure and deploy its stock of knowledge and skills.

The multidimensional absorptive capacity construct elucidates and affirms the process approach of dynamic capabilities. Lane et al. (2006, pp. 856-858) conceptualise and illustrate a coherent process model of absorptive capacity including its antecedents and outcomes (see Figure 10). They summarise the model as follows:

At its center is the new definition of absorptive capacity, to the left are drivers partially or totally external to the firm, above and below the center are drivers internal to the firm, and to the right are outcomes of absorptive capacity. Please note that because the focus of the model is on absorptive capacity, arrows indicating relationships between drivers or between drivers and outcomes have been omitted for simplicity's sake. (Lane et al., 2006, p. 856)

Consequently, establishing the co-ordination essential for an effective integration of new or outside knowledge and skills can be seen as an important management task (Grant, 1996, p. 120). In conclusion, the refined concept of absorptive capacity allows a focused investigation of distinct learning routines along a multi-stage process.



Source: Adopted from Lane et al. (2006, p. 856, figure 4)

Figure 10: The conceptualisation of absorptive capacity

The Implications for the Present Research

The ability to anticipate better where gainful opportunities in the value chain arise and to invest in the capabilities and relationships to exploit them, distinguishes innovative manufacturers from the ordinary (Fine, 1999, p. 76). An impressive example can be found in the history of the Japanese automotive industry as follows:

How could Japan succeed in establishing its own car industry in the presence (in the pre-war period) of the technologically far-advanced companies, Ford and GM? Two factors appear to be most significant. One is the presence of entrepreneurs, such as Toyoda and Aikawa, who were willing to take risks and sustain efforts under adversity. The other is the capability of engineers to absorb foreign technology and the capability of workers to absorb new production processes. (Odagiri and Gotō, 1996, p. 202)

This absorptive capacity has a strong relationship to innovation—an outcome of organisational learning (Lane et al., 2006, p. 849). Moreover, the evaluation and utilisation of external and internal resources particularly with the purpose to drive a firm's innovation process is often referred to as *open innovation* (Chesbrough, 2003a,b; Mortara and Ford, 2012; Mortara et al., 2009, 2010). In consequence, the present research investigates absorptive capacity routines in the context of technical process innovation.

Absorptive capacity enriches a firm's learning ability and constitutes the foundation for building an innovation capability. Zahra et al. (2010, p. 133) claim that "[...] managers interested in building new capabilities can learn a great deal from analyzing their company's experiences with technological innovations, capturing this learning and integrating it with the firm's absorptive capacity". However, the development of absorptive

capacity is often inherited in activities such as production and technological development and thus considered as a by-product (Abernathy, 1978; Baldwin, 1962; Mowery, 1983; Rosenberg, 1982; Teece, 1977). Nevertheless, the present research acknowledges this by-product as a fundamental building block for a firm's innovation capability. In summary, the concept of absorptive capacity advances the comprehension of technical process innovation capability by emphasising a firm's ability to explore, transform and exploit new or outside knowledge and skills.

2.3.5 Co-Ordination Mechanisms

The following review of *Co-Ordination Mechanisms* is twofold: the description of the concept itself and the evaluation of implications for the present research.

The Concept of Co-Ordination Mechanisms

The acknowledged founder of organisation theory, the German sociologist Max Weber (1864*-1920[†]; *The Theory of Social and Economic Organization*) provided a rational basis for organisational efficiency (Wren, 2005, p. 227). In particular his notion of bureaucracy based upon rational-legal authority should be the key of a more systematically functioning of large-scale organisations (Weber, 1947, p. 337). The required systematic division of labour can be seen as a “[...] *system of consciously coördinated activities or forces of two or more persons*” (Barnard, 1938, p. 73, emphasis in original) and the organisational structure as “[...] the sum total of the ways in which it divides its labor into distinct tasks and then achieves coordination among them” (Mintzberg, 1979b, p. 2). To understand different structural configurations, Mintzberg disaggregated the organisation³ into five basic parts, namely (1) operating core, (2) strategic apex, (3) middle line, (4) technostructure and (5) support staff (see Figure 11). These basic parts are defined as follows:

At the base of the logo is the *operating core*, wherein the operators carry out the basic work of the organization—the input, processing, output, and direct support tasks associated with producing the products or services. Above them sits the administrative component, which is shown in three parts. First, are the managers, divided into two groups. Those at the very top of the hierarchy, together with their own personal staff, form the *strategic apex*. And those below, who join the strategic apex to the operating core through the chain of command (such as it exists), make up the *middle line*. To their left stands the *technostructure*, wherein the analysts carry out their work of standardizing the work of others, in addition to applying their analytical techniques to help the organization adapt to its environment. Finally, we

³ A different model which represents the cybernetic school of thought was elaborated and refined by Stafford Beer (1972, 1975, 1979, 1984, 1985). His *Viable System Model* (VSM) focuses primarily on regulated flows to explain how an organisation is capable of independent existence. According to Beer (1984, p. 14), the following five necessary and sufficient subsystems are involved: (1) implementation, (2) co-ordination, (3) control, (4) intelligence and (5) policy. However, Beer's model causes controversial debates as summarised by Jackson (1988, p. 557): “In the operational research/management science community, Beer is held in high esteem and his work is regarded as being amongst the most substantial, creative and stimulating in the whole literature of the discipline. In the related area of organization theory, however, his writings receive little serious attention”.

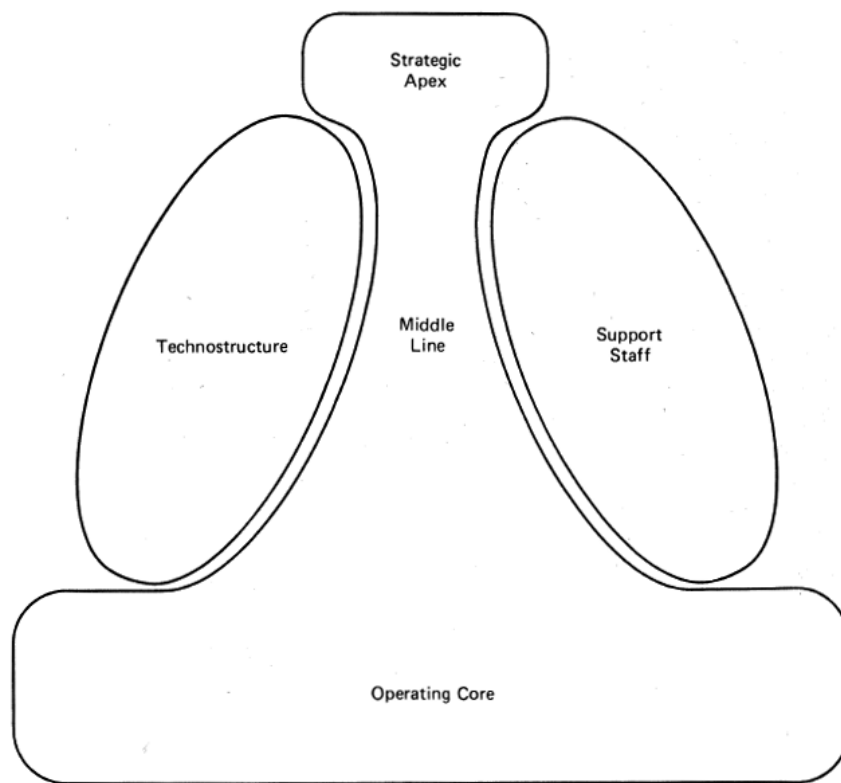
add a fifth group, the *support staff*, shown to the right of the middle line. This staff supports the functioning of the operating core indirectly, that is, outside the basic flow of operating work. The support staff goes largely unrecognized in the literature of organizational structuring, yet a quick glance at the chart of virtually any large organizational structuring indicates that it is a major segment, one that should not be confused with the other four. Examples of support groups in a typical manufacturing firm are research and development, [...] legal council, payroll, [and] public relations [...]. (Mintzberg, 1979b, p. 19, emphasis in original)

For example, in a firm dominated by the technostructure and the force for efficiency (e. g. in a simple and stable environment), the organisational structure might be labelled as a *machine bureaucracy*; in contrast to this, when the force for innovation becomes paramount (e. g. in a complex and dynamic environment) and the support staff is the firm's key part, the organisational structure might be labelled as an *adhocracy* (Mintzberg, 1980, 1981, 1991). Notwithstanding these structural configurations, Mintzberg's (1979b, p. 3) *co-ordination mechanisms* hold the different parts together and thus determine in large parts organisational efficiency (see Figure 12 and Table 7).

One of the earliest advocates analysing managerial activities in organisations is the Constantinople-born French mining engineer Henri Fayol (1841^{*}-1925[†]; *Industrial and General Administration*). With his industrial experience, Fayol developed the first theory of management thought by isolating managerial ability from technical knowledge (Reid, 1995; Wren, 1995, 2005). He distinguished particularly between technical operations (e. g. production and technological development) and administrative operations with elements such as planning, organising, commanding, co-ordinating and controlling (Fayol, 1930, p. 8). These elements are originally defined by Fayol (1930, p. 9)—see [1]—and later refined and paraphrased with the acronym POSDCORB by Gulick (1937, p. 13)—see [2]—as follows:

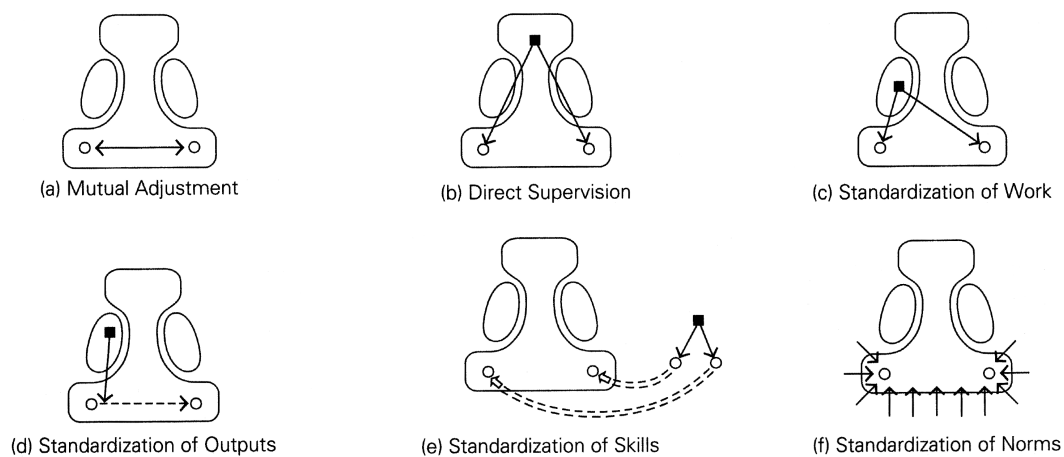
[1] To *plan* means to study the future and arrange the plan of operations. To *organise* means to build up the material and human organisation of the business, organising both men and materials. To *command* means to make the staff do their work. To *co-ordinate* means to unite and correlate all activities. To *control* means to see that everything is done in accordance with the rules which have been laid down and the instructions which have been given. (Fayol, 1930, p. 9, emphasis added)

[2] *Planning*, that is working out in broad outline the things that need to be done and the methods for doing them to accomplish the purpose set for the enterprise; *Organizing*, that is the establishment of the formal structure of authority through which work subdivisions are arranged, defined and co-ordinated for the defined objective; *Staffing* that is the whole personnel function of bringing in and training the staff and maintaining favorable conditions of work; *Directing*, that is the continuous task of making decisions and embodying them in specific and general orders and instructions and serving as the leader of the enterprise; *Co-ordinating*, that is the all important duty of interrelating the various parts of the work; *Reporting*, that is keeping those to whom the executive is responsible informed as to what is going on, which thus includes keeping himself and his subordinates informed through records, research and inspection; *Budgeting*, with all that goes with budgeting in the form of fiscal planning, accounting and control. (Gulick, 1937, p. 13, emphasis added)



Source: Adopted from Mintzberg (1979b, p. 20, figure 2.1)

Figure 11: The basic parts of the organisation



Source: Adopted from Mintzberg (1995, p. 353, figure 2)

Figure 12: The basic mechanisms of co-ordination

Table 7: The basic mechanisms of co-ordination

<i>Co-ordination Mechanism</i>	<i>Definition</i>
Mutual Adjustment	Mutual adjustment achieves the coordination of work by the simple process of informal communication. Under mutual adjustment, control of the work rests in the hands of the doers [...]. Because it is such a simple coordinating mechanism, mutual adjustment is naturally used in the very simplest of organizations [...]. Paradoxically, it is also used in the most complicated, because, [...] it is the only one that works under extremely difficult circumstances.
Direct Supervision	Direct supervision achieves coordination by having one individual take responsibility for the work of others, issuing instructions to them and monitoring their actions [...]. In effect, one brain coordinates several hands [...].
Standardization of Work Processes	Work processes are standardized when the contents of the work are specified, or programmed.
Standardization of Outputs	Outputs are standardized when the results of the work, for example the dimensions of the product or the performance, are specified. [...] With outputs standardized, the interfaces among tasks are predetermined [...].
Standardization of Skills	Skills (and knowledge) are standardized when the kind of training required to perform the work is specified. [...] So standardization of skills achieves indirectly what standardization of work processes or of work outputs does directly: it controls and coordinates the work.
Standardization of Norms*	Standardization of norms means that the workers share a common set of beliefs and can achieve coordination based on it [...].

Note: * This cultural based mechanism was added by Mintzberg at a later stage.

Source: Compiled from [Mintzberg \(1979b, pp. 3-7\)](#) and * from [Mintzberg \(1995, p. 354\)](#)

Similarly the definition provided by Fayol, [Malone and Crowston \(1994, p. 90, emphasis in original\)](#) define *co-ordination* as “[...] *managing dependencies between activities*”. Therefore, co-ordination mechanisms are composed of additional activities needed to manage the following three different kinds of dependencies: (1) fit dependencies—arise when multiple activities collectively produce a single resource, (2) flow dependencies—arise when one activity produces a resource that is used by another activity and (3) share dependencies—arise when a single resource is used by multiple activities ([Malone et al., 1999, p. 429](#)). For this reason, occurring problems in organisational routines suggest not sufficiently managed dependencies and call for appropriate co-ordination mechanisms to solve the issue.

The Implications for the Present Research

Innovative manufacturers must balance at least two competing forces to avoid the productivity dilemma: (1) efficiency and (2) innovation (Abernathy, 1978, p. 173). As outlined above, these forces can be addressed by different organisational structures such as machine bureaucracy and adhocracy. The former is most common among large, mature mass-production firms such as motor vehicle manufacturers and is primarily co-ordinated by the standardisation of work processes from the technostructure (Mintzberg, 1981, pp. 108-109). The latter is suitable for carrying out multidisciplinary innovation projects and is primarily co-ordinated by mutual adjustment among all of its parts but with emphasis on the collaboration of its support staff (Mintzberg, 1981, pp. 111-113). In consequence, the present research investigates co-ordination mechanisms such as standardisation of work processes and mutual adjustment since both appear as the prime co-ordination mechanisms relevant to the proposed conceptual framework (see on page 20).

A firm's efficiency forces can be assigned in large part to existing mainstream (i.e. production) capabilities and its innovation forces mainly to newstream (i.e. technological development) capabilities. According to this, a firm's production planning unit as part of its technostructure pulls to rationalise by means of standardised work processes, whereas a firm's process R&D unit as part of its support staff pulls to collaborate by means of informal communication (Pisano, 1997, pp.155-161). In order to balance these competing forces and to avoid co-ordination problems, particularly when new or significantly improved production methods need to be implemented in an already existing socio-technical transformation system, arising dependencies between activities need to be sufficiently managed (Crowston, 1997, p. 159). However, co-ordination is noticed "[...] most clearly when it is lacking" and thus the present research needs to have a sense of problems in the interaction between critical (i.e. strategically relevant) sets of activities such as production and technological development (Malone and Crowston, 1994, p. 90). In summary, the concept of co-ordination mechanisms promotes the insights into technical process innovation capability by operationalising the crucial nexus between resources, activities and (higher-order) capabilities.

2.4 PRACTICAL APPROACHES

In this section promising practical approaches such as *Engineering Design Models*, *Project Management Models* and *Process Reference Models* are examined. These approaches contain widely recognised and used industry standards which reveal insights into the adopted resource and capability architecture in its real-life context.

2.4.1 *Engineering Design Models*

Activities concerning the technological development are closely related to engineering design. For this reason, the following understanding of *design* and its linkage to innovation is adopted:

[...] design establishes and defines solutions to and pertinent structures for problems not solved before, or new solutions to problems which have previously been solved in a different way. This means that design encompasses all activities from finding a first concept to the production of hardware drawings. [...] The first phase begins with an idea and ends with concepts; it brings into existence something which had not existed before and is therefore taking place in the border area between imagination and reality. We can say this phase begins with opening the mind for a scanning of possibilities; some of these possibilities will assume forms which are first unclear, but gradually become defined. Of all the design phases, the first phase makes the highest demand on one's imagination and intuition. This reaching into the unknown and attempting to consolidate and formulate an idea can be a very heavy burden for the designer; but at the same time, it is perhaps his greatest challenge. The work performed here is truly creative and, in an almost radical sense, personal. This is the situation and condition where the unexpected, the unpredictables—the breakthroughs and inventions—are born. (Blumrich, 1970, p. 1551)

The field of design theory and methodology has yielded a considerable number of textbooks on design methodologies (Cross, 1989; Dieter, 2000; Dixon and Poli, 1995; French, 1985; Hubka and Eder, 1982; Pahl and Beitz, 1984; Pugh, 1991; Suh, 1988; Ullman, 1997; Ulrich and Eppinger, 2008). *Design methodology* as such is particularly concerned with:

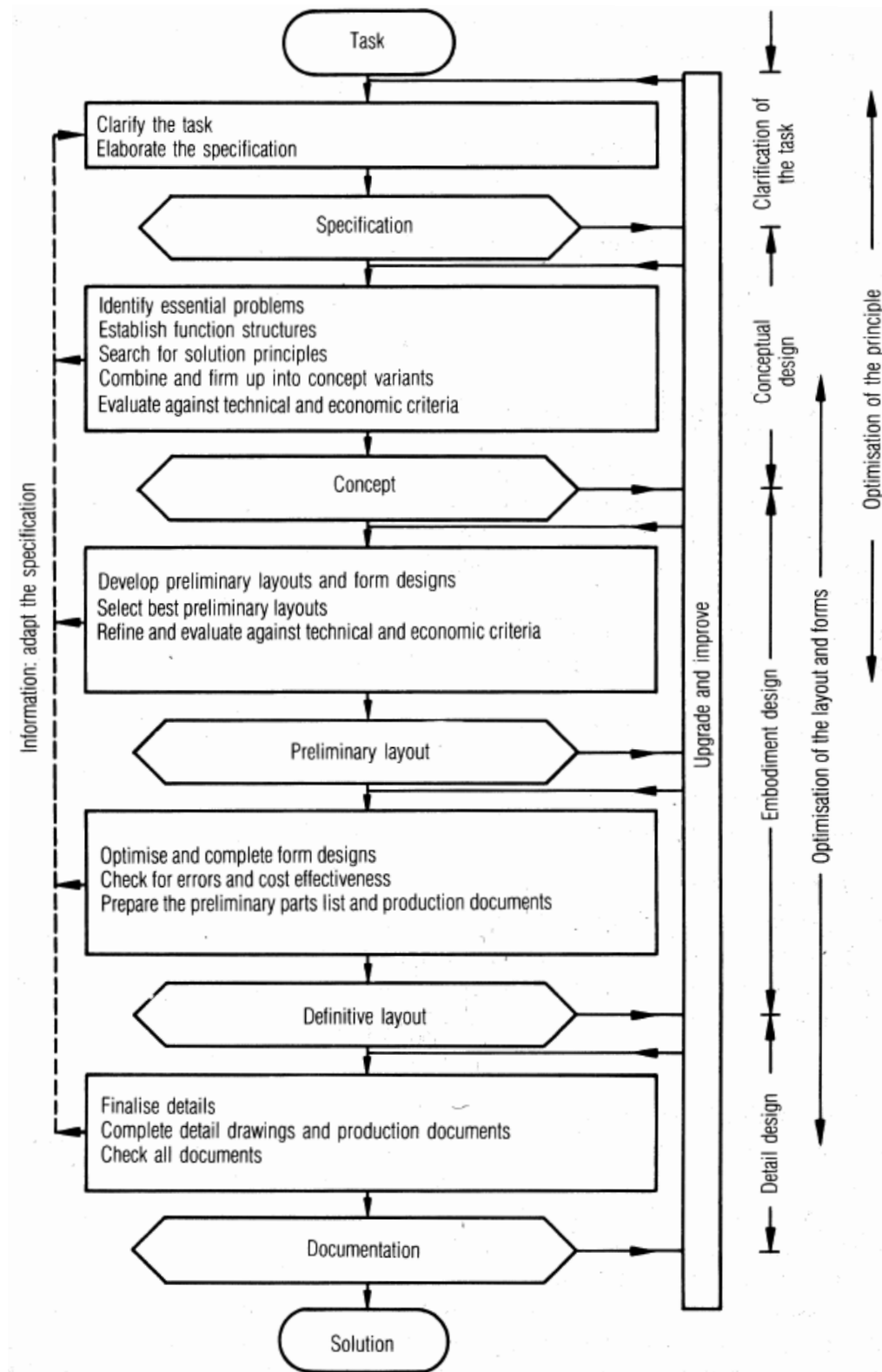
[...] the study of how designers work and think; the establishment of appropriate structures for the design process; the development and application of new design methods, techniques and procedures; and reflection on the nature and extent of design knowledge and its application to design problems. (Cross, 1984, pp. vii-viii)

A thorough review of available methods, techniques and procedures can be found in Finger and Dixon (1989a,b); Tomiyama et al. (2009). The design process includes three essential stages: (1) analysis, (2) synthesis and (3) evaluation (Asimow, 1962; Dixon, 1966; Jones, 1970). However, this abstract approach does not explain the design process in much detail and thus provides only limited guidance to practitioners (Wynn, 2007; Wynn and Clarkson, 2005). In consequence, procedural approaches which tend to be more specific in nature are seen as more useful to disaggregate the newstream (i.e. technological development) capability.

A design model is seen as an abstract but useful approximation of the real design process (Box, 1976; O'Donovan et al., 2005). One of the most well-known design models was developed by Pahl and Beitz (1977, 1984) and offers practitioners an algorithmic and systematic procedure to follow (Cross, 2000, p. 34). Their model consists of the following four phases which, in turn, involve several working steps: (1) clarification of the task, (2) conceptual design, (3) embodiment design and (4) detail design (see Figure 13). This design-focused model outlines the essential steps to proceed from problem to solution (Wynn, 2007, p. 29). However, the design process by itself needs to be considered in a firm's specific environment with all its influencing factors (Hales, 1987; Hales and Gooch, 2004). But, even so, the outlined model provides sufficient indication of the real design process.

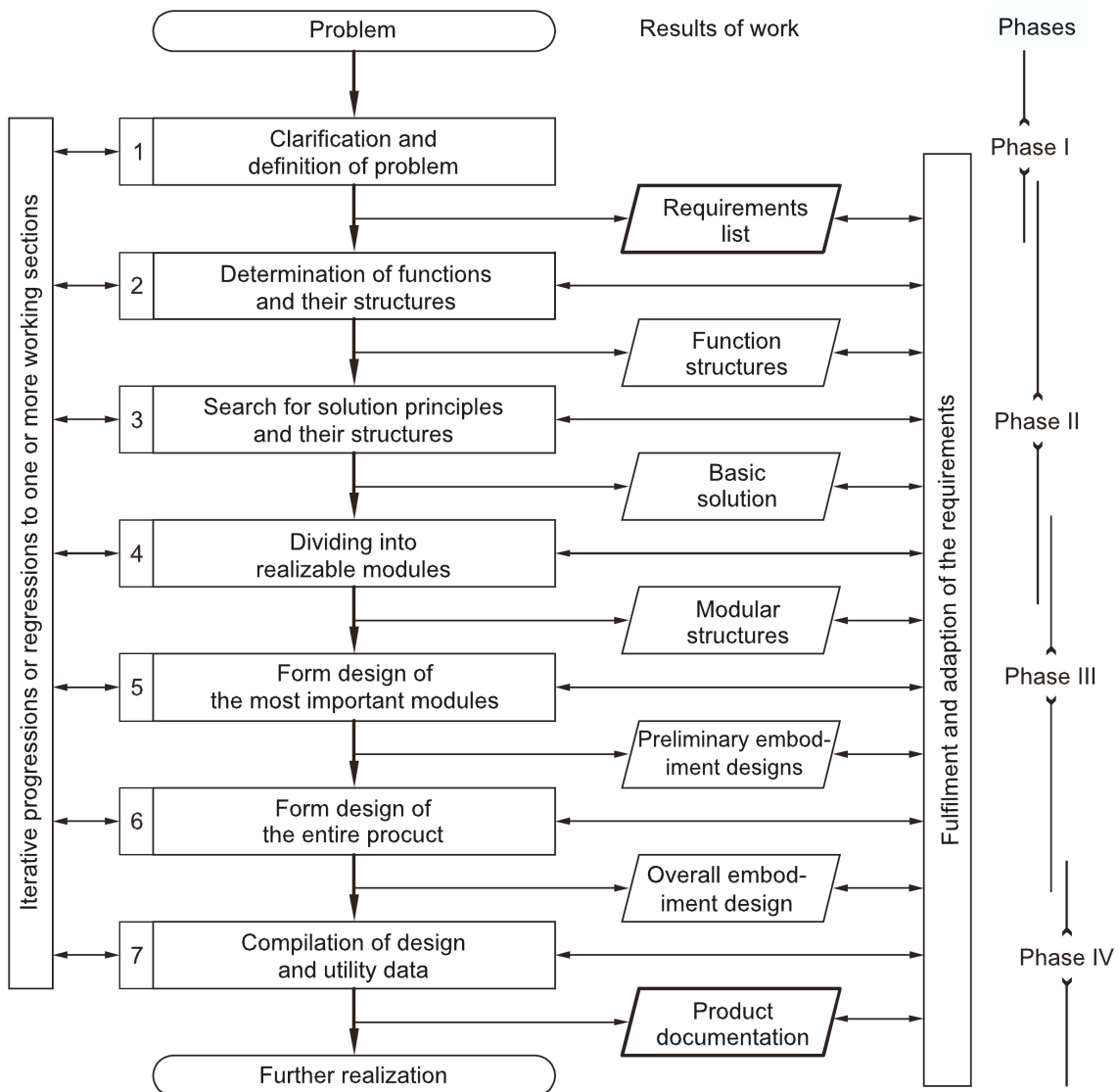
Remarkable work on design methodology study especially in the domain of *mechanical design* has been done in Germany (Cross, 2000, p. 38). This domain deals with the physical principles, the proper functioning and the production of mechanical systems (Ashby, 2005a, p. 12). Significant research efforts resulted in guidelines of the *Association of German Engineers* (Verband Deutscher Ingenieure, VDI) which represents one of the largest technical-scientific associations in Europe. For example, the design model from Pahl and Beitz (1977, 1984) clearly influenced the suggested procedure of systematic engineering design (see Figure 14). Selected guidelines with greatest relevance to the design of technical systems are VDI 2206 (2004a), VDI 2220 (1980), VDI 2221 (1993), VDI 2222 Parts 1-2 (1997; 1982), VDI 2223 (2004b) and VDI 5200 Parts 1-4 (2011). These industry-oriented guidelines are generally accepted technical rules by practitioners and thus a considerable reservoir of technological development knowledge.

Design models often provide only an incomplete description of the activities needed to put a new or significantly improved production method in operation. The difference between design and innovation models can be made clear by comparing their scopes; both models start with a stimulus (e.g. problem or idea) but the former ends usually with a detailed solution structure and its documentation for subsequent stages, whereas the latter is complete only after the innovation is carried out into practice (Blumrich, 1970; Errasti et al., 2011; Fagerberg et al., 2005; Knight, 1967; Saren, 1984). A comprehensive model which bridges this gap is formally known as *idea-to-launch* or *stage-gate* process and is built upon a sound empirical basis (Cooper, 1983, 1994, 2006, 2014; Cooper and Kleinschmidt, 1986). In his original model, Cooper (1983, p. 6) presented the following seven stages: (1) idea, (2) preliminary assessment, (3) concept, (4) development, (5) testing, (6) trial and (7) launch. While the stages 1-4 can be seen as a disaggregated design process, the stages 5-7 provide the missing link to complete an innovation—the industrialisation.



Source: Adopted from Pahl and Beitz (1984, p. 41, figure 3.3)

Figure 13: The design model according to Pahl and Beitz



Source: The English translation was adopted from VDI guideline 2223 (2004b, p. 5, figure 1); German original in VDI guideline 2221 (1993, p. 9, figure 3.3)

Figure 14: The design model according to VDI 2221

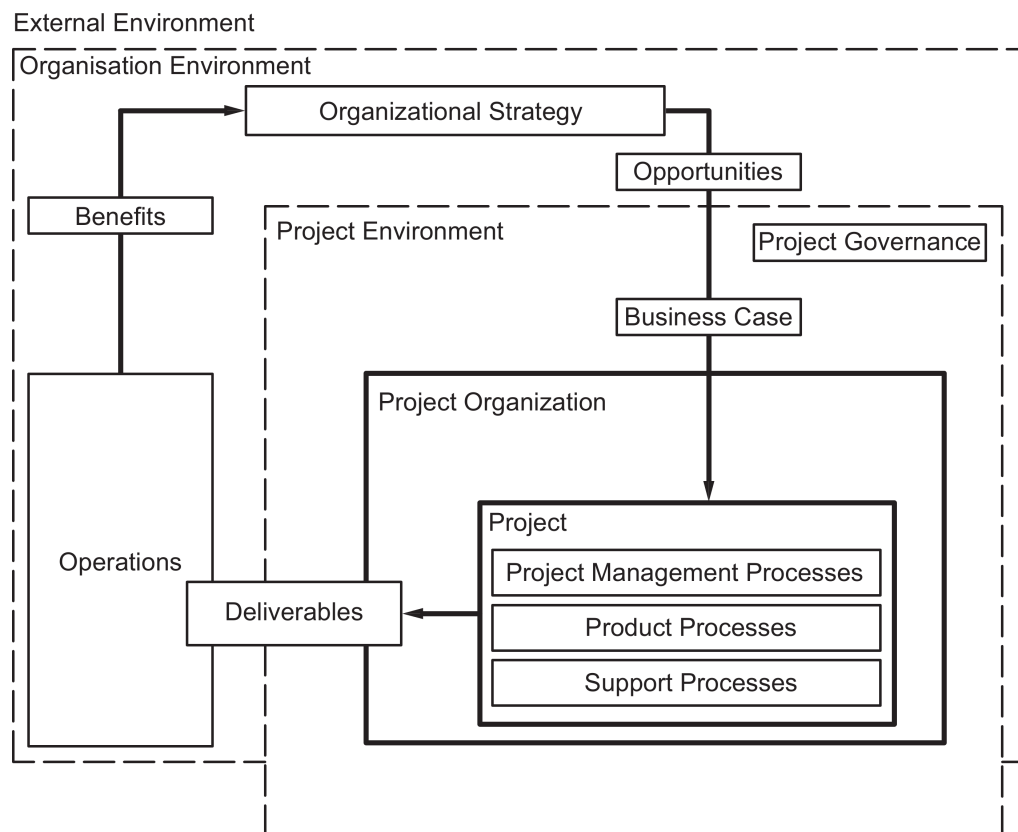
Despite promising attempts in the literature either to detail some of the stages or to cover all of them, most of the work unfortunately incorporates a strong focus on product structures or process engineering rather than technical processes (Austin et al., 2001; Blass, 1997; Dietz and Neumann, 2000; Fairlie-Clarke and Muller, 2003; Lager, 2011; Li, 2009; Macmillan et al., 2001; Shahidipour et al., 2000). In summary, engineering design models describe a multiple-stage process beginning with a stimulus for innovation (e. g. problem or idea), detailing necessary working steps and ending with an innovation introduced into practice.

2.4.2 Project Management Models

Projects are often seen as the means to accomplish strategic objectives (see Figure 15). The International Organization for Standardization (ISO) compiled several national project management standards—for example, ANSI/PMI 99-001-2013 as the American ANSI standard, BS ISO 15188 (2001) and BS 6079 (2010) as the English BSI standard and DIN 69901 as the German DIN standard—and published the international standard ISO 21500, *Guidance on Project Management*. Subsequently, ISO 21500 was adopted by national standards bodies as their top-level project management standard (BSI, 2012; DIN, 2012). For this reason, the common understanding of a project is as follows:

A project consists of a unique set of processes consisting of coordinated and controlled activities with start and end dates, performed to achieve project objectives. Achievement of the project objectives requires the provision of deliverables conforming to specific requirements. A project may be subject to multiple constraints [...]. (BSI, 2012, p. 3)

As a result, managing projects in order to achieve strategic objectives relies heavily on the managerial activity of co-ordination—the crucial nexus between resources, activities and (higher-order) capabilities.



Note: Boxes represent project management concepts, arrows represent a logical flow by which the concepts are connected and dotted lines represent organisational boundaries.

Source: Adopted from BSI (2012, p. 3, figure 1)

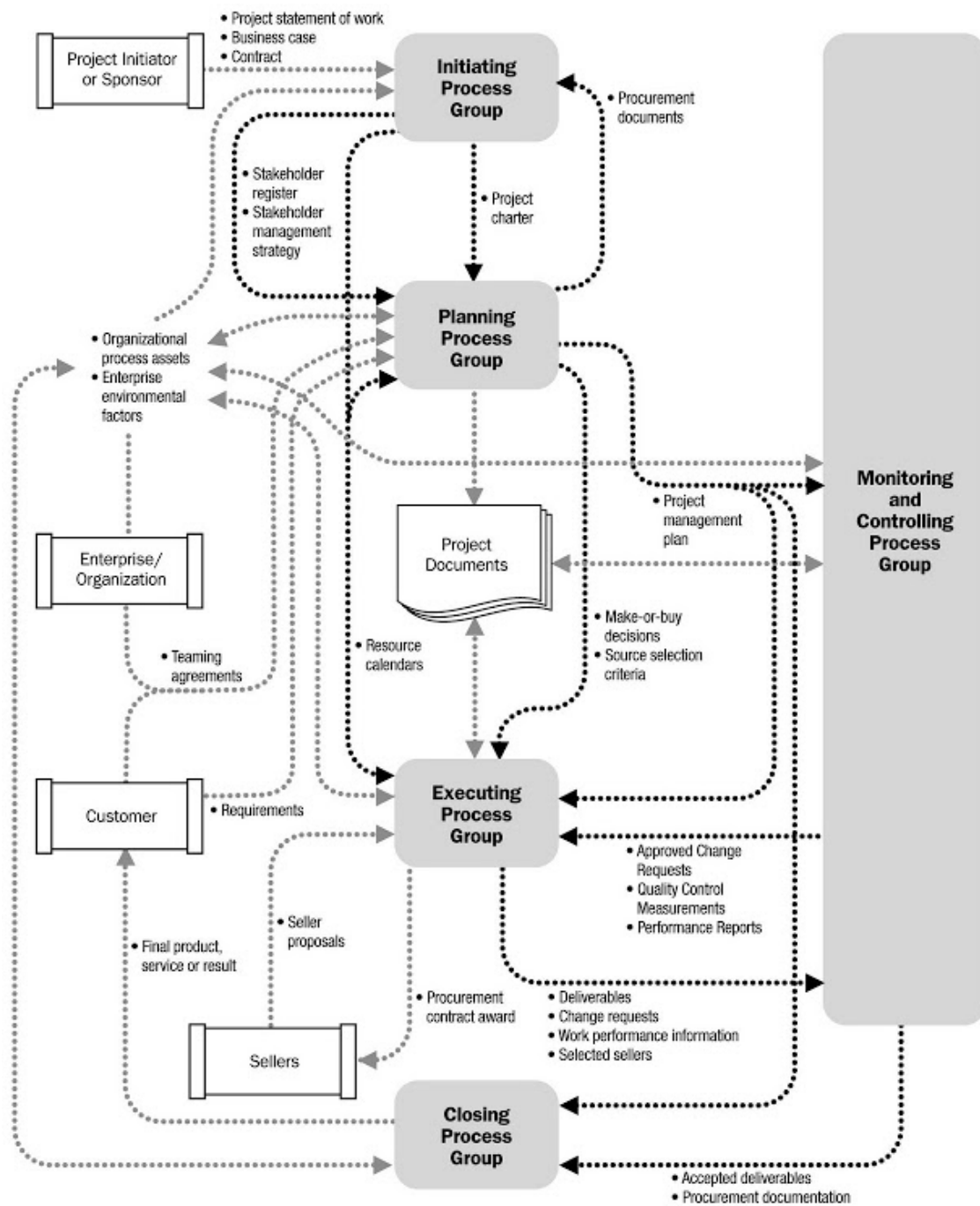
Figure 15: The project management concepts and their relationships

Project management processes which are independent of application areas or industry focus are required to drive a project to completion (BSI, 2012; PMI, 2013). This set of processes can be clustered into five process groups: (1) initiating processes, (2) planning processes, (3) executing processes, (4) monitoring and controlling processes and (5) closing processes (PMI, 2013, pp. 52-58). However, the five process groups have strong interrelationships (see Figure 16). *Organisational Process Assets* (OPAs) and *Enterprise Environmental Factors* (EEFs) link all process groups (i. e. the project environment) with the organisation environment. These assets and factors are defined as follows:

Organizational process assets are the plans, processes, policies, procedures, and knowledge bases specific to and used by the performing organization. They include any artifact, or knowledge from any or all of the organizations involved in the project that can be used to perform or govern the project. The process assets also include the organization's knowledge bases such as lessons learned and historical information. Organizational process assets may include completed schedules, risk data, and earned value data. Organizational process assets are inputs to most planning processes. Throughout the project, the project team members may update and add to the organizational process assets as necessary. Organizational process assets may be grouped into two categories: (1) processes and procedures, and (2) corporate knowledge base. (PMI, 2013, p. 27)

Enterprise environmental factors refer to conditions, not under the control of the project team, that influence, constrain, or direct the project. Enterprise environmental factors are considered inputs to most planning processes, may enhance or constrain project management options, and may have a positive or negative influence on the outcome. (PMI, 2013, p. 29)

In summary, project management models emphasise the required co-ordination of organisational process assets and enterprise environmental factors in a multiple-stage process to achieve the project objectives and thus to provide measurable benefits for an organisation.



Note: The darker dotted lines represent relationships between Process Groups; the lighter dotted lines are external to the Process Groups.

Source: Adopted from PMI (2013, p. 53, figure 3.3)

Figure 16: The interactions among the project management process groups

2.4.3 Process Reference Models

This subsection details two distinct process reference models: (1) *Manufacturing and Technology Readiness Levels* and (2) *Capability Maturity Model Integration for Development*.

Manufacturing and Technology Readiness Levels

The United States Department of Defense (DoD) as well as the National Aeronautics and Space Administration (NASA) offer reference models based on systems engineering (SE) in order to assess risks prior to production and uncertainties of new technological advances (DoD, 2007, 2012; NASA, 1995, 2007). These *Manufacturing Readiness Levels* (MRLs) and *Technology Readiness Levels* (TRLs) are defined as follows:

Manufacturing Readiness Levels (MRLs) are designed to be measures used to assess the maturity of a given technology from a manufacturing prospective. The purpose of MRLs [is] to provide decision makers (at all levels) with a common understanding of the relative maturity (and attendant risks) associated with manufacturing technologies, products, and processes being considered to meet DoD requirements. (DoD, 2007, p. 1.7)

TRL is, at its most basic, a description of the performance history of a given system, subsystem, or component relative to a set of levels first described at NASA HQ in the 1980s. The TRL essentially describes the state of the art of a given technology and provides a baseline from which maturity is gauged and advancement defined. (NASA, 2007, p. 296)

These readiness levels provide a scale for practitioners to determine manufacturing/technological maturity in the course of innovation projects (see Table 8). Supplementary risk areas (i.e. threads and subthreads) elaborated for each manufacturing readiness level support the development of risk mitigation plans and actions in order to achieve project objectives (DoD, 2012; GAO, 2010). Overall, this distinct stage-gate orientation enables a promising refinement of Cooper's (1983, p. 6) original idea-to-launch process to incorporate the needed focus on technical processes.

In general, technical process innovation projects "[...] start with the recognition of a need or the discovery of an opportunity and proceed through various stages of development to a final disposition" (NASA, 2007, p. 19). During a project, two noticeable categories are used to assign manufacturing/technology readiness levels: (1) scale of demonstration units and (2) locus of experimentation. The former can be further subdivided into 2-D (flat) models, non-functional 3-D models, functional prototypes, user test models and organisation/system models (Leonard-Barton, 1991, p. 62). The latter can be further subdivided into process R&D laboratory, pilot plant located at R&D site, pilot plant located at production site and full-scale commercial factory (Pisano, 1997, p. 43). Both subdivisions mirror an increasing representativeness of the final disposition. Moreover, the locus of experimentation can also be used to appropriately match manufacturing readiness levels with the concept of absorptive capacity (i.e. exploratory learning, transformative learning and exploitative learning) and the recursive nature of

technical systems (i. e. technology, technical process and transformation system). For example, MRL 1 is seen as equivalent to a *technical process innovation stimulus*, MRL 2-4 detail the learning routine *explore manufacturing technologies* in a laboratory environment, MRL 5-7 detail the learning routine *transform manufacturing processes* in a production relevant/representative environment which exemplifies the 'transmission belt' between technology and transformation system and MRL 8-10 detail the learning routine *exploit manufacturing systems* in a pilot/serial line environment ending with an *implemented technical process innovation*. In summary, MRLs are useful means to delineate technical process innovation projects employed by R&D and production departments.

Table 8: The manufacturing and technology readiness levels

<i>Definition (DoD)</i>	<i>MRL</i>	<i>TRL</i>	<i>Definition (NASA)</i>
Basic manufacturing implications identified	1	1	Basic principles observed and reported
Manufacturing concepts identified	2	2	Technology concept and/or application formulated
Manufacturing proof of concept developed	3	3	Analytical and experimental critical function and/or characteristic proof of concept
Capability to produce the technology in a laboratory environment	4	4	Component and/or breadboard validation in laboratory environment
Capability to produce prototype components in a production relevant environment	5	5	Component and/or breadboard validation in relevant environment
Capability to produce a prototype system or subsystem in a production relevant environment	6	6*	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
Capability to produce systems, subsystems or components in a production representative environment	7	7	System prototype demonstration in a target/space environment
Pilot line capability demonstrated; ready to begin low rate initial production	8	7	[see above]
Low rate production demonstrated; capability in place to begin full rate production	9	8	Actual system completed and “flight qualified” through test and demonstration (ground or flight)
Full rate production demonstrated and lean production practices in place	10	9	Actual system “flight proven” through successful mission operations

Note: * TRL of 6 is required for a technology to be integrated into a SE process.

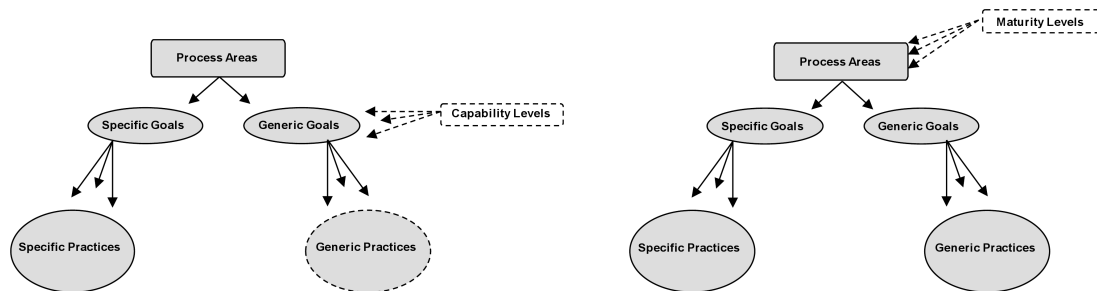
Source: Compiled from DoD (2012, pp. 2.2-2.5, 3.2) and NASA (2007, pp. 277, 296)

Capability Maturity Model Integration for Development

The *Capability Maturity Model Integration for Development*, in short CMMI-DEV, suggested by the Software Engineering Institute (SEI) at Carnegie Mellon University provides guidance for practitioners to improve processes in a development environment (SEI, 2010, p. ii, preface). The model's architecture consists of process areas, generic/specific goals and generic/specific practices which can be used for two different improvement paths as follows:

The differences between the structures are subtle but significant. The staged representation uses maturity levels to characterize the overall state of the organization's processes relative to the model as a whole, whereas the continuous representation uses capability levels to characterize the state of the organization's processes relative to an individual process area. (SEI, 2010, p. 22)

Drawing on the continuous representation of the architecture (see Figure 17 on the left), defined consecutive *capability levels* illustrate characteristics that must be present to achieve each level (see Table 9). This consecutive nature of capability levels requires an increasing routinisation of activities. Therefore, arising dependencies between mainstream (i.e. production) capabilities and newstream (i.e. technological development) capabilities must be sufficiently managed. In consequence, CMMI-DEV offers a collection of best practices enabling in particular the needed co-ordination in a development environment.



Source: Adopted from SEI (2010, p. 22, figure 3.1)

Figure 17: The two different improvement paths

The notion of process *institutionalisation*—refining Mintzberg's (1979b; 1995) co-ordination mechanisms of standardisation—plays a key role to routinise activities in the process of capability building. Its core is understood as follows:

[...] institutionalization implies that the process is ingrained in the way the work is performed and there is commitment and consistency to performing (i.e., executing) the process. An institutionalized process is more likely to be retained during times of stress. When the requirements and objectives for the process change, however, the implementation of the process may also need to change to ensure that it remains effective. (SEI, 2010, p. 65)

Table 9: The consecutive capability levels

<i>Capability Level</i>	<i>Definition</i>
Incomplete (Level 0)	An incomplete process is a process that either is not performed or is partially performed. One or more of the specific goals of the process area are not satisfied and no generic goals exist for this level since there is no reason to institutionalize a partially performed process.
Performed (Level 1)	A performed process is a process that accomplishes the needed work to produce work products; the specific goals of the process area are satisfied. [...] The application of institutionalization (the CMMI generic practices at capability levels 2 and 3) helps to ensure that improvements are maintained.
Managed (Level 2)	A managed process is a performed process that is planned and executed in accordance with policy; employs skilled people having adequate resources to produce controlled outputs; involves relevant stakeholders; is monitored, controlled, and reviewed; and is evaluated for adherence to its process description. The process discipline reflected by capability level 2 helps to ensure that existing practices are retained during times of stress.
Defined (Level 3)	A defined process is a managed process that is tailored from the organization's set of standard processes according to the organization's tailoring guidelines; has a maintained process description; and contributes process related experiences to the organizational process assets. [...] A defined process clearly states the purpose, inputs, entry criteria, activities, roles, measures, verification steps, outputs, and exit criteria. At capability level 3, processes are managed more proactively using an understanding of the interrelationships of the process activities and detailed measures of the process and its work products.

Source: Compiled from SEI (2010, pp. 24-25)

Generic goals embody the degree of institutionalisation and, applied sequentially and in order, describe the progression of process institutionalisation from a performed process over a managed process to a defined process (SEI, 2010, pp. 65-68). Focusing on capability levels 2 and 3, the associated generic goals are then to institutionalise a managed process and to institutionalise a defined process (SEI, 2010, pp. 69, 115). These generic goals can be achieved by generic/specific practices which exemplify in the context of the present research approved co-ordination mechanisms (see Table 10). In summary, CMMI-DEV supports a firm's effort to build and maintain its technical process innovation capability by specifying relevant co-ordination mechanisms needed to institutionalise knowledge and skills of technical process innovation projects.

Table 10: The co-ordination mechanisms for capability levels 2 and 3

	<i>Description</i>
<p><i>Generic Practices for Capability Level 2</i></p>	<ul style="list-style-type: none"> • Establish and maintain an organizational policy for planning and performing the process • Establish and maintain the plan for performing the process • Provide adequate resources for performing the process, developing the work products, and providing the services of the process • Assign responsibility and authority for performing the process, developing the work products, and providing the services of the process • Train the people performing or supporting the process as needed • Place selected work products of the process under appropriate levels of control • Identify and involve the relevant stakeholders of the process as planned • Monitor and control the process against the plan for performing the process and take appropriate corrective action • Objectively evaluate adherence of the process and selected work products against process descriptions, standards, and procedures, and address noncompliance • Review the activities, status, and results of the process with higher level management and resolve issues
<p><i>Specific Practices for Capability Level 3</i></p>	<ul style="list-style-type: none"> • Establish and maintain descriptions of lifecycle models approved for use in the organization • Establish and maintain the project's defined process from project startup through the life of the project • Establish and maintain tailoring criteria and guidelines for the organization's set of standard processes • Establish and maintain the organization's set of standard processes • Establish and maintain work environment standards • Establish and maintain organizational rules and guidelines for the structure, formation, and operation of teams • Establish and maintain the organization's measurement repository • Establish and maintain the organization's process asset library • Contribute process related experiences to organizational process assets • Incorporate process related experiences derived from planning and performing the process into organizational process assets

Source: Compiled from SEI (2010, pp. 69-114, 122-124, 159, 169, 192-201, 213)

2.5 SUMMARY

This literature review has focused on positioning the research itself and illuminating the foundations upon which the present research is based by investigating the following three subjects in more detail: (1) relevant *Categorical Taxonomies*, (2) substantial *Theoretical Foundations* and (3) promising *Practical Approaches*. The central research phenomenon—*technical process innovation capability*—was defined and mapped into a conceptual framework which graphically explains the key factors to be investigated and their role in the broader context of competitive advantage. These building blocks, namely resources, activities and capabilities, are linked through co-ordination and grounded in the domain of strategic management. A promising environment to study the addressed research phenomenon is seen in the automotive industry which is well-established for case study-based fieldwork in organisations. In consequence, the present research attempts to answer the following major research question: *In what way does a world leading motor vehicle manufacturer build and maintain its technical process innovation capability?*

In order to answer this major research question, profound understanding of innovative manufacturers is needed. Adopting an intra-organisational perspective, strategically relevant resources such as technological development knowledge and production skills can be reconfigured through the application of learning routines. In the context of the present research, the following three top-level learning routines are of particular interest: (1) explore manufacturing technologies, (2) transform manufacturing processes and (3) exploit manufacturing systems. These routines, employed by R&D and production departments, start with a stimulus for innovation (e. g. problem or idea) and proceed through various stages of design and industrialisation to an innovation introduced into practice. To carry out a new or significantly improved production method, dependencies between mainstream (i. e. production) capabilities and newstream (i. e. technological development) capabilities must be sufficiently managed. Last, but by no means least, co-ordination mechanisms are needed to hold all parts together and to institutionalise associated knowledge and skills of technical process innovation projects. In conclusion, the present research investigates the three top-level learning routines in depth and aims to provide a detailed account for building and maintaining a technical process innovation capability.

METHODOLOGY

*Hypotheses non fingo.
I do not feign hypotheses.*

—Isaac Newton

Principia Mathematica (1713 ed.) 'Scholium Generale'
(Knowles, 1999, p. 543, no. 8)

THE MAIN OBJECTIVE OF THIS METHODOLOGY CHAPTER IS TO DESCRIBE HOW THE PRESENT RESEARCH WAS DONE AND WHAT ASSUMPTIONS AND DECISIONS WERE INVOLVED.

3.1 OVERVIEW

This methodology chapter describes the proposed design of the present research and the underlying rationale of inherent methodological choices (Azevedo et al., 2011; Blaikie, 2010; Kallet, 2004). In order to accomplish these major tasks, the following three subjects are outlined in more detail: (1) *Preliminary Considerations*, (2) *Data Gathering* and (3) *Data Analysis*. According to the first, the author's philosophical assumptions are considered which influence the logic of enquiry in seeking answers to the stated set of research questions. The second expands in more detail how the required data were obtained and processed. Finally, the third describes the interwoven processes to 'generate meaning'. Thus, the chapter provides the essential information by which the quality and authenticity of the present research can be judged.

3.2 PRELIMINARY CONSIDERATIONS

This section considers the author's basic perceptions of *Research Philosophy*, *Research Paradigm* and *Research Strategy* which have greatest relevance to the proposed research design. Their underlying assumptions predetermine and direct the logic of enquiry in seeking answers to the stated set of research questions (Blaikie, 2010; Guba, 1990; Robson, 2011).

3.2.1 Research Philosophy

Research philosophy is centred on a critical examination of the social sciences: their logics, methods and results (Little, 1999; Sklar, 1999). In general, researchers should be clear about their *intellectual puzzle*—the essence of their enquiry—which encapsulates ontologically meaningful and epistemologically workable or explainable positions (Mason, 2002, pp. 13, 18). For this reason, *Ontological Assumptions* and *Epistemological Assumptions* shall be considered in more detail. These assumptions are about the nature of social reality and existence and the best ways in which we can come to know that reality (Blaikie, 2010, p. 9). However, it is to emphasise that the adopted “[..] philosophical assumptions about ontology and epistemology are always contentious and debatable, because that is all they are—assumptions” (Gill et al., 2010, p. 201). Nevertheless, their particular combination influences the adopted research paradigm.

Ontological Assumptions

Ontology derived from Greek ὄντως (*ontōs*) meaning “being” and λόγος (*logos*) meaning “reason”—also referred to as *metaphysics*—is most generally concerned with the philosophical investigation of the nature, constitution and structure of social reality and existence (Butchvarov, 1999, p. 563). The ontological position can be located on a spectrum between realism (i. e. materialism—there are only material entities) at one end and nominalism (i. e. idealism—there are only mental entities) at the other end (Butchvarov, 1999; Easterby-Smith et al., 2012). Simply put, ontology describes “[...] our ‘official’ philosophical inventory of things that are” (Loux, 1998, p. 15). Underlying assumptions cover aspects such as truth and facts (see Table 11). In conclusion, a researcher’s philosophical viewpoint regarding the nature of the central research phenomenon needs to be placed on the ontological spectrum.

Table 11: The ontological spectrum

	<i>Ontological Position</i>			
	<i>Realism</i>	<i>Internal Realism</i>	<i>Relativism</i>	<i>Nominalism</i>
<i>Truth</i>	Single truth	Truth exists, but is obscure	There are many ‘truths’	There is no truth
<i>Facts</i>	Facts exist and can be revealed	Facts are concrete, but cannot be accessed directly	Facts depend on viewpoint of observer	Facts are all human creations

Source: Adapted from Easterby-Smith et al. (2012, p. 19, table 2.2)

The central research phenomenon—*technical process innovation capability*—was operationally defined in the previous chapter (see on page 20) to enable concrete observations in the course of this study (Denzin, 1970, pp. 40-41). Observable entities in the context of the present research are composed of material and mental entities which are largely embodied in the adopted resource and capability architecture. For example, material entities are tangible assets such as machinery or engineering artefacts and physical project deliverables such as new or significantly improved production methods implemented in a socio-technical transformation system. Whereas learning routines which explore, transform and exploit knowledge and skills are primarily concerned with the behaviour of people rather than with inanimate objects and thus reflect to a certain extent mental entities. For this reason, the present research takes a compromise position between realism and relativism what might be termed *transcendental realism* assuming that “[...] the ultimate objects of scientific inquiry exist and act (for the most part) quite independently of scientists and their activity” (Bhaskar, 2011, p. 12). Moreover, the author sympathises with Robson’s (2011, p. 38) suggestion of “[...] pragmatically selecting ideas and terminology from different realist approaches which appears likely to be useful for the real world researcher”. In summary, the investigation of technical process innovation capability is influenced by the author’s *objectivist* ontological stance.

Epistemological Assumptions

Epistemology derived from Greek ἐπιστήμη (*epistēmē*) meaning “knowledge” and λόγος (*logos*) meaning “reason” is “[...] the study of the nature of knowledge and justification; specifically, the study of (a) the defining features, (b) the substantive conditions or sources, and (c) the limits of knowledge and justification” (Moser, 1999, p. 273). In other words:

Epistemology, or the theory of knowledge, is concerned with how we know what we do, what justifies us in believing what we do, and what standards of evidence we should use in seeking truths about the world and human experience. Audi (1998, back cover blurb)

An ongoing debate among philosophers is centred on whether the principles, procedures and ethos established in the natural sciences are appropriate to study social research phenomena (Bryman, 2012, p. 27). Therefore, the epistemological position can be located on a spectrum between positivism at one end and interpretivism at the other end (Easterby-Smith et al., 2012; Taylor and Bogdan, 1998; Willis, 2007). Underlying assumptions cover methodological implications (see Table 12). In conclusion, a researcher’s philosophical viewpoint regarding the nature of knowledge and how knowledge can be demonstrated needs to be placed on the epistemological spectrum.

Table 12: The epistemological spectrum

	<i>Epistemological Position</i>			
	<i>Strong Positivism</i>	<i>Weak Positivism</i>	<i>Weak Interpretivism</i>	<i>Strong Interpretivism</i>
<i>Aim</i>	Discovery	Exposure	Convergence	Invention
<i>Start</i>	Hypotheses	Propositions	Questions	Critique
<i>Design</i>	Experiment	Large surveys; multi-cases	Cases and surveys	Engagement and reflexivity
<i>Data Type</i>	Numbers and facts	Numbers and words	Words and numbers	Discourse and experiences
<i>Analysis/ Interpretation</i>	Verification/ falsification	Correlation and regression	Triangulation and comparison	Sense-making; understanding
<i>Outcome</i>	Confirmation of theories	Theory testing and generation	Theory generation	New insights and actions

Source: Adapted from [Easterby-Smith et al. \(2012, p. 25, table 2.5\)](#)

A firm's technical process innovation capability can be investigated through the following three top-level learning routines: (1) explore manufacturing technologies, (2) transform manufacturing processes and (3) exploit manufacturing systems. These social processes involve, for example, knowledge components such as procedural and meta-cognitive knowledge and the application of knowledge creation modes which reveal that "[...] knowledge is a social and historical product and that 'facts' come to us laden with theory" ([Miles et al., 2014, p. 7](#)). Due to the social complexity of building and maintaining a technical process innovation capability, it is assumed that triangulating multiple sources of evidence which include the experiences of people involved in technical process innovation projects and describing them in sufficient detail are appropriate means to contribute to theory generation. For this reason, the present research draws on the position of *weak interpretivism* which is close to the centre of the spectrum but with blurred lines in both directions. In summary, the investigation of technical process innovation capability is influenced by the author's *subjectivist* epistemological stance.

3.2.2 Research Paradigm

The ontological and epistemological assumptions outlined above influence the adopted research paradigm and result in a basic set of beliefs which directs a researcher's enquiry ([Blaikie, 2010; Guba, 1990](#)). According to [Guba \(1990, p. 18, emphasis in original\)](#), a research paradigm "[...] cannot be proven or disproven in any foundational sense; if that were possible there would be no doubt about how to practice inquiry". Moreover, few researchers will fit accurately into the compartments of any given paradigm classification ([Hood, 2006, p. 215](#)).

In the context of the present research and regarding the underlying combination of the objectivist ontological and subjectivist epistemological point of view, the author labels himself *pragmatic realist*. The basic consideration of a pragmatic stance emphasises the relation of theory to praxis and acknowledges the concrete experiences of people gained from direct action as the starting point for observations and reflections (Kolb et al., 1979; Seigfried, 1999). This philosophy was coined, among others, by the American philosophers Charles Sanders Peirce (1839^{*}-1914[†]), William James (1842^{*}-1910[†]) and John Dewey (1859^{*}-1952[†]). The essence of pragmatism and the appropriateness for the present research can be summarised as follows:

The key point is that any meaning structures must come from the lived experience of individuals. [...] Pragmatism is a valuable perspective in management research because it focuses on processes that are particularly relevant to studies of knowledge and learning [...]. (Easterby-Smith et al., 2012, p. 32)

The central idea is that the meaning of a concept consists of its practical implications. Hence, truth is simply defined as 'what works'. In relation to research, a pragmatist would advocate using whatever philosophical or methodological approach works best for the particular research problem at issue. (Robson, 2011, p. 28)

[...] the researcher should adopt an *opportunistic* approach to fieldwork in organizations. Fieldwork is permeated with the conflict between what is theoretically desirable on the one hand and what is practically possible on the other. (Buchanan et al., 1988, p. 53, emphasis in original)

A critical discussion regarding general characteristics and shortcomings of pragmatism is beyond the scope here; however, a comprehensive list for consideration can be found in Johnson and Onwuegbuzie (2004, pp. 18-19, tables 1-2). In summary, the adopted *pragmatic realist* paradigm does not only bias the author but also influences the choice of the research strategy in seeking answers to the stated set of research questions.

3.2.3 Research Strategy

The research strategy refers to the logic of enquiry in seeking answers to the stated set of research questions (Robson, 2011, p. 43). According to Blaikie (2007, 2010), the following four research strategies can be distinguished: (1) inductive, (2) deductive, (3) retroductive and (4) abductive. The underlying aims and steps of these strategies provide guidance for choosing an appropriate logic of enquiry (see Table 13). In order to select the research strategy, it is necessary to reiterate the research purpose of this case study-based dissertation—which is to *explore* and *describe* in what way the technical process innovation capability is built and maintained by R&D and production departments at a world leading motor vehicle manufacturer—and to match it with the aims of the four research strategies.

Table 13: The logic of four research strategies

	<i>Inductive</i>	<i>Deductive</i>	<i>Retroductive</i>	<i>Abductive</i>
<i>Aim</i>	To establish descriptions of characteristics and patterns	To test theories, to eliminate false ones and corroborate the survivor	To discover underlying mechanisms to explain observed regularities	To describe and understand social life in terms of social actors' meanings and motives
<i>Start</i>	Collect data on characteristics and/or patterns Produce descriptions	Identify a regularity that needs to be explained Construct a theory and deduce hypotheses	Document and model a regularity and motives Describe the context and possible mechanisms	Discover everyday lay concepts, meanings Produce a technical account from lay accounts
<i>Finish</i>	Relate these to the research questions	Test hypotheses by matching them with data explanation in that context	Establish which mechanism(s) provide(s) the best	Develop a theory and elaborate it iteratively

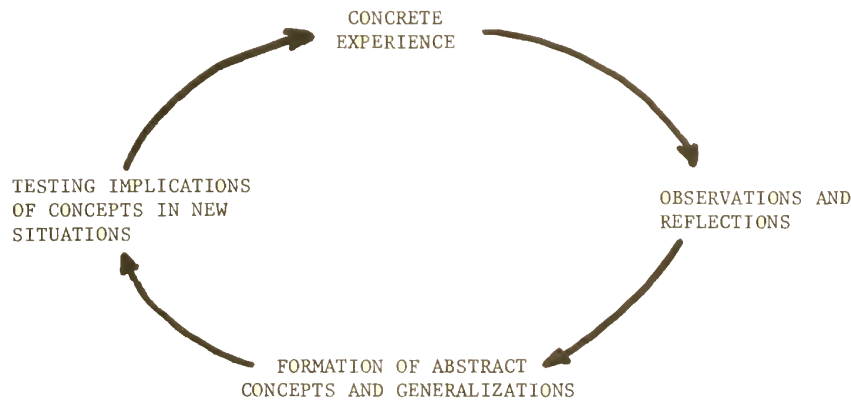
Source: Adapted (extracted) from [Blaikie \(2010, p. 84, table 4.1\)](#)

Drawing on [Handfield and Melnyk \(1998, pp. 324-425, table 1\)](#), the research purpose of exploration and description through case studies is clearly linked to the inductive generation of theory. A critical discourse on the justification of induction itself can be found in [Harrod \(1956\)](#); [Swinburne \(1974\)](#). In consequence, the present study draws on the *inductive* research strategy in seeking answers to the stated set of research questions.

In the broadest sense, induction means “[...] the inference from particular to general” ([Cohen, 2005, p. 432](#)). The following definition does not only outline the rationale of induction in more detail but also exemplifies its consistency with the adopted ontological and epistemological assumptions:

Induction is a reasoning process through which theory is generated out of specific instances of observation and experience. So inductive reasoning entails making general inferences about a phenomenon through the observation of particular instances of the phenomenon. ([Johnson and Duberley, 2000, p. 16, box 2.3](#))

This reasoning process is largely compatible with the theory of learning within organisations which was significantly influenced by pragmatism ([Easterby-Smith et al., 2012, p. 32](#)). For example, the inductive logic of enquiry can be matched with the right half of [Kolb's](#) experiential learning cycle which illustrates how individuals and organisations learn (see Figure 18).



Source: Adopted from Kolb (1973, p. 2, figure 1)

Figure 18: The experiential learning cycle

Adapted to the present research, the starting-point of the enquiry will be to collect data on concrete experiences of people involved in technical process innovation projects, followed by reflecting on these experiences from various perspectives and producing a detailed account for building and maintaining a technical process innovation capability and the enquiry finishes with relating this abstract conceptualisation with (limited) generalisations to the stated set of research questions. In summary, the present research applies the *inductive* research strategy in seeking answers to the stated set of *what*-type research questions and to accomplish the overall research purpose of *exploration* and *description* (see Table 14).

Table 14: The links between research purpose, strategy and question

Research Purpose	Research Strategy				Research Question
	Inductive	Deductive	Retroductive	Abductive	
Exploration	***			***	What
Description	***			***	What
Explanation	*	***	***		Why
Prediction	**	***			What
Understanding				***	Why
Change		*	**	**	How
Evaluation	**	**	**	**	What and Why
Assess impacts	**	**	**	**	What and Why

Note: *** major activity; ** moderate activity; * minor activity. These 'weightings' of the links between objectives and research strategies are indicative only.

Source: Adapted from Blaikie (2010, p. 105, table 4.2)

3.3 DATA GATHERING

According to Nandhakumar and Jones (1997, p. 110), “[t]he term ‘data-gathering’ is used for convenience—some research traditions would suggest that data are created through the research process rather than existing independently of it”. This section is centred on questions of where do the data come from and how to select and collect them (Blaikie, 2010, p. 159). For this reason, core elements of the proposed research design such as *Sources of Data*, *Selection of Data* and *Collection of Data* are expanded in more detail.

3.3.1 *Sources of Data*

In this subsection *Case Research* and the *Design of Case Study* are thoroughly explained. The former justifies the method-of-choice to investigate the central research phenomenon in its natural setting, while the latter determines the unit of analysis.

Case Research

It is widely acknowledged that *case research* is appropriate when existing theory does not sufficiently explain the research phenomenon under consideration and the research purpose clearly devotes effort to theory generation (Barratt et al., 2011; Benbasat et al., 1987; Eisenhardt and Graebner, 2007; Handfield and Melnyk, 1998; Meredith, 1998; Voss et al., 2002; Yin, 2009). Moreover, case research is preferred when investigating a contemporary research phenomenon in depth and within its real-life context without any control or manipulation of its behaviour by the researcher (Yin, 2009, pp. 11, 18). Framed by substantial theoretical foundations and relevant practical approaches, the present research addresses the call of two recent systematic literature reviews for further research on the strategic management of process innovations (Frishammar et al., 2012; Keupp et al., 2012). For this reason, technical process innovation capability is studied intensively within an organisation—the phenomenon’s natural setting. In consequence, case research is the method-of-choice in order to select suitable units for study (Blaikie, 2010, p. 159).

Depending on which epistemological stance is taken, case research can be conducted in various ways. The literature distinguishes broadly between three different schools of thought (see Table 15). According to the adopted pragmatic realist paradigm, the present research draws primarily on the school of thought coined by Eisenhardt (1989); Eisenhardt and Graebner (2007) with influences from positivism and interpretivism. For example, the well defined focus including prior instrumentation which is often needed to obtain the participation of an organisation and its members in case research is guided by positivism (Darke et al., 1998, pp. 281-284). On the other hand, the rich picture of the three top-level learning routines (i.e. explore manufacturing technologies, trans-

Table 15: The different schools of thought in case research

	<i>Positivism</i>	<i>Positivism and Interpretivism</i>	<i>Interpretivism</i>
<i>Advocate</i>	Yin (1989)	Eisenhardt (1989)	Stake (1995)
<i>Design</i>	Prior	Flexible	Emergent
<i>Sample</i>	Up to 30	4-10	1 or more
<i>Analysis</i>	Cross-case	Both	Within-case
<i>Theory</i>	Testing	Generation	Action

Source: Adapted from Easterby-Smith et al. (2012, p. 57, table 3.1)

form manufacturing processes and exploit manufacturing systems) which is required to provide a detailed account for building and maintaining a technical process innovation capability is guided by interpretivism (Easterby-Smith et al., 2012, p. 55). Therefore, in the context of the present research, design issues are more strongly affected by positivism (Yin, 1989) and analysis issues are more strongly affected by interpretivism (Stake, 1995).

Design of Case Study

A research design, implicit or explicit, “[...] is the logical sequence that connects the empirical data to a study’s initial research questions and, ultimately, to its conclusions” (Yin, 2009, p. 26). In addition, a *case study* is formally defined as follows:

A case study examines a phenomenon in its natural setting, employing multiple methods of data collection to gather information from one or a few entities (people, groups, or organizations). The boundaries of the phenomenon are not clearly evident at the outset of the research and no experimental control or manipulation is used. (Benbasat et al., 1987, p. 370)

According to Yin (2009, p. 27), case study designs comprise the following five components: (1) a study’s questions; (2) its propositions, if any; (3) its unit(s) of analysis; (4) the logic linking the data to the propositions and (5) the criteria for interpreting the findings. The major research question—*In what way does a world leading motor vehicle manufacturer build and maintain its technical process innovation capability?*—was derived in the previous chapter (see on page 20) to provide the scope and direction for the present research. Moreover, the two subsidiary research questions entail propositions that point to what should be studied and where to look for relevant evidence in seeking answers to the major research question (Yin, 2009, p. 28). Focusing on the third component (the fourth and fifth component will be addressed in section *Data Analysis*), the unit of analysis defines what the ‘case’ is (Miles and Huberman, 1994, p. 25). In consequence, it is essential for case research to clearly determine the unit of analysis which is largely influenced by the stated set of research questions.

The *units of analysis* in the context of the present research are examples of *current or recent technical process innovations* within a world leading motor vehicle manufacturer. The adopted *organisational technologists'* viewpoint in order to study these examples can be summarised as follows:

These researchers are interested in the factors that influence the generation of technological innovations at the level of organizational subunits, such as the R&D or the manufacturing departments. Their work ranges from understanding the factors that improve technical performance in R&D laboratories [...] to identifying the criteria that influence the choice and use of technological innovations in various organizational subunits [...]. Researchers in this group may concentrate on idea generation and problem solving stages of the generation phase within R&D and design departments, or they may focus on the initiation stage of the adoption phase in manufacturing or other functional departments. [...] Again, these researchers' *emphasis on the movement of an innovation through various departments* proves that the department or subunit is the focal level of analysis; however, organizational technologists *study both the generation and adoption phases of the innovation process* within such subunits [...]. (Gopalakrishnan and Damanpour, 1997, p. 21, emphasis added)

Ideally, the investigated technical process innovation projects cover all three top-level learning routines in full and thus include manufacturing readiness levels 1-10. To reiterate, these routines, employed by R&D and production departments, start with a stimulus for innovation and proceed through various stages of design and industrialisation to an innovation introduced into practice. However, it is assumed that an initial screening of candidate cases will reveal technical process innovation projects at different manufacturing readiness levels. Therefore, multiple-cases within one organisation need to be investigated to 'construct' a complete picture which depends largely on the integrative power of the researcher (Benbasat et al., 1987, p. 371, table 1). This proposed *single-company multiple-case design* was particularly inspired by the work of Spear (1999) at Toyota Motor Corporation which resulted in the landmark article *Decoding the DNA of the Toyota Production System* (Spear and Bowen, 1999). In summary, the present research focuses on examples of current or recent technical process innovations within a world leading motor vehicle manufacturer to provide a rich picture of the central research phenomenon—*technical process innovation capability*.

3.3.2 Selection of Data

In this subsection the *Sampling Plan* and the *Number of Cases* are thoroughly explained. The former outlines the sequential sampling process to select an appropriate site, while the latter considers the multiple-case design.

Sampling Plan

In case research it is essential that the selection of an appropriate site is carefully thought out (Benbasat et al., 1987, p. 373). For this reason, the present research applied a sequential sampling process at the outset (Erickson, 1986, p. 143). The associated sampling plan comprised the following three sets of selection criteria in order to determine industry group, organisation and cases:

1. The selected industry group
 - plays an important role in the global economy,
 - affords an opportunity to investigate innovation capability and
 - serves as an established research environment for empirical studies.
2. The selected organisation
 - is a world leading representative of its industry group,
 - exemplifies an innovative manufacturer and
 - allows access to its people and resources.
3. The selected cases
 - affect the competitive priorities of their organisation,
 - comprise new or significantly improved production methods and
 - are obtainable current or recent examples.

At the beginning, an industry group was determined according to the first set of selection criteria. In the context of the present research the *automotive industry* was selected which is formally labelled as 'motor vehicle manufacturing'—North American Industry Classification System (NAICS) code 3361—or 'motor vehicles and motor vehicle equipment'—Standard Industrial Classification (SIC) code 371. This industry group is not only one of the most globalised industries in the world but also an acknowledged driver of economic growth (Donnelly et al., 2002; Taylor and Taylor, 2008). Moreover, the automotive industry deserves close study because it "[...] affords an unparalleled opportunity to study technological change over the full range of its development" (Abernathy, 1978, pp. 8-9). Last, but by no means least, the automotive industry is home to a large body of empirical research on production systems and product development (Abernathy, 1978; Clark and Fujimoto, 1991; Fujimoto, 1989, 1999; Liker, 2004; Monden, 1983, 2012; Ohno, 1988; Schonberger, 1982, 2007; Shingo, 1989; Spear, 1999; Spear and Bowen, 1999; Sugimori et al., 1977; Womack and Jones, 1996; Womack et al., 1990). In consequence, the selected industry group is considered as an appropriate environment from which to select an organisation.

Following the sequential sampling process, an organisation was then determined according to the second set of selection criteria. The intra-organisational perspective of the present research draws solely on the motor vehicle manufacturer¹ *Bayerische Motoren Werke Aktiengesellschaft (BMW AG)*. A self-portrait taken out of its annual report 2014 is used to briefly introduce² the 'case company':

Bayerische Motoren Werke Aktiengesellschaft (BMW AG), which is based in Munich, Germany, is the parent company of the BMW Group. The primary business objective of the BMW Group is the development, manufacture and sale of engines as well as of all vehicles equipped with those engines. [...] The BMW Group is one of the most successful makers of cars and motorcycles worldwide and among the largest industrial companies in Germany. With BMW, MINI and Rolls-Royce, the BMW Group owns three of the strongest premium brands in the automotive industry. The vehicles it manufactures set the highest standards in terms of aesthetics, dynamics, technology and quality, a fact borne out by the BMW Group's leading position in engineering and innovation. [...] The BMW Group operates on a global scale and is represented in more than 140 countries worldwide. Its research and innovation network is spread over twelve locations in five countries. At 31 December 2014 the Group's production network comprised a total of 30 locations in 14 countries. (BMW, 2014a, p. 18)

In addition to the used selection criteria, three underlying rationales justify the single-company design as follows: First, in a study of capability building it is seen as more useful to have continuity in tracing activities in one well-known company "[...] than to piece together a fragmented overview of the entire industry" (Abernathy, 1978, p. 9). Second, the chosen single-company design focuses on comparisons within the same organisational context which enables contextual insights to be illustrated in much more detail (Dyer Jr. and Wilkins, 1991, p. 614). Third, by seeing a concrete example of the adopted resource and capability architecture, the reader/reviewer has a much easier time imagining how the proposed conceptual framework might actually be applied to other empirical settings (Siggelkow, 2007, p. 22).

Relevant studies with a similar single-company design are, for example, Spear (1999) and Hales (1987); the former examined in depth Toyota's production system (i. e. production capability) and the latter studied in detail a firm's engineering design process (i. e. technological development capability). Most important, the carefully selected organisation allows insights into its operating practice and in this context into the resource and capability architecture in its real-life context.

¹ Referring to the North American Industry Classification System (NAICS) code 336111 'automobile manufacturing' or equivalent to the Standard Industrial Classification (SIC) code 3711 'motor vehicles and passenger car bodies'.

² Further information can be found online at <http://www.bmwgroup.com/> (BMW, 2015a).

Having determined the industry group and organisation, the last sampling stage was concerned with selecting appropriate cases according to the third set of selection criteria. These criteria were primarily derived from the proposed conceptual framework and the determined unit(s) of analysis. Moreover, a common practice in inductive research is to utilise a *theoretical* (i. e. analytical) sampling method (Blaikie, 2010; Eisenhardt, 1989; Eisenhardt and Graebner, 2007; Glaser and Strauss, 1967; Meredith, 1998; Yin, 1989). Drawing on Eisenhardt and Graebner (2007, p. 27), “[t]heoretical sampling simply means that cases are selected because they are particularly suitable for illuminating and extending relationships and logic among constructs”. In the context of the present research, the adopted theoretical sampling method to select those cases can be described as follows:

The initial case or cases will be selected according to the theoretical purposes that they serve, and further cases will be added in order to facilitate the development of the emerging theory. As theory development relies on comparison, cases will be added to facilitate this. An important concept in this process is ‘theoretical saturation’. Cases are added until no further insights are obtained; until the researcher considers that nothing new is being discovered. (Blaikie, 2010, p. 179)

In summary, two initial cases were determined at the outset according to the third set of selection criteria and further cases were then added in the course of the present research by means of the outlined theoretical sampling method which completed the described sampling plan.

Number of Cases

The single-company multiple-case design of the present research focuses on few cases which enable an detailed investigation of the central research phenomenon (Voss et al., 2002, p. 201). Despite the applied concept of ‘theoretical saturation’, a first indication regarding the number of cases can be given as follows:

Finally, while there is no ideal number of cases, a number between 4 and 10 cases usually works well. With fewer than 4 cases, it is often difficult to generate theory with much complexity, and its empirical grounding is likely to be unconvincing, unless the case has several mini-cases within it [...]. With more than 10 cases, it quickly becomes difficult to cope with the complexity and volume of the data. (Eisenhardt, 1989, p. 545)

However, to ‘construct’ a complete picture and to provide a detailed account for building and maintaining a technical process innovation capability, the three top-level learning routines and thus all manufacturing readiness levels 1-10 need to be sufficiently covered. For this reason, the present research investigated a total of fifteen cases (see Table 16).

Table 16: The technical process innovation projects (cases)

<i>Process Family</i>				<i>Case ID</i>	<i>Manufacturing Readiness Level</i>									
<i>S</i>	<i>J</i>	<i>F</i>	<i>O</i>		<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>	<i>8</i>	<i>9</i>	<i>10</i>
	*			#1	*	*	*	*	*	*	*	*	*	*
			*	#2	*	*	*	*	*	*	*	*	*	*
*				#3	*	*	*	*	*	*	*	*	*	
	*			#4	*	*	*	*	*	*	*	*		
		*		#5	*	*	*	*	*	*	*	*		
	*			#6	*	*	*	*	*	*	*			
*				#7	*	*	*	*	*	*				
*				#8	*	*	*	*	*	*				
	*			#9	*	*	*	*	*					
	*			#10	*	*	*	*	*					
	*			#11	*	*	*	*	*					
	*			#12	*	*	*	*	*					
	*			#13	*	*	*	*	*					
	*			#14	*	*	*	*	*					
*				#15	*	*	*	*	*					

Note: S = shaping; J = joining; F = finishing; O = others; * covered by case. The 'mapping' of the covered MRLs is indicative only.

Source: The author

The total set of cases can be divided into initial major cases (i. e. cases #1-2; determined according to the third set of selection criteria) and thirteen subsidiary cases (i. e. cases #3-15; added by means of the outlined theoretical sampling method). Potential cases might be detected by screening the manufacturer's product portfolio for any upcoming 'breakthrough products' via published press kits/releases (Bhoovaraghavan et al., 1996; Wheelwright and Clark, 1992). For example, case #1 is inseparably connected to the case company's new all-electric motor vehicle (BMW i3) whose start of production (SOP) in a new production facility was imminent (BMW, 2010, 2013a,c,d). This revolutionary new all-electric motor vehicle required, among others, revolutionary new processes in carbon-fibre-reinforced plastic (CFRP) body manufacture. An excerpt from a published press kit is used to briefly introduce³ case #1—CFRP adhesive bonding process:

³ A video published by the BMW Group can be found online at <https://www.youtube.com/watch?v=q2nFKkbV63Y> (BMW, 2014b).

The CFRP composite components are bonded together in the new body shop in Leipzig. This is where the basic structure of the Life module takes shape. A high level of geometric integration means that the CFRP structure requires only a third of the number of body components used in a conventional steel body; the Life module's basic CFRP structure comprises around 150 CFRP parts in total. There is no noise from bolting or riveting and no sparks from welding in the manufacturing process for a CFRP body. Instead, only the latest bonding technology is used, which is 100 per cent automated. In this unique, BMW-developed assembly process, the individual components are positioned at a precisely defined bond line gap in order to ensure the resulting joint is as strong as possible. The bonded joints of each BMW i3 measure a total of 160 metres in length. In order to minimise hardening times for volume production of the BMW i3, BMW has greatly accelerated the hardening process. Significant advances in the development of the adhesive mean it is now workable for only 90 seconds after being applied to a component and before adhesion begins. An hour and a half later it has fully hardened and achieved its full strength. This represents a tenfold acceleration of conventional adhesive hardening times. In order to further reduce the hardening time below 10 minutes, BMW has developed a supplementary thermal process. This involves heating specific points on the CFRP parts which are to be bonded, thereby accelerating the hardening process even further. (BMW, 2013d, p. 5)

Case #2 is—in contrast to case #1—largely product-independent and exemplifies a special type of technical process innovation because it cannot be classified according to the three process families of (1) shaping, (2) joining and (3) finishing (BMW, 2013b; Knight, 2014). Another excerpt from a published press release is used to briefly introduce⁴ case #2—human-robot co-operation:

At the BMW Group's Spartanburg site, the future has already begun: In door assembly, people and robots work side by side—without a safety fence—in one team. US plant Spartanburg is the first BMW Group production facility worldwide that has succeeded in implementing direct human-robot cooperation in series production. Four collaborative robots equip the insides of the doors of BMW X3 models with sound and moisture insulation. In a first step, the foil with the adhesive bead is put in place and slightly pressed on by assembly line workers. Prior to the introduction of the new system, workers then carried out the fixing process by means of a manual roller. Today, systems with roller heads on robot arms handle this labor-intensive task, which requires maximum precision. The sealing protects the electronics in the door and the entire vehicle interior against moisture. [...] The direct interaction of man and machine requires top security standards as the robots are placed in the workers' direct surrounding without any protective devices. They run at a low speed within a defined environment and are stopped immediately in case their sensors detect an obstacle in their way. [...] Thanks to the fully automated process, the rolling power applied to the fixing process can be measured exactly. As a result, the processing quality can be monitored on a permanent basis. (BMW, 2013b, pp. 1-2)

In summary, the present research started with two initial cases which provide examples for polar types regarding the 'product-process innovation continuum' and continued with adding thirteen subsidiary cases until theoretical saturation was reached (Bhoo-varaghavan et al., 1996; Eisenhardt, 1989; Garcia, 2010; Garcia and Calantone, 2002; Pettigrew, 1990).

⁴ A video published by the BMW Group can be found online at <https://www.youtube.com/watch?v=8oyqTiaccxIY> (BMW, 2015d).

3.3.3 Collection of Data

In this subsection the *Instrumentation Plan* and the *Sources of Evidence* are thoroughly explained. The former describes activities to obtain and process case study data, while the latter is concerned with the triangulation of multiple data sources.

Instrumentation Plan

The instrumentation plan which is centred on questions of how to obtain case study data and how to process them needs to be carefully thought out prior to commencing data collection in an organisation (Darke et al., 1998; Miles and Huberman, 1994; Voss et al., 2002). This well-defined focus enables researchers to collect specific kinds of data from case participants in systematic ways (Mintzberg, 1979a, p. 585). A common technique used by qualitative researchers to obtain primary data is interviewing (Chadderton and Torrance, 2011; Creswell, 2009; Silverman, 2011). *Semi-structured* interviews, for example, are in line with the adopted research paradigm and the flexibility in their design (i.e. degree of standardisation) allows asking further unplanned questions in response to what the interviewee says (Bryman, 2012; Robson, 2011). For this reason, semi-structured interviews are seen as appropriate to investigate the underlying step-by-step logic of highly confidential and commercially sensitive innovation projects (Easterby-Smith et al., 2002, p. 87). In consequence, the outlined instrumentation plan describes the performed activities before, during and after an interview session.

At the beginning, a list of guiding questions was developed and linked to the subsidiary research questions (see Table 17). This derived *interview guide* had a strong “[...] directive function with regard to excluding unproductive topics” and ensured sufficient focus on capability building (Flick, 2009, p. 167). Once the potential interviewee has been formally requested in writing, most often a personal meeting of about half an hour followed in an informal environment. The aim of this briefing was not only to explain in more detail the purpose of the present research, what specific kind of data will be required and how the interview session will proceed but also to build rapport with the case participant. At this stage, the potential interviewee was also asked for permission to use a recording device during the interview and he or she was assured that the information obtained during the interview would remain confidential and anonymous, unless otherwise agreed to. Subsequent to the briefing, the actual interview was scheduled and a meeting room booked.

Table 17: The guiding questions for semi-structured interviews

Guiding Question	SRQ	
	1	2
What is the activity that must be accomplished (regarding MRLs 1-10)?	*	
What are the means that are used to perform an activity?	*	
What are the data or objects that are transformed by the activity into output?	*	
What are the data or objects that are produced by an activity?	*	
What are the conditions required to produce correct output?	*	
How are knowledge and skills identified to perform an activity?		*
How are knowledge and skills (externally) acquired to perform an activity?		*
How are knowledge and skills (internally) developed to perform an activity?		*
How are knowledge and skills shared or distributed to perform an activity?		*
How are knowledge and skills protected or preserved?		*

Note: MRL = manufacturing readiness level; SRQ = subsidiary research question; * addressed by guiding question. The 'mapping' of the SRQs is indicative only.

Source: The author (derived from Hopf, 2009; NIST, 1993; Probst, 1998)

The interview session itself lasted on average an hour and a half and started with a brief introduction and a polite talk about uncontroversial matters such as background information about the innovation project which have already been addressed in the briefing. The core of the interview was then in a conversational mode which can be described as follows:

The researcher has a list of questions or fairly specific topics to be covered, often referred to as an *interview guide*, but the interviewee has a great deal of leeway in how to reply. Questions may not follow on exactly in the way outlined on the schedule. Questions that are not included in the guide may be asked as the interviewer picks up on things said by interviewees. But, by and large, all the questions will be asked and a similar wording will be used from interviewee to interviewee. (Bryman, 2012, p. 471, emphasis in original)

This conversation was usually recorded with an electronic device and manual notes were taken visible to the interviewee. For example, answers regarding the activities that must be accomplished were immediately sketched as rough 'process flowcharts' and deepened. The central value of this interaction during an interview is "[...] that it allows *both* parties to explore the meaning of the questions and answers involved" (Brenner et al., 1985, p. 3, emphasis in original). The interview ended with an explicit appreciation of the interviewee's time and contribution.

After the interview session, the recording was downloaded from the electronic device and then fully (i.e. 'verbatim' or word for word) transcribed into text format with a word processing software. The data collected (i.e. recording file, transcript and scanned notes) were stored electronically in a case study data base and imported into a computer assisted qualitative data analysis software (CAQDAS) for further analysis⁵. Due to the prolonged engagement with the case company, informal follow-ups with some case participants took place after the actual interview in order to get feedback regarding rival explanations or conclusions of the final analysis. Overall, the outlined instrumentation plan allowed a systematic collection of primary data from first hand by means of semi-structured interviews and a straightforward data processing afterwards.

Sources of Evidence

The present research triangulates multiple sources of evidence such as semi-structured interviews, written documents and direct observations (Chadderton and Torrance, 2011; Creswell, 2009; Patton, 2002; Silverman, 2011). These sources focus, among others, on different routine components (i.e. performative aspects, ostensive aspects and artefacts). For example, semi-structured interviews of specific people that bring the routine to life provide insights into the actual performance/action of the routine. Written documents such as standard operating procedures or training manuals exemplify the abstract idea/pattern of the routine. Lastly, direct observations of general physical settings such as laboratory or production relevant/representative environments facilitate the understanding of the routine in its real-life context. In consequence, the triangulation of multiple data sources allows the author to 'construct' a complete picture of the three top-level learning routines (i.e. explore manufacturing technologies, transform manufacturing processes and exploit manufacturing systems).

As described in the instrumentation plan, the major part of case study data was obtained through semi-structured interviews. Similar to the number of cases, the question of how many interviews are enough is subject to an ongoing debate (Baker and Edwards, 2012; Guest et al., 2006; Onwuegbuzie and Collins, 2007; Sandelowski, 1995). The right sample size is a balance act best described as follows:

In general, sample sizes in qualitative research should not be so small as to make it difficult to achieve data saturation, theoretical saturation, or informational redundancy. At the same time, the sample should not be so large that it is difficult to undertake a deep, case-oriented analysis. (Onwuegbuzie and Collins, 2007, p. 289)

For this reason, the sampling of case participants followed the logic of *snowball sampling* until theoretical saturation was reached (Blaikie, 2010, p. 179). As a result, 50 case participants across the organisational hierarchy of R&D and production departments were interviewed whereby approximately two thirds of the obtained data originated from

⁵ The following commercial products were used to record, transcribe and process the case study data: *Samsung Galaxy SII* (mobile phone), *ASR* (audio recorder application program), *VLC media player* (multimedia player), *Microsoft Word 2010* (word processing software), *Dropbox* (cloud storage provider or 'case study data base') and *MAXqda11* (computer assisted qualitative data analysis software).

Table 18: The case study data obtained through semi-structured interviews

<i>Organisational Level</i>	<i>Interviewee [number]</i>	<i>Share</i>	<i>Recording [hh:mm]</i>	<i>Share</i>	<i>Transcript [pages]</i>	<i>Share</i>
Top-Level Managers	2	04%	01:22	02%	32	02%
Middle-Level Managers	9	18%	06:36	09%	180	10%
Lower-Level Managers	10	20%	16:16	23%	315	17%
Non-Managerial Employees	29	58%	22:33	66%	1335	71%
<i>Total</i>	<i>50</i>	<i>100%</i>	<i>70:47</i>	<i>100%</i>	<i>1862</i>	<i>100%</i>

Source: The author

non-managerial employees and one third of the obtained data came from different management levels (see Table 18). Perhaps it was no coincidence that non-managerial employees focused more on specific within-case activities and managers were more concerned with the co-ordination of generic cross-case activities. This perception is in line with the words of Henri Fayol as follows:

In all undertakings, the essential characteristics of the lower grades of employees is the professional ability appertaining to the particular undertaking, and the characteristics which is essential for the heads of concerns is administrative ability. (Fayol, 1930, p. 10)

In addition, almost 300 written documents (e. g. annual reports, press kits/releases, company magazines, standard operating procedures and training manuals) were added to the case study data base. Last, but by no means least, direct observations of routines in their natural setting—less formal field visits to understand the technical background information and environmental conditions—complemented the insights. In short, multiple data sources were triangulated in order to provide a detailed account for building and maintaining a technical process innovation capability.

3.4 DATA ANALYSIS

In the broadest sense, data analysis is defined as “[...] a process of resolving data into its constituent components, to reveal its characteristic elements and structure” (Dey, 1993, p. 30). The underlying step-by-step logic of this section follows a common form in qualitative research called *thematic (coding) analysis* (Auerbach and Silverstein, 2003; Boyatzis, 1998; Guest et al., 2012). According to Robson (2011, p. 476, box 17.4), this process can be summarised as follows:

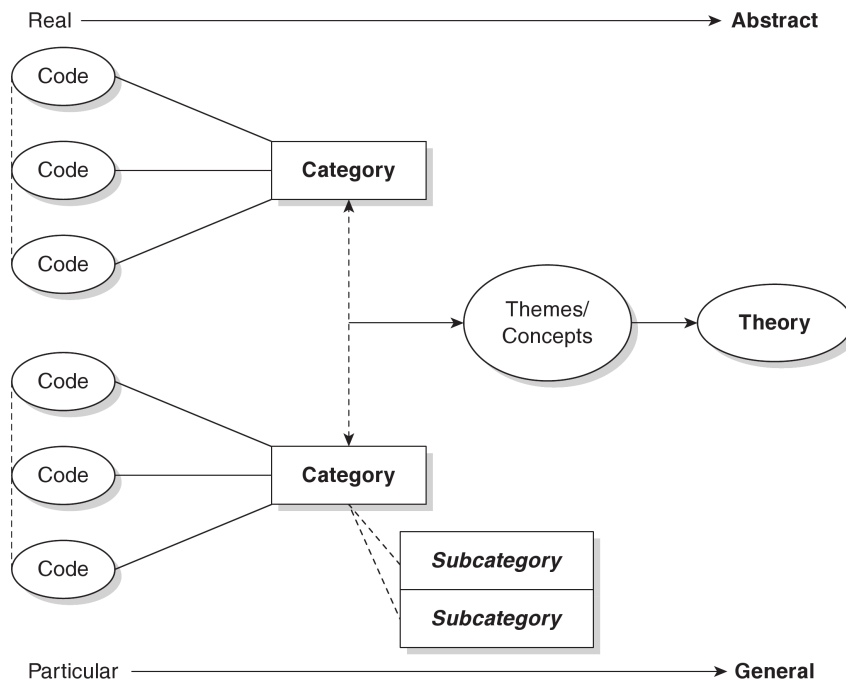
- familiarise with the obtained data,
- generate initial codes,
- identify potential themes,
- construct networks and matrices and
- integrate and interpret the findings.

Although the nature of the adopted approach to qualitative analysis—which also addresses Yin’s (2009, p. 27) forth and fifth component of case study designs (see on page 63)—is iterative and cyclical, it is best reported sequentially with *Condensing the Data, Displaying the Data and Making Good Sense* (Miles and Huberman, 1994; Miles et al., 2014).

3.4.1 *Condensing the Data*

In the present research, the analysis of the case study data started almost in parallel with their collection. For example, the manual transcription process of the audio recording just after the interview session allowed the author to immerse in the data through repeated listening and thorough reading and rereading (Robson, 2011, p. 478). Moreover, while familiarising with the raw data or information, initial notes were taken when similarities/differences between interviews, documents and observations attracted attention. This highlighting or signposting of text passages which immediately strike the researcher is also referred to as indexing (Seale, 1999, p. 154) or pre-coding (Saldaña, 2013, p. 19). In consequence, the increasing contextual understanding in the course of data collection improved the efficiency of remaining interview sessions and played a key role regarding theoretical saturation.

Subsequent to the data collection, the data condensation process was performed. Data condensation is widely acknowledged as an essential part of qualitative data analysis because it “[...] sharpens, sorts, focuses, discards, and organizes data in such a way that ‘final’ conclusions can be drawn and verified” (Miles et al., 2014, p. 12). For this reason, the following two sequential coding cycles were accomplished: (1) generating initial codes and (2) identifying potential themes (Robson, 2011, p. 476, box 17.4).



Source: Adopted from Saldaña (2009, p. 12, figure 1.1)

Figure 19: The codes-to-theory model

For the first coding cycle, the *descriptive coding* method was utilised (Miles and Huberman, 1994; Saldaña, 2013). This method condensed in a word or short phrase the basic topic of a selected text passage and built purely from interaction with the data—without a start list of codes—a categorical inventory of their contents (Saldaña, 2013, pp. 88-89). Basic topics included *activities, settings, conditions or constraints* as well as *strategies, practices or tactics* (Gibbs, 2007, pp. 47-48, table 4.1). Having completed the first coding cycle, the inductively generated set of codes was then organised and partially recoded through two iterations of code mapping from a long list of codes to an initial hierarchy of major categories and subsidiary categories (Saldaña, 2013, p. 194). At this stage, the familiarity with concepts from the literature such as the manufacturing readiness levels enhanced sensitivity to subtle nuances in the data that might otherwise have been overlooked (Corbin and Strauss, 2008; Robson, 2011; Tuckett, 2005). As a result, the full data set was meaningfully pre-structured in order to facilitate the identification of potential themes.

For the second coding cycle, the *pattern coding* method was utilised (Miles and Huberman, 1994; Saldaña, 2013). This method pulled together major categories from the first coding cycle into a smaller and more select list of potential themes (see Figure 19). For example, a large set of initial codes summarising a plethora of activities to carry out experiments were iteratively merged into a smaller set of analytic units representing 'test series' at different stages of an innovation project. A detailed examination of these recurring 'test series' revealed insights into the resource and capability architecture in its real-life context. In other words:

Some categories may contain clusters of coded data that merit further refinement into subcategories. And when the major categories are compared with each other and consolidated in various ways, you begin to transcend the “reality” of your data and progress toward the thematic, conceptual, and theoretical. (Saldaña, 2013, p. 12)

The selected theme-identification techniques were *repetitions, similarities & differences* and *cutting & sorting* (Ryan and Bernard, 2003, p. 102, figure 1). Special emphasis was given to the cutting & sorting technique which involved “[...] identifying quotes or expressions that seem somehow important and then arranging the quotes/expressions into piles of things that go together” (Ryan and Bernard, 2003, p. 94). However, it is to note that the utilisation of these three techniques was biased by the perception of the proposed conceptual framework. In summary, the pre-structured data corpus was again rearranged/reclassified and potential themes—relevant to the stated set of research questions—were identified.

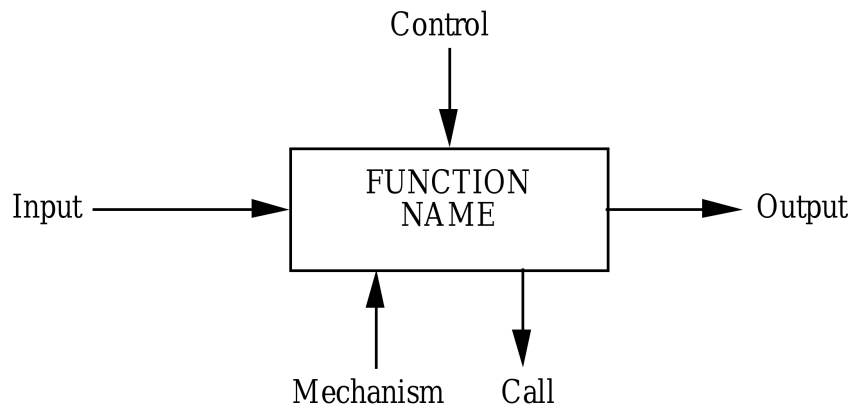
3.4.2 *Displaying the Data*

In the course of data condensation, the emerging codes, categories and themes were tied together into data displays such as networks and matrices. A *data display* is defined as “[...] an organized, compressed assembly of information that allows conclusion drawing and action” (Miles et al., 2014, p. 12). The specific design of networks (i.e. arrays of nodes with links between them) and matrices (i.e. tables with rows and columns) was largely driven by the stated set of research questions (Miles et al., 2014, p. 109). In the context of the present research, networks were seen as appropriate to illustrate the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments. In addition, matrices were considered as suitable to outline the strategies, practices or tactics which institutionalise the knowledge and skills of technical process innovation projects. Therefore, graphical and tabular formats were utilised to display the condensed data.

For example, the rough ‘process flowcharts’ from the interview sessions were refined with insights from the data condensation process and their graphical formatting was aligned with the syntax and semantic rules of IDEFo diagrams (see Figure 20). An IDEFo (Integration DEFinition language o) function model can be characterised as follows:

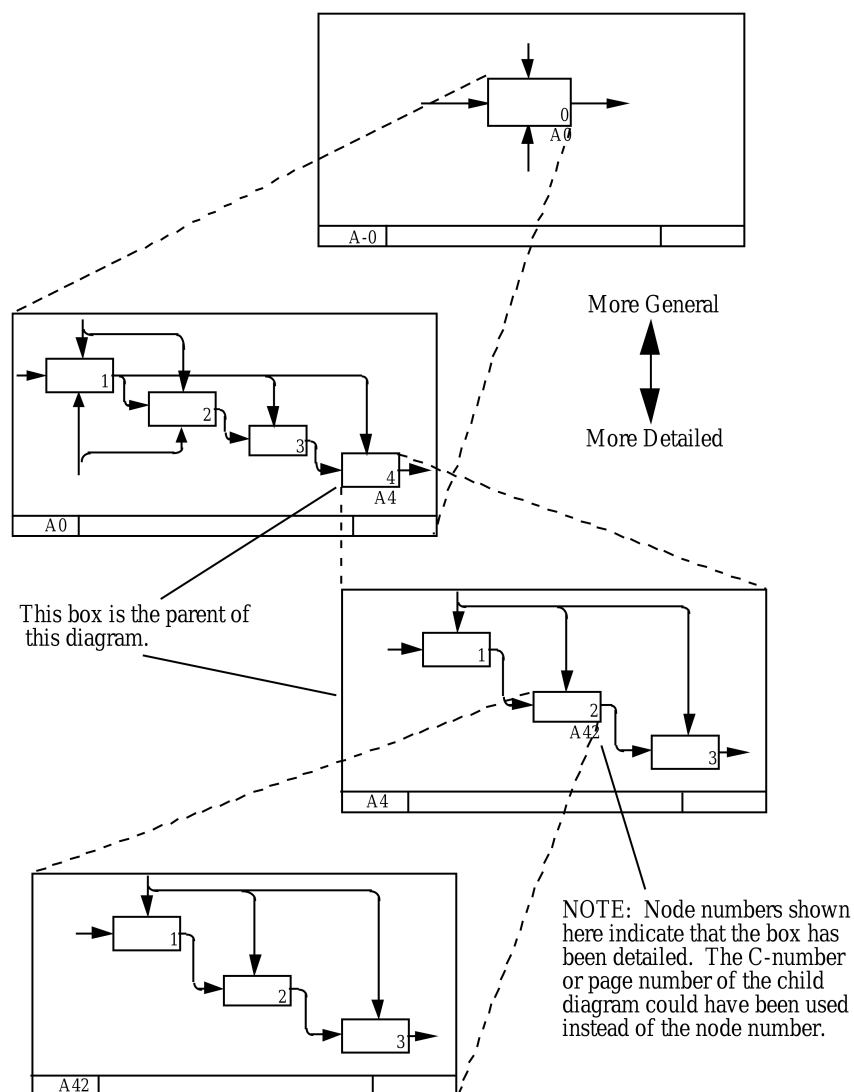
[1] It is comprehensive and expressive, capable of graphically representing a wide variety of business, manufacturing and other types of enterprise operations to any level of detail. [2] It is a coherent and simple language, providing for rigorous and precise expression, and promoting consistency of usage and interpretation. [3] It enhances communication between systems analysts, developers and users through ease of learning and its emphasis on hierarchical exposition of detail. [4] It is well-tested and proven, through many years of use in Air Force and other government development projects, and by private industry. [5] It can be generated by a variety of computer graphic tools; numerous commercial products specifically support development and analysis of IDEFo diagrams and models. (NIST, 1993, p. vii)

This adopted systems engineering technique is widely used in industry and formally classified as a task dependency model designed to capture activities and their different



(a) Arrow positions and roles

Source: Adopted from NIST (1993, p. 11, figure 3)



(b) Decomposition structure

Source: Adopted from NIST (1993, p. 16, figure 6)

Figure 20: The IDEF0 diagram features

components such as inputs to activities, outputs from activities, controls or constraints on activities and mechanisms which support activities (Clarkson and Eckert, 2005; Godwin et al., 1989; Kusiak et al., 1994; NIST, 1993; Wynn, 2007).

In contrast to the elaborate IDEFo diagrams, the two-dimensional matrices were organised straightforwardly. The rows contain information about strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects. The columns refer to manufacturing readiness levels 1-10 which start with a stimulus for innovation and proceed through various stages of design and industrialisation to an innovation introduced into practice.

Both utilised formats include manufacturing readiness levels as an analytic unit not only to facilitate a step-by-step within-case analysis but also to allow an integrative cross-case analysis where applicable (see again Table 16). At the end, it was essential to go through the coded text passages once more to ensure that the displays reflect the data and the data support the displays which maintains the 'chain of evidence' (Robson, 2011; Yin, 2009). In summary, a complete picture was 'constructed' through networks and matrices in seeking answers to the stated set of research questions and to assist the process of conclusion drawing.

3.4.3 *Making Good Sense*

The general strategy for analysing the obtained data is based on the adopted resource and capability architecture. Moreover, the two subsidiary research questions point to what should be studied and where to look for relevant evidence (Yin, 2009, p. 28). Having condensed and displayed the data, the different displays were further integrated and interpreted to draw conclusions (Robson, 2011, p. 476, box 17.4). While this process depends largely on the integrative power of the researcher, three consecutive steps facilitated the within-case and cross-case synthesis (Benbasat et al., 1987, p. 371, table 1). First, the IDEFo diagrams were seen as a kind of 'value stream' which represents the activities, mechanisms and controls required to design and industrialise new or significantly improved production methods (Womack and Jones, 1996, p. 309). Second, this co-ordinated multi-stage process was divided into analytic units (i.e. manufacturing readiness levels 1-10), whereof strategies, practices or tactics have been worked out regarding the institutionalisation of associated knowledge and skills. Third, the conclusions were primarily drawn at these intersections through *noting patterns/themes* (see selected theme-identification techniques on page 76), *seeing plausibility* and *clustering* and subsequently assigned to the following three top-level learning routines: (1) explore manufacturing technologies, (2) transform manufacturing processes and (3) exploit manufacturing systems (Miles et al., 2014, pp. 277-280). As a result, the integration and interpretation of the condensed and displayed data allowed drawing conclusions which address the stated set of research questions.

The 'goodness' of the interpretation (i. e. the quality of the findings) was primarily assessed against criteria for *trustworthiness*. Lincoln and Guba (1985, p. 219) translated the four conventional criteria for trustworthiness into naturalistic ones⁶: (1) objectivity—confirmability, (2) reliability—dependability, (3) internal validity—credibility and (4) external validity—transferability. These standards for the quality of the findings were addressed through the following tactics proposed by Miles et al. (2014, pp. 295-300, 302-303, 309-310):

- *checking for researcher effects* (e. g. awareness of the familiarity with concepts from the literature and the perception of the proposed conceptual framework),
- *checking for representativeness* (e. g. multiple-case design and case participants across the organisational hierarchy of R&D and production departments),
- *using extreme cases* (e. g. two initial cases #1-2 exemplify polar types regarding the 'product-process innovation continuum'),
- *getting feedback from participants* (e. g. conversational mode with case participants during interview sessions and informal follow-ups afterwards) and
- *triangulating* (e. g. multiple sources of evidence such as semi-structured interviews, written documents and direct observations).

Generally, the present research is concerned with *analytic, theoretical or modified generalisation* instead of statistical generalisation (Robson, 2011; Stake, 1995). Therefore, the information richness of the investigated technical process innovation projects and the integrative power of the researcher determine the trustworthiness of the drawn conclusions more than, for example, the chosen sample size (Patton, 2002, p. 245). Moreover, some shortcomings and limitations of the present research are related to the nature of fieldwork in organisations as follows:

It is desirable to ensure representativeness in the sample, uniformity of interview procedures, adequate data collection across the range of topics to be explored, and so on. But the members of organizations block access to information, constrain the time allowed for interviews, [...] go on holiday, and join other organizations in the middle of your unfinished study. In the conflict between the desirable and the possible, the possible always wins. (Buchanan et al., 1988, pp. 53-54)

In summary, recognising the difficulty of justifying all the required decisions of the proposed methodology, the author's adopted pragmatic stance sympathises with Blaug's (1980, p. 27, emphasis in original) central conclusion: "[...] just as there is no logic of discovery, so there is no demonstrative *logic* of justification either".

⁶ The detailed rationale for this redefinition can be found in Lincoln and Guba (1985, pp. 289-331).

3.5 SUMMARY

This methodology chapter has focused on describing how the present research was done and what assumptions and decisions were involved by outlining the following three subjects in more detail: (1) *Preliminary Considerations*, (2) *Data Gathering* and (3) *Data Analysis*. The present research investigates the three top-level learning routines in depth and aims to provide a detailed account for building and maintaining a technical process innovation capability in seeking answers to the stated set of research questions. For this reason, a single-company multiple-case design was proposed and 15 examples of current or recent technical process innovations within a world leading motor vehicle manufacturer were carefully selected according to a predefined sampling plan. In order to allow a systematic collection of primary data from first hand, the performed activities before, during and after an interview session were described in an instrumentation plan. Additionally, to 'construct' a complete picture of the three top-level learning routines, the gained understanding from 50 semi-structured interviews—with case participants across the organisational hierarchy of R&D and production departments—was complemented with insights from almost 300 written documents and many direct observations in form of less formal field visits. Thus, the triangulation of multiple data sources allowed a detailed investigation of the central research phenomenon in its natural setting.

The underlying step-by-step logic of the data analysis followed a common form in qualitative research called thematic (coding) analysis. After familiarising with the data, two coding cycles were performed to generate initial codes and to identify potential themes. Parallel to this data condensation, the emerging codes, categories and themes were displayed through networks and matrices in an iterative and cyclical manner. At the end, the different data displays were further integrated and interpreted in order to 'generate meaning'. During the processes of data gathering and data analysis, several tactics (e. g. checking for researcher effects, getting feedback from participants, etc.) were used to verify the findings. It is recognised that the conclusions were limited, among others, by the author's perception of the proposed conceptual framework. However, the underlying resource and capability architecture is fairly well grounded in the domain of strategic management and thus the conclusions are seen as reasonably robust.

RESULTS

*Actioni contrarium semper et aequalem esse reactionem.
To every action there is always opposed an equal reaction.*

—Isaac Newton

Principia Mathematica (1687) Laws of Motion 3
(Knowles, 1999, p. 543, no. 7)

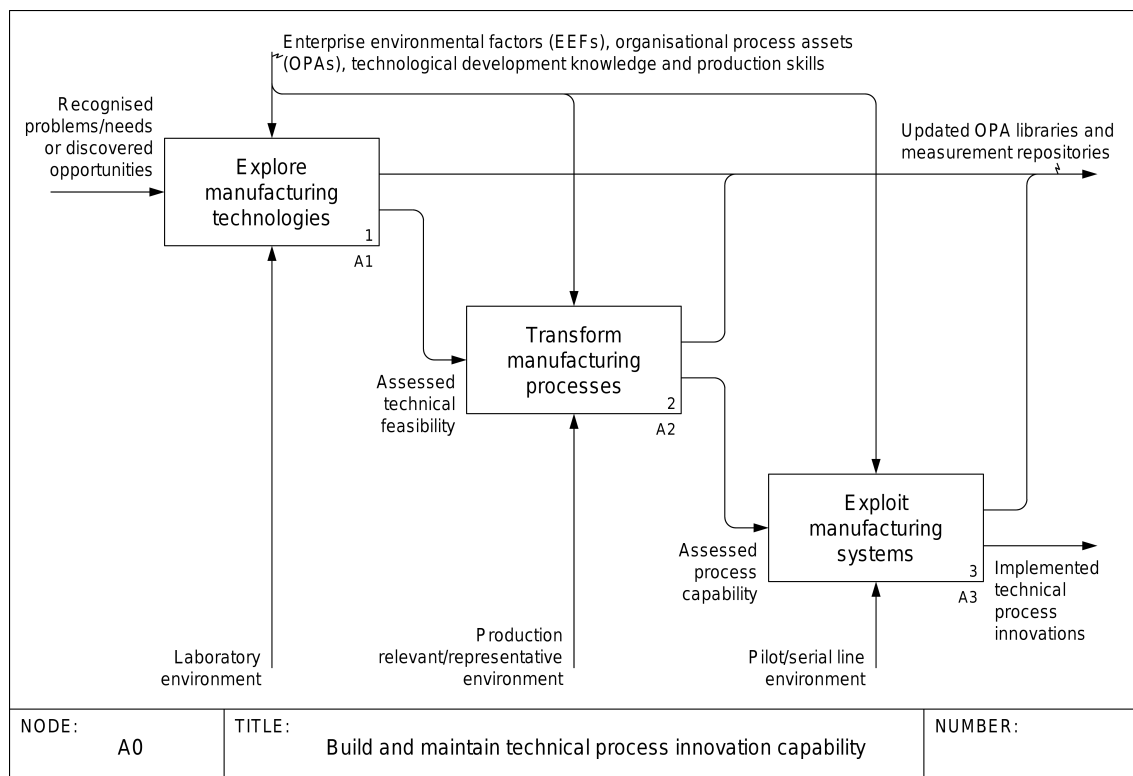
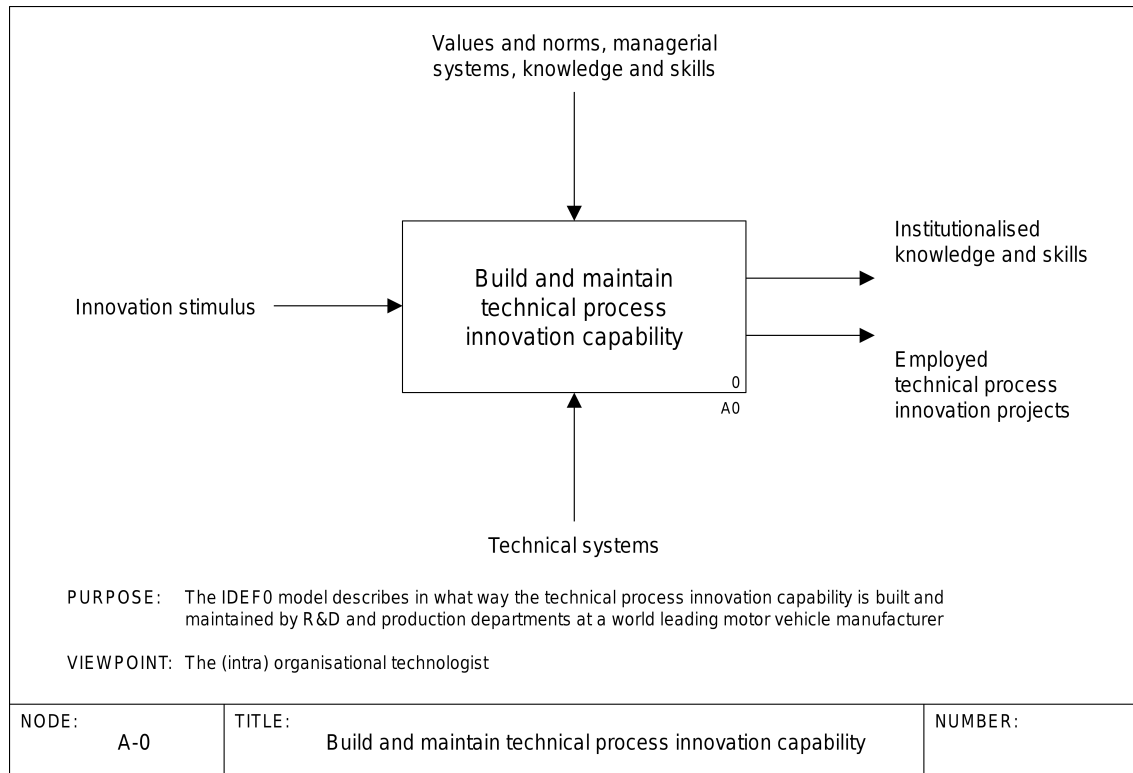
THE MAIN OBJECTIVE OF THIS RESULTS CHAPTER IS TO ‘CONSTRUCT’ A COMPLETE PICTURE AND TO PROVIDE A DETAILED ACCOUNT FOR BUILDING AND MAINTAINING A TECHNICAL PROCESS INNOVATION CAPABILITY.

4.1 OVERVIEW

This results chapter describes in what way the technical process innovation capability is built and maintained by R&D and production departments at the Bayerische Motoren Werke Aktiengesellschaft (BMW AG). An organisational technologists’ viewpoint is adopted and an IDEFo (Integration DEfinition language o) function model is used to ‘construct’ a complete picture (see Figure 21). The top-level function being modelled—*build and maintain technical process innovation capability*—contains the following three top-level learning routines:

1. *Explore Manufacturing Technologies* (Node A1)
2. *Transform Manufacturing Processes* (Node A2)
3. *Exploit Manufacturing Systems* (Node A3)

These three top-level learning routines convert recognised problems/needs or discovered opportunities into implemented technical process innovations and updated organisational process asset (OPA) libraries and measurement repositories. Technical systems which are designed and industrialised step by step in a laboratory environment, production relevant/representative environment and pilot/serial line environment are indispensable means to perform the learning routines. On the other hand, the conditions required to perform the learning routines are largely determined by enterprise environmental factors (EEFs), organisational process assets (OPAs), technological development knowledge and production skills. Finally, intermediate results such as the assessed technical feasibility and the assessed process capability represent the passage from one phase to another.



Source: The author

Figure 21: The IDEF0 diagram - Nodes A-0 and A0

According to the hierarchical structure of the IDEFo function model, each top-level learning routine is partitioned into its components and aligned with the associated manufacturing readiness levels (MRLs). In particular, the lower-level 'child diagrams' (i. e. Nodes A11, A12, A13, A21, A22, A23, A31, A32 and A33) describe the results and exemplify the 'chain of evidence' in order to answer the stated set of research questions. Thus, the chapter provides a detailed account for building and maintaining a technical process innovation capability.

4.2 EXPLORE MANUFACTURING TECHNOLOGIES (NODE A1)

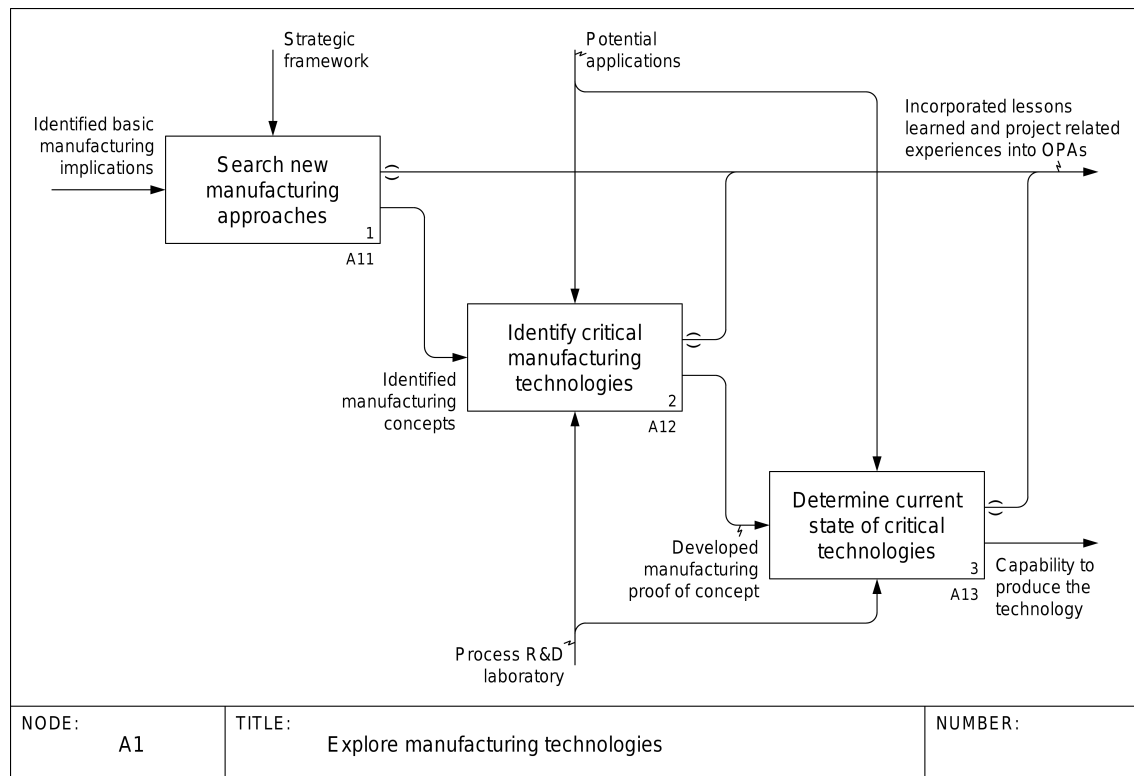
The top-level learning routine *explore manufacturing technologies* starts with identified basic manufacturing implications (i. e. recognised problems/needs or discovered opportunities) which are usually linked with the production department's innovation strategy. Depending on the scale of the technical process innovation projects, 'newstream organisations' or 'incubators' are established in order to provide a work environment with sufficient freedom. BMW's most prominent example of a 'newstream organisation' was described as follows:

[P]roject i, launched in late 2007, is an initiative to develop sustainable and pioneering mobility concepts. There must also be a collateral transfer of know-how from this project to the company as a whole and to future vehicle projects. The long-term goal of project i is to bring fresh thinking to the company's technologies, processes and vehicle concepts, whether in production, development or sales. [...] But how best to implement this mission? Ultimately, what is required is not just new processes and technologies but a complete critical reappraisal of automobile design as we know it. That is why project i transcends existing structures and brings together in a single unit experts and 'outside-the-box' thinkers from throughout the company. This small but efficient and dynamic organisational unit is tasked with defining the aims and requirements for sustainable mobility solutions of tomorrow and aligning them with future customer requirements. To help this team shed all constraints and preconceptions, the project is not brand-specific. This allows the think tank to take an unconventional and independent approach, yet at the same time to work with the full support of experts drawn from the entire company. In a culture of open and transparent knowledge-sharing, project i leverages expertise from all parts of the company. (BMW, 2010, pp. 11-12)

During the exploration phase of the technical process innovation projects, the following manufacturing readiness levels (MRLs) are achieved (see Figure 22):

- manufacturing concepts identified (MRL 2),
- manufacturing proof of concept developed (MRL 3) and
- capability to produce the technology in a laboratory environment (MRL 4).

The established process R&D laboratories enable the project teams to explore new manufacturing technologies by means of experimental hardware models and laboratory tooling. In order to maintain the new knowledge and skills, the used organisational process assets (e. g. plans, processes, policies, procedures and knowledge bases) are revised by the project teams throughout the exploration phase as necessary.



Source: The author

Figure 22: The IDEFo diagram - Node A1

4.2.1 Search New Manufacturing Approaches (Node A11)

A summary can be found at the end of this subsection (see Figure 23 and Table 19).

Define and Analyse Basic Problems (Node Reference A11.1)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

At the beginning of the fiscal year, the production department's strategic framework is assessed and its strategic themes and objectives are gradually adapted if necessary. As part of the internal strategic analysis, manufacturing shortfalls are addressed when the results regarding the operations performance objectives deviate significantly from the plan. Moreover, the current state of manufacturing systems along the process chain (e. g. press shop, body shop, paint shop and assembly line) is scrutinised in order to elicit process end-user constraints, needs and expectations. Internal subject matter experts are consulted as follows:

It is very important to have many discussions with experts across all departments and hierarchical levels within BMW. For instance, we talk to the production representatives of the different product lines to understand their strategic issues and where they see upcoming challenges. In the meantime, we have a short list of around 60-70 'contrarians' who know where the shoe pinches. They play a key role in identifying needs for predevelopment and process research in the production department. (Lower-level manager, interviewed on 26 June 2014, translated by the author)

The insights of the internal strategic analysis are then translated into basic problems and their root causes are systematically determined as needed. Incorporated into the production department's strategic framework, the documented problem statements provide then the basis for demand-induced technical process innovations.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

The production department has a set of standard processes in place with which basic problems are defined and analysed. Strengths, weaknesses and innovation opportunities for current manufacturing systems are periodically reviewed as part of the internal strategic analysis to define areas for demand-induced technical process innovations. This activity is closely interwoven with the annual development/adaptation of the corporate innovation strategy as follows:

At the turn of the year, we question the fit of our corporate innovation strategy with internal and external needs and adapt the strategy as needed; there exist annually recurring standard processes on [BMW] Group-level for it. When this task is completed, we derive the relevant requirements from the corporate innovation strategy which affect the production department and develop our strategic framework. For this reason, we discuss with our internal process partners the manufacturing processes and work on the demand-side of the 'strategic orientation frame'. (Lower-level manager, interviewed on 23 July 2014, translated by the author)

The qualitative findings are supplemented by analyses of the established and maintained measurement repositories in which process performance data are stored. Their investigation is performed by means of statistical and other quantitative techniques such as statistical process control and process capability analysis. In short, the knowledge and skills to define and analyse basic problems are institutionalised through performance measurement and causal analysis practices to elicit manufacturing shortfalls.

Search and Create Ideas/Solutions (Node Reference A11.2)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

In addition to the internal perspective, the production department's strategic framework is completed with findings from the external strategic analysis. Technology intelligence processes capture relevant information about basic technology research, emerging technological trends and the competitive environment. The delivered insights needed to understand manufacturing opportunities provide then the basis for supply-induced

technical process innovations. However, the evolved 'strategic orientation frame' remains permeable for creative ideas which do not fit into the strategic objectives and themes in the first place as follows:

It is not uncommon that you have shot an arrow and, at the end, after the arrow is in the wall, you paint the target around the arrow and you are happy that everything worked out perfectly. [...] I do even believe that 'flashes of genius' have more potential to differentiate us from our competitors than strategically derived ideas because our competitors often follow similar innovation strategies which are based on similar analyses. (Top-level manager, interviewed on 30 September 2014, translated by the author)

At the end of the first quarter, the revised strategic framework is approved by the production department's top-management committee and then communicated by managers across the department. During the next three months, it is the responsibility of the organisational units and subunits to generate ideas/solutions for their assigned strategic objectives and themes. With the beginning of the third quarter, the results of the decentralised ideation are presented to peers and the higher level management by means of posters, drawings or demonstration units at the production department's annual 'idea exhibition'.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

The production department's central innovation unit has the ownership of the innovation process and manages the associated stage-gate model. In order to support the organisational units and subunits with their generation of ideas/solutions, the innovation unit provides its methodological expertise in terms of different search approaches as well as creativity and problem solving techniques as a service. Moreover, the innovation unit organises the annual 'idea exhibition' to bring together the results of the decentralised ideation which have already achieved 'discussion maturity' with potential end-users as follows:

At the 'idea exhibition', we demonstrated a collaborative robot system and have obtained feedback what people think of the system which was actually throughout positive. In addition, they pointed out potential applications for the system. Three months later, the group leader of process planning at the Spartanburg site contacted us that he has heard from our approach and that they have quality issues with the fixing process of the moisture insulation in their door assembly. Up to this point we worked on a supply-induced innovation derived from our technology cluster Autonomous Co-operating Systems (ACS) without any predetermined use cases. (Non-managerial employee, interviewed on 11 June 2014, translated by the author)

This one-week 'idea exhibition' is primarily used as a vivid communication platform with guided tours, interactive presentations and initial technology demonstrations where ideas/solutions providers receive feedback from relevant stakeholders. In short, the knowledge and skills to search and create ideas/solutions are institutionalised through systematic ideation services and open exchange platforms to support ideas/solution providers.

Evaluate and Select Manufacturing Concepts (Node Reference A11.3)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

After the annual 'idea exhibition', the ideas/solutions providers incorporate the feedback from relevant stakeholders into their potential solution sketches and rework the manufacturing concepts. Towards the end of the year, the submitted manufacturing concepts are screened in the production department's central predevelopment committee and subsequently decided in the top-management committee. This procedure was described as follows:

The evaluation and selection of manufacturing concepts has two stages. In the first stage, we ensure that the submitted innovation project proposals contain all information needed for robust decision-making. This includes not only the problem statement and project objectives but also details about potential end-users, benefits and so on. Then we rate the eligible concepts which are classified according to our strategic themes and rank them in descending priority. In the second stage, the proposals are presented in random order to the top-management who then follow a similar procedure. At the end, we merge the two rankings, resolve any differences and allocate the available innovation funding. (Lower-level manager, interviewed on 23 July 2014, translated by the author)

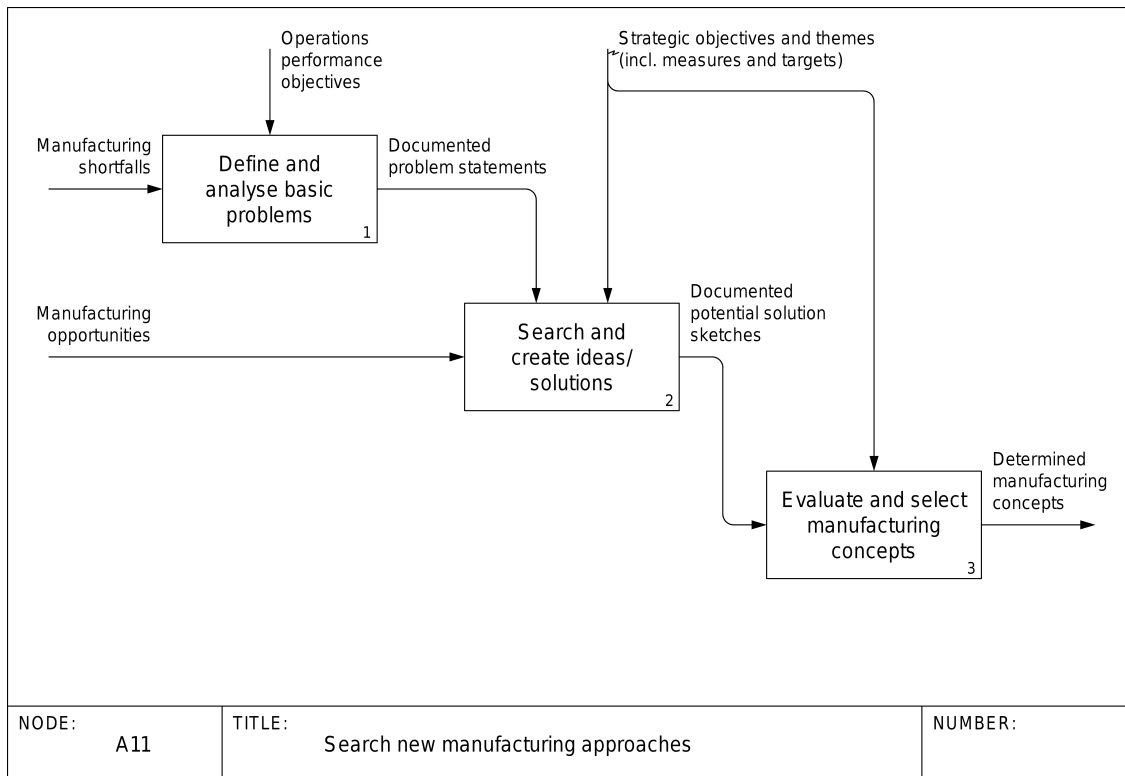
With the official mandate of the top-management committee, the determined manufacturing concepts are provided with adequate resources in terms of budget and capital investment for further development. As a result, the approved innovation program for the new fiscal year is communicated to all relevant stakeholders and the technical process innovation projects can be formally initiated.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

Manufacturing concepts are only considered in the evaluation and selection process when the organisational units and subunits have formally submitted their innovation project proposals. The production department's central predevelopment committee acts as a quality gatekeeper to ensure decision-making effectiveness in the top-management committee. For this reason, the innovation unit supports the ideas/solutions providers to establish the estimates of their project planning parameters in order to achieve 'prioritisation maturity'. The importance of innovation for the top-management is described by the production department's head of innovation as follows:

You can always argue with the top-management about more creative freedom or more funding for predevelopment and process research but I think this is not the crucial question. I think the mindset in the production department is already the right one. And the fact that our top-management committee deals three times a year for several hours with innovation in terms of content, yes, they look at the projects and discuss their content, already shows the importance of innovation. [...] The top-management committee is aware that these ideas are the seeds for future success and hence they invest their time, their precious time. Well, I think there is already the right mindset. (Middle-level management, interviewed on 01 August 2014, translated by the author)

The rigorous process enables a deliberate decision of how much budget and capital investment will be committed to selected manufacturing concepts and it provides valuable top-management support from the outset. In short, the knowledge and skills to evaluate and select manufacturing concepts are institutionalised through robust decision-making practices to decide promising manufacturing concepts.



Source: The author

Figure 23: The IDEFo diagram - Node A11

Table 19: The strategies, practices or tactics regarding MRLs 1-2

<i>Manufacturing Readiness Levels 1-2</i>	
<i>Strategies, Practices or Tactics</i>	<ul style="list-style-type: none"> • Establish and maintain performance measurement and causal analysis practices to elicit manufacturing shortfalls • Establish and maintain systematic ideation services and open exchange platforms to support ideas/solution providers • Establish and maintain robust decision-making practices to decide promising manufacturing concepts

Source: The author

4.2.2 Identify Critical Manufacturing Technologies (Node A12)

A summary can be found at the end of this subsection (see Figure 24 and Table 20).

Understand and Assimilate State-of-the-Art (Node Reference A12.1)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

As soon as the authorised technical process innovation projects are initiated, the most recent stage of technological development with the greatest relevance to the determined manufacturing concepts is investigated. This activity is often guided by specific technology needs which are derived from potential applications (i. e. use cases or products). Various sources such as patent databases, scientific publications, conferences, research institutes, suppliers, manufacturers, competitors or industrial fairs are used to identify the latest manufacturing technologies. On the other hand, internal sources such as subject matter experts or documented technical data packages also reveal insights as follows:

It must be mentioned that we do not only adopt the external perspective for our search activities but also utilise internal sources. In other words, we bring together all process partners or we discuss the issues with all relevant process partners in order to find out what we already know about it. And that is indeed astonishing how much we already know about new technologies but the knowledge or expertise is just spread all over the place and not consolidated yet because there was just no need for it. (Middle-level manager, interviewed on 09 September 2014, translated by the author)

The developed understanding of the relevant state-of-the-art is used to assimilate the latest manufacturing technologies to the context-specific technology needs. At that point, the developed manufacturing technology concepts have usually achieved a maturity level that allows the project teams to set up experimental hardware models in a process R&D laboratory.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

At the beginning of the technical process innovation projects, discussions with subject matter experts and the screening of the production department's process asset libraries for project files or technical data packages from similar innovation projects play a key role. However, the project manager of the initiated innovation project is often the ideas/solutions provider and hence not necessarily a member of the production department's central innovation unit. For this reason, the innovation unit offers proactively access to its broad internal and external network and serves as an analogue 'information hub' which connects the ideas/solutions providers to known specialists in the domain as follows:

The complexity of today's cutting-edge technology—as used in automotive construction—demands multidisciplinary cooperation both in-house and beyond a company's walls. [...] The BMW Group maintains excellent relations with internationally recognised scientific institutions, such as the Fraunhofer [Society] and the Max Planck Society, as well as universities and higher education institutions around the world. Such ties are of high value, especially in terms of basic research before competition becomes an issue, as research alliances enable the company to focus its own resources more efficiently and to spread technical and economic risk. (BMW, 2007, p. 19)

In addition, a digital 'information hub'—comparable to social networks or social media platforms—has been established to provide in-house a web-based discussion forum to all members of the BMW Group. In short, the knowledge and skills to understand and assimilate state-of-the-art are institutionalised through information hubs and research alliances to access the latest stage of technological development.

Identify and Analyse Critical Functions/Characteristics (Node Reference A12.2)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

Having developed the manufacturing technology concepts, an essential activity is the identification and analysis of their critical functions/characteristics which may affect the broad performance goals (e. g. takt time and technical availability) of the manufacturing systems later on. Therefore, analytical predictions or assumptions are derived and interpreted in a systematic manner. This includes the development of alternative solution principles and the analysis of their features. For example, in case #1 (*CFRP adhesive bonding process*), a facilitated workshop series was hosted to discuss various process chain scenarios as follows:

In another session we scrutinised all processes and components in the process chain to meet the high sustainability ambitions of the project. One thought was to completely eliminate the largest energy guzzlers such as metal forming processes and painting. For this reason, we discussed the following process chain scenarios: (A) status quo process chain, (B) energy-optimised status quo process chain, (C) no press shop and no paint shop, (D) no press shop and only paint shop pretreatment and (E) no press shop, no body shop and no paint shop. At that point, carbon-fibre-reinforced plastic (CFRP) came into play because we have said, okay, we do not need to paint CFRP, we simply join a full-CFRP vehicle body structure in the body shop and plank it afterwards in the assembly line. (Non-managerial employee, interviewed on 24 July 2014, translated by the author)

The identified critical functions/characteristics of the manufacturing technology concepts are then analysed to determine adequate analytical predictions. Drawing on these preliminary considerations, the project teams derive procedures and criteria which are required to test and validate their concepts with experimental hardware models.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

Depending on the availability of the latest manufacturing technologies and their intellectual property rights, a common practice is to systematically establish and document alternative solution principles. This process is supported as needed by the production department's central innovation unit with its methodological expertise in terms of creativity and problem solving techniques. For promising solution principles, invention disclosures are initiated as soon as possible in order to protect the intellectual property (IP) as follows:

At that point, we are mostly instructed to write invention disclosures in order to start our internal IP process. The ideal case is to do this as soon as we have the idea even when we do not know whether the ideas work at all or the concepts are feasible. (Non-managerial employee, interviewed on 02 April 2014, translated by the author)

BMW's in-house patent attorneys support the project teams and prepare, amend and file patent applications if applicable. In short, the knowledge and skills to identify and analyse critical functions/characteristics are institutionalised through support mechanisms to aid ideas/solutions providers in generating conceptual alternatives.

Test and Validate Manufacturing Technology Concepts (Node Reference A12.3)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

Once the manufacturing technology concepts and the associated analytical predictions are developed, a hands-on 'impulse experiment' is conducted to further advance the emerging understanding of the technical feasibility. Experimental hardware models—which are set up either in-house or, more often, external in process R&D laboratories of research institutes, suppliers or manufacturers—are used to test and validate the concepts. For example, in case #2 (*human-robot co-operation*), the functionality of the manufacturing technology concept was demonstrated together with a leading robotics producer as follows:

In December 2011 we visited Universal Robots in Denmark and we constructed a rudimentary test set-up in their laboratory. We mounted a roller head on the robot arm and clamped a car door in a vice. Then, we programmed and demonstrated rolling scenarios and tested the robot arm's force control. So, all in all, we spent two days in Denmark to get a feel for the functionality of the robot arms and to show if our concept is practical. (Non-managerial employee, interviewed on 11 June 2014, translated by the author)

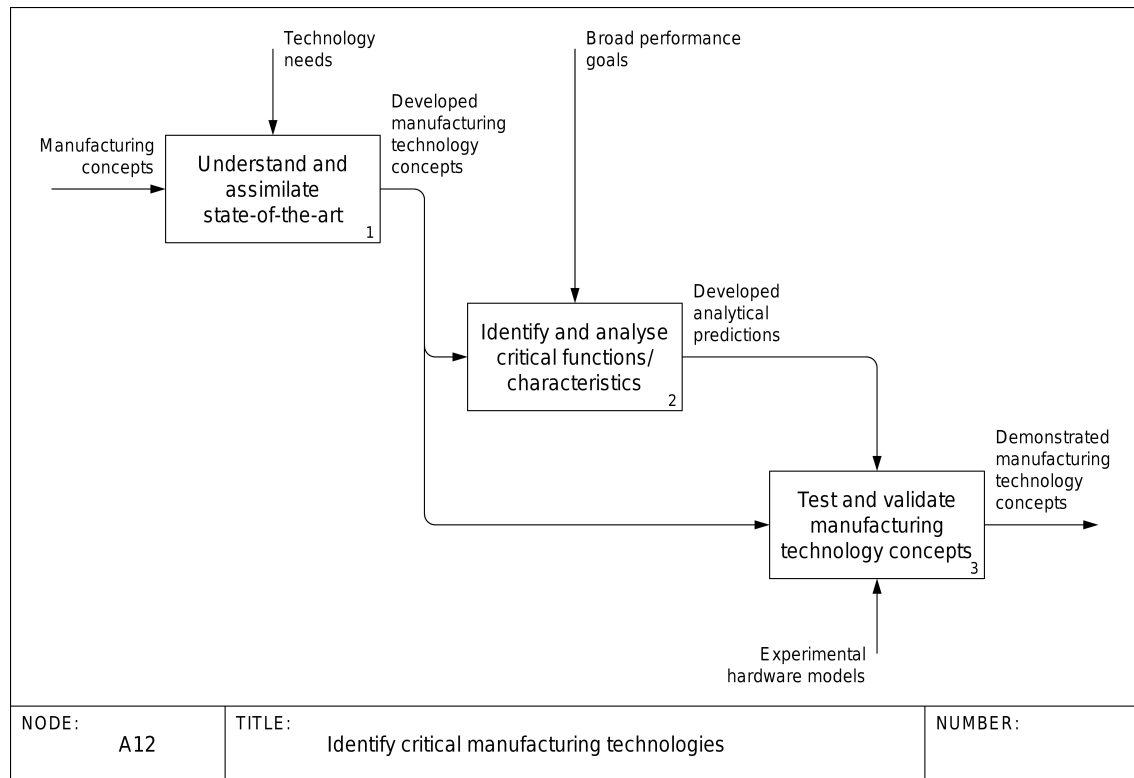
Commonly, a simplified sampling plan with different scenarios, materials or shapes is used to investigate some initial process variables including (upper/lower) control limits relevant for a descriptive process model at a later stage. As a result, the demonstrated manufacturing technology concepts allow the project teams to narrow down the appropriate fields of application.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

At the transition from descriptive concepts to demonstrated 'hardware' concepts, it is essential to gain access to process R&D laboratories. The production department has established several test areas for different manufacturing technologies (e. g. robot laboratory or rapid prototyping centre) equipped with laboratory tooling and special test/inspection apparatuses. For example, the project manager of case #2 (*human-robot co-operation*) emphasised the importance of protected 'incubators' with adequate degrees of freedom as follows:

The next very important thing is, that you need physical space, some kind of 'incubator', not only to give things a try but also to provide your employees a workplace which encourages creativity. And I cannot offer them this atmosphere in a large business office because they need a space where they can muddle along, physically build their concepts and install test cases for future-oriented applications. (Lower-level manager, interviewed on 26 June 2014, translated by the author)

Small-scale innovation projects test their manufacturing technologies often with external partners in order to reduce costs and to spread project risks prior to investing in laboratory tooling. In short, the knowledge and skills to test and validate manufacturing technology concepts are institutionalised through work environment standards in process R&D laboratories to encourage initial experimenting.



Source: The author

Figure 24: The IDEFo diagram - Node A12

Table 20: The strategies, practices or tactics regarding MRL 3

<i>Manufacturing Readiness Level 3</i>	
<i>Strategies, Practices or Tactics</i>	<ul style="list-style-type: none"> • Establish and maintain information hubs and research alliances to access the latest stage of technological development • Establish and maintain support mechanisms to aid ideas/solutions providers in generating conceptual alternatives • Establish and maintain work environment standards in process R&D laboratories to encourage initial experimenting

Source: The author

4.2.3 Determine Current State of Critical Technologies (Node A13)

A summary can be found at the end of this subsection (see Figure 25 and Table 21).

Derive and Detail Manufacturing Requirements (Node Reference A13.1)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

Based on the technical feasibility and potential applications of the manufacturing technology concepts, manufacturing requirements are derived. These requirements are outlined for each technology component in order to identify any critical interfaces. Moreover, the requirements list which decomposes the top level performance requirements of the work product is then further detailed into functionality and quality attributes. For example, in case #1 (*CFRP adhesive bonding process*), the manufacturing requirements were developed as follows:

First of all, we collected the requirements of the adhesive bond and its bond strength. When a potential application is requested, we usually know the material of the two substrates being bonded, the underlying takt time and manufacturing constraints in terms of loads and forces on the substrates or limited accessibility of the bond line, all these issues. Then, we translated the requirements into attributes regarding the surface pretreatment on the substrates, viscosity of the adhesive, working time, fixture time, bond line thickness and so on and so forth. (Lower-level manager, interviewed on 06 February 2014, translated by the author)

The described functionality and quality attribute requirements are documented in a 'statement of work' which establishes the baseline for the design of the laboratory tooling. At this stage, the 'statement of work' is also used to select external partners who can either provide an adequate laboratory tooling or obtain access to their process R&D laboratories in order to produce technology demonstrators.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

In large-scale innovation projects, formal meetings are used to bring together development teams, subject matter experts and potential end-users to carry out, for example, a quality function deployment (QFD) with which manufacturing requirements can be systematically derived. Small-scale innovation projects use mostly informal interviews with relevant stakeholders rather than facilitated workshops. Nevertheless, the involvement of potential end-users at this stage is essential for all projects as follows:

But the key is surely to involve the potential end-users well enough in advance so that their issues can be taken into account. Frankly speaking, because they have the experiences from everyday operations and the innovation projects in which they have been involved right from the start turned out to be the more successful ones at the end. (Middle-level manager, interviewed on 27 October 2014, translated by the author)

The manufacturing requirements are then documented by means of standard 'statement of work' templates with predetermined requirement categories to ensure completeness. An established requirements traceability matrix helps to manage changes as they evolve in the course of the innovation projects. In short, the knowledge and skills to derive and detail manufacturing requirements are institutionalised through early-stage involvement of potential end-users to incorporate their manufacturing requirements.

Produce and Evaluate Technology Demonstrators (Node Reference A13.2)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

The laboratory tooling is used to enable familiarisation with the manufacturing technology and to investigate initial process variables in order to get a feel for their impact on the defined manufacturing requirements. Depending on strategic considerations (e.g. availability of intellectual property rights, knowledge sharing with external partners or needed capital investment), the laboratory tooling is as often as not set up in one of the production department's test areas. For example, in case #8 (*laser-based rapid prototyping process*), the decision was made to continue the development in-house as follows:

We have done that more or less in parallel, so after the external 'impulse experiment' with the Fraunhofer Institute for Laser Technology has revealed that the process works or basically is feasible, it was only a question of how do we get there. So, the matter was clear from the outset, if we want to add value, we can, of course, commission an external parameter study, but we need to be able to do this in-house as well. Otherwise, we would always need to qualify suppliers who have such a system to do this for us. For this reason, in the context of the innovation project, we decided, okay, we will set up the equipment here. (Non-managerial employee, interviewed on 02 April 2014, translated by the author)

As soon as the laboratory tooling is available or access to it is obtained, technology demonstrators are produced and evaluated according to the documented functional and quality attribute requirements. At this stage, particular focus is on sufficient reproducibility of the technology demonstrators which shows the capability to produce the manufacturing technology in a process R&D laboratory.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

The laboratory tooling needed to demonstrate manufacturing technologies in-house is often provided free of charge or at lower costs by production equipment suppliers because of their hope to get a big contract later on. Attributes such as candour, fairness and trust are not only necessary between BMW and its external partners but also between the management and the project teams. For example, in case #2 (*human-robot co-operation*), the mindset and behaviour of the management influenced the project progress as follows:

Well, in principle, it was important to have some degrees of freedom that I can just do my job here and build this robot system. Because, if I had a boss who recalculates every single cable or questions every part I have asked for, believe me, I would not have build a second system. Then, I would not fancy any more work and probably I would have simply said, sorry, the concept is not working. (Non-managerial employee, interviewed on 11 June 2014, translated by the author)

At this stage of the innovation projects, the production department's test areas are like experimental playgrounds or 'incubators' used to enable familiarisation with the manufacturing technologies. In short, the knowledge and skills to produce and evaluate technology demonstrators are institutionalised through innovation incubators with adequate degrees of freedom to protect immature work products.

Identify and Assess Manufacturing Risks/Cost Drivers (Node Reference A13.3)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

After the manufacturing technologies are demonstrated, the 'potential study' is completed with the estimation of any cost-effectiveness implications. Defined risk categories (e.g. technology risks, quality risks or regulatory risks) are used to identify potential manufacturing risks as well as hidden cost drivers and to determine their relative importance. For example, in case #7 (*advanced composite forming process*), the initial risk assessment as part of the 'potential study' was described as follows:

I would say that the management of risks runs always in parallel with the project but at that point we must formally assess and document them to meet the acceptance criteria of our innovation stage-gate model. We did it together with our internal and external process partners because then you can really classify the risks and specifically say what are the risks in the process, what are the risks of the mixing head and the fluidity of the resin or the mould and the moulding pressure and so on. It is only to raise awareness of potential risks and to estimate associated costs to mitigate them. (Non-managerial employee, interviewed on 20 February 2014, translated by the author)

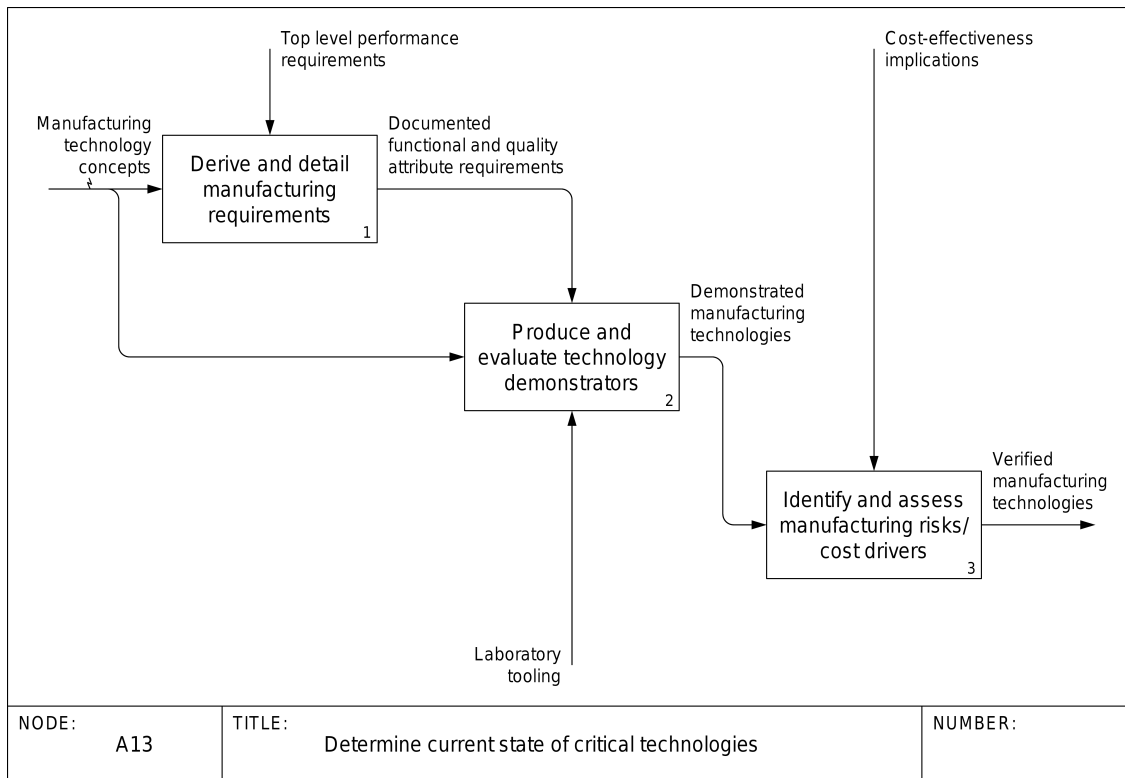
In addition, risk mitigation plans are developed to reduce adverse impacts on the project objectives. As a result, the identified and assessed manufacturing risks and cost drivers complete the understanding of the assimilated manufacturing technologies.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

The established risk management standards support the project teams to identify and analyse risks and to determine their relative importance. However, the existing managerial system with its incentive scheme also influences the assessment of manufacturing risks/cost drivers. The required entrepreneurial mindset of the project managers is described as follows:

So, I think the most important mechanism is actually the awareness that a project termination or premature closure is not equal to 'I have not done my job'. Therefore, the rewards and sanctions as well as the agreement on objectives should not be designed in a way that only a completed project is a successful project and the project manager did a good job. This is the most crucial measure for me and so I believe that a measure like an innovation transfer rate is complete nonsense. This is a target that leads to a misallocation of resources in the organisation. [...] So, all project managers need the consciousness, hey, I am in a risky business, this is like take in hand venture capital which means that some ideas come through and some do not. It is as simple as that or I just paint my world very simple. (Middle-level manager, interviewed on 01 August 2014, translated by the author)

For this reason, it is essential to align the project's cost-effectiveness objectives with the rewards and sanctions policies for project managers. In short, the knowledge and skills to identify and assess manufacturing risks/cost drivers are institutionalised through systematic procedures to objectively evaluate the demonstrated manufacturing technologies.



Source: The author

Figure 25: The IDEFo diagram - Node A13

Table 21: The strategies, practices or tactics regarding MRL 4

<i>Manufacturing Readiness Level 4</i>	
<i>Strategies, Practices or Tactics</i>	<ul style="list-style-type: none"> • Establish and maintain early-stage involvement of potential end-users to incorporate their manufacturing requirements • Establish and maintain innovation incubators with adequate degrees of freedom to protect immature work products • Establish and maintain systematic procedures to objectively evaluate the demonstrated manufacturing technologies

Source: The author

4.3 TRANSFORM MANUFACTURING PROCESSES (NODE A2)

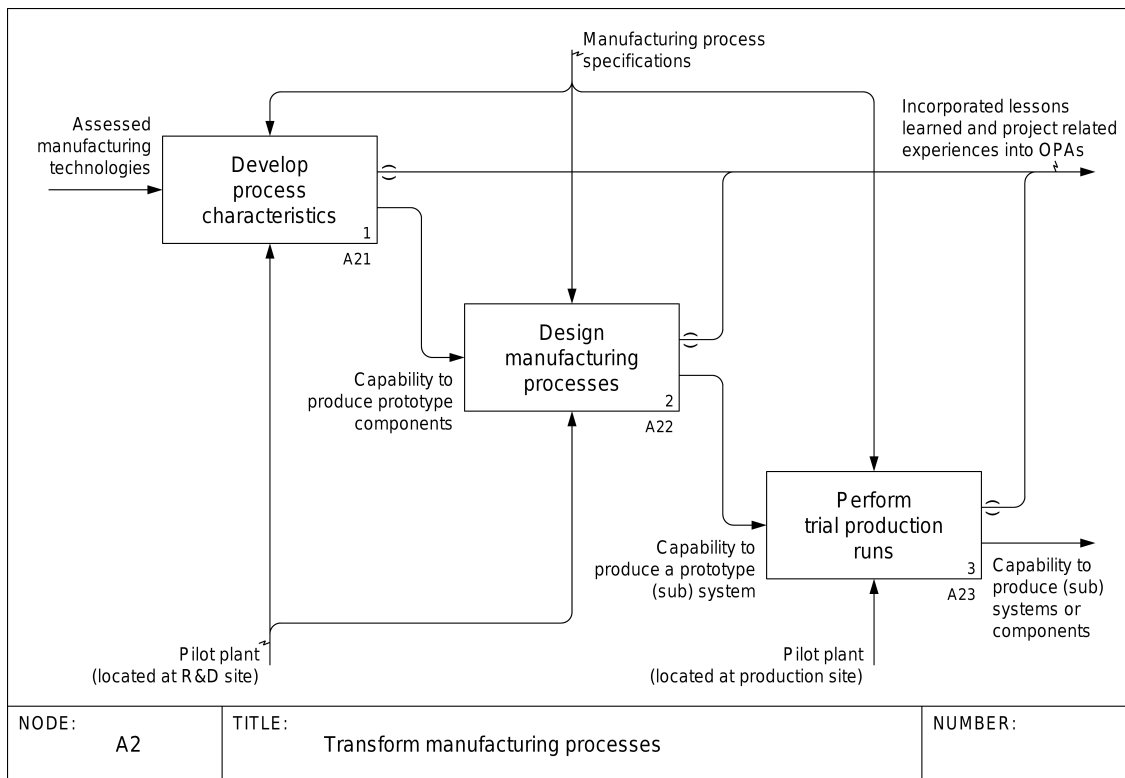
The top-level learning routine *transform manufacturing processes* is the 'transmission belt' between the capability to produce the technology in a laboratory environment and the capability to produce systems, subsystems or components in a production representative environment. For example, referring to case #1 (*CFRP adhesive bonding process*), this natural progression of manufacturing maturity was described as follows:

The newly produced CFRP composite components from the new Leipzig pressing plant and supplied CFRP parts from the Landshut pressing plant are assembled in the new car body construction hall. [...] There is no noise pollution from screwing or riveting, no sparks flying during welding, and only the latest adhesive technology is used, which is 100 per cent automated. A technology mastered by BMW alone. In the unique joining process developed by BMW, the individual components are assembled without touching to an adhesive gap of 1.5 millimetres in order to ensure optimal strength after the adhesive procedure. In the newly developed manufacturing process, all connecting components in the Life module [or passenger cell] are always separated by the same gap and so receive the same amount of adhesive. Only this precision guarantees perfect power transmission between the individual CFRP components and therefore the highest standard of quality in the mass production series. [...] To minimise [the curing time] for mass production of the BMW i3, BMW has greatly accelerated this curing process. A newly developed adhesive can now be processed for only 90 seconds before developing adhesion following application to a component. Half an hour later it is hard. This property represents a ten-fold acceleration of a traditional bonding process. In order to further reduce the curing time to the single-digit minute range, BMW has developed an additional thermal process. This involves additional heating of specific adhesion points on the CFRP parts to be bonded to further accelerate the curing process by a factor of 32. (BMW, 2013a, pp. 8-9)

During the transformation phase of the technical process innovation projects, the following manufacturing readiness levels (MRLs) are achieved (see Figure 26):

- capability to produce prototype components in a production relevant environment (MRL 5),
- capability to produce a prototype system or subsystem in a production relevant environment (MRL 6) and
- capability to produce systems, subsystems or components in a production representative environment (MRL 7).

The established pilot plants which are located at the R&D and production sites enable the project teams to transform new manufacturing processes by means of prototype tooling and pre-production tooling. In order to maintain the new knowledge and skills, the used organisational process assets (e. g. plans, processes, policies, procedures and knowledge bases) are revised by the project teams throughout the transformation phase as necessary.



Source: The author

Figure 26: The IDEFo diagram - Node A2

4.3.1 Develop Process Characteristics (Node A21)

A summary can be found at the end of this subsection (see Figure 27 and Table 22).

Plan and Define Descriptive Process Models (Node Reference A21.1)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

The developed understanding of the manufacturing technologies and their initial process variables largely based on 'impulse experiments', technology demonstrators and 'potential studies' is used to compile and refine descriptive process models. In the most general sense, a descriptive process model comprises a list of systematically identified process variables such as process inputs and outputs and their relationships. For example, in case #9 (*thermal welding process for metallic materials*), the relevant process inputs were selected as follows:

At the beginning, I have outlined 22 parameters which may influence the process. Now, it is immediately obvious that I cannot examine 22 different parameters, this is just not practicable. Therefore, I have decomposed the process inputs further into process parameters [i.e. adaptable during the process] and system parameters [i.e. non-adaptable during the process] and then, according to the investigated state-of-the-art and the manufacturing requirements, I have selected five process parameters which I want to examine with a full factorial design more closely. (Non-managerial employee, interviewed on 15 May 2014, translated by the author)

A goal statement derived from the documented 'statement of work' supports this process by narrowing down the parameters of interest. At the end, the descriptive process models incorporate the key specifications/manufacturing indices and result in thoroughly designed sampling plans.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

The production department's test areas are open spaces on which various project teams put their laboratory tooling or pilot plants next to each other. This coexistence of early-stage predevelopment and process research constitutes an informal and supportive innovation community. In addition, cumulative cross-project learning is promoted through regular meetings with the focus on process families such as the 'joining process circle' or process classes such as the 'welding process circle'. For example, project team members of cases #10-14 (*mechanical and thermal welding processes for polymeric materials*), discuss their process variables and compare and contrast relevant results as follows:

I plan to perform, among others, the double cantilever beam (DCB) test according to ISO 15024 [determination of mode I interlaminar fracture toughness] and the tensile bond strength test according to our in-house standard with defined sample geometries. We enter our results into a shared list so that we can compare the used process parameters of the 4-5 processes and the respective tensile bond strength which is particularly important to assign the processes later on to target applications of the vehicle body structure or hang-on parts. This exchange with my colleagues is very helpful to select the relevant process parameters because our processes can often be influenced by similar parameters. (Non-managerial employee, interviewed on 11 April 2014, translated by the author)

Such meetings are practices to accumulate experiences and to articulate and codify knowledge of various innovation projects working on similar manufacturing processes within process families or process classes. In short, the knowledge and skills to plan and define descriptive process models are institutionalised through synchronisation mechanisms between similar innovation projects to foster cumulative learning.

Perform and Analyse Basic Parameter Studies (Node Reference A21.2)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

The capability to produce the technology is now absolutely necessary to execute the designed sampling plans in two basic parameter studies with appropriate demonstration units. In the first 'test series', the manufacturing process is applied to 2-D (flat) models; while in the second 'test series', the manufacturing process is applied to non-functional 3-D models. For example, in case #15 (*conventional composite forming process*), a lessons learned regarding the basic parameter studies was described as follows:

At the beginning, we bypassed the two basic parameter studies and started our 'test series' with a functional prototype which was available and we hoped to reduce our development time. However, the functional prototype did not match the requirements and we ended up with more questions than answers. Now, we need to go back and perform the parameter studies with some sample geometries to better understand our process model. (Non-managerial employee, interviewed on 15 May 2014, translated by the author)

Both basic parameter studies normally include quasi-static and dynamic tests to analyse the key process variables of the descriptive process model. The used prototype tooling is specifically designed for the different demonstration units and adapted from 'test series' to 'test series'. Overall, the two basic parameter studies which are typified through increasing representativeness of the demonstration units and increasing degree of automation of the pilot plants are considered as the centre-piece of process research.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

Innovation projects with a clearly defined target application at the outset conduct the process research most often in-house in one of the production department's test areas. However, similar to the production of technology demonstrators, the innovation projects have the freedom to perform the basic parameter studies in-house or with the support of external partners. For example, in case #4 (*adhesive injection bonding process*), the parameter study was initiated at the suppliers site as follows:

We ordered the pilot plant for our test area but the delivery time was very long. For this reason, the production equipment supplier offered us that in the meantime we can use the equipment in his process R&D laboratory to start our parameter study. So, I have asked the 'process planner' to join me because it is a completely new process for us and so he can already see what he has to expect for later design stages. (Non-managerial employee, interviewed on 03 April 2014, translated by the author)

Depending on the project objectives and the defined target applications, the project teams usually invest in their own pilot plants in order to fully control the gained process know-how. In short, the knowledge and skills to perform and analyse basic parameter studies are institutionalised through pilot plants located at the R&D site to develop an understanding of the key process variables.

Interpret and Report Data-Based Process Models (Node Reference A21.3)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

After each parameter study is conducted, the documented key process variables are interpreted and matched with the derived goal statement. Manufacturability, producibility and quality considerations are increasingly important to determine the optimised set of process and system parameters. For example, in case #8 (*laser-based rapid prototyping process*), the optimisation efforts were driven by cost-effectiveness implications as follows:

We only get further funding to continue our investigation if we can prove that we are able to make a transfer [i. e. to confirm a target application for the manufacturing process]. However, our set of parameters is still too expensive to be attractive for potential end-users simply because the used equipment configuration and the machine-hour rate are expensive. For this reason, we need to think about a cheaper equipment or at least to think about a concept how we can reduce our costs. (Non-managerial employee, interviewed on 02 April 2014, translated by the author)

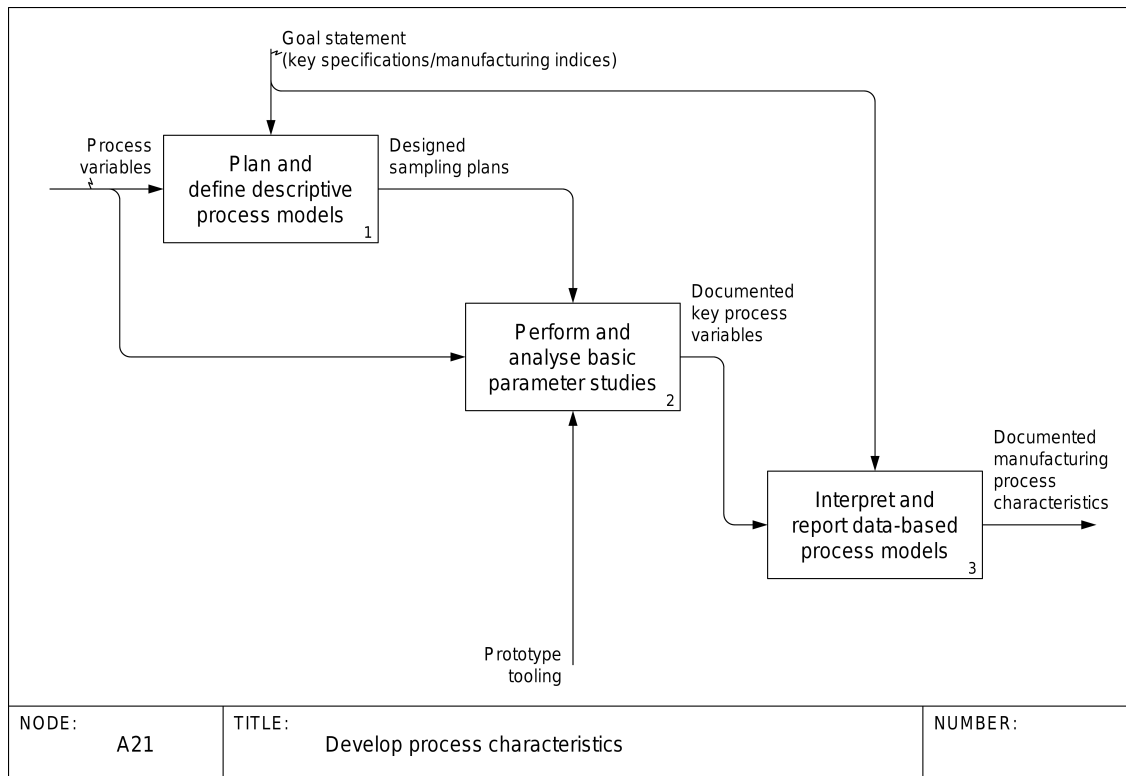
In most cases, the production department's central predevelopment committee manages the capital investment for relevant production equipment which is only released when the acceptance criteria of the innovation stage-gate model are met. As a result, the manufacturing processes are characterised with data-based process models and hence achieved a maturity level so that they can be offered to the different product lines for defined target applications.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

The identified sets of process and system parameters are codified know-how of the manufacturing processes. Therefore, the production department has established various measurement repositories to make the approved results generally available to other organisational units and subunits. For example, in case #1 (*CFRP adhesive bonding process*), the reporting of the data-based process model was described as follows:

The CAWIS [computer aided welding and joining information system] report is finally the documentation of your process model that has been elaborated in compliance with all manufacturing requirements. So, you have performed your basic parameter study in the correct way according to the given standards and now you document all the identified process characteristics in this CAWIS report. For example, you have detected any specific welding parameters or bonding parameters and then you document them in this database. So you know, if you need to join a plate pairing with another plate pairing, you need such and such welding parameters because they are documented in the CAWIS report. (Non-managerial employee, interviewed on 12 March 2014, translated by the author)

As soon as the manufacturing process characteristics are documented, 'transfer maturity' of the manufacturing processes is achieved which describes the capability to produce prototype components in a production relevant environment. In short, the knowledge and skills to interpret and report data-based process models are institutionalised through central measurement repositories to make results of the parameter studies available as needed.



Source: The author

Figure 27: The IDEFo diagram - Node A21

Table 22: The strategies, practices or tactics regarding MRL 5

<i>Manufacturing Readiness Level 5</i>	
<i>Strategies, Practices or Tactics</i>	<ul style="list-style-type: none"> • Establish and maintain synchronisation mechanisms between similar innovation projects to foster cumulative learning • Establish and maintain pilot plants located at the R&D site to develop an understanding of the key process variables • Establish and maintain central measurement repositories to make results of the parameter studies available as needed

Source: The author

4.3.2 Design Manufacturing Processes (Node A22)

A summary can be found at the end of this subsection (see Figure 28 and Table 23).

Plan and Define Process Architecture (Node Reference A22.1)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

Having confirmed a target application for the manufacturing process and successfully met the acceptance criteria of the innovation stage-gate model, a modification of the prototype tooling is needed to produce functional prototypes. In the event that all previous 'test series' have been performed with external partners, a pilot plant must be established in one of the production department's test areas. Therefore, the functional and quality attribute requirements are adjusted according to the target application and a process architecture (i. e. conceptual design of the pilot plant) is elaborated. For example, in case #4 (*adhesive injection bonding process*), the process architecture was planned and defined as follows:

First of all, you need to know the adhesive system or the type of the adhesive system for your target application because you can use single part systems or two-part mixable systems. Another key question is whether you want a stationary process and you move the substrates or do you want a mobile process perhaps mounted on a robot head. So, this should be clear at the outset. Then you can arrange the different process components such as the reactant tanks, the mixing head or the dispenser but very often you have limited installation space available and you need to consider influential parameters such as dispensing volume, nozzle diameter, viscosity of the adhesive or working time when you conceptualise the equipment. (Non-managerial employee, interviewed on 03 April 2014, translated by the author)

Simultaneously, a structured tendering process for the pilot plant is initiated which includes tasks such as preparing tender documents, processing quotations, giving technical placing suggestions and the placing of an order itself. Finally, the designed process architecture can be further detailed with selected production equipment suppliers.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

At this stage of the innovation projects, the technical expertise of production equipment suppliers is used to discuss the process architecture (i. e. conceptual design of the pilot plant). In most cases, the screening of potential suppliers is conducted by the project teams themselves. For example, in case #8 (*laser-based rapid prototyping process*), the project team consulted relevant suppliers as follows:

We wrote a specification in which we detailed our ideas and what we want to implement. But otherwise, we totally trusted their [suppliers] competence because we had very little knowledge about the relevant process components. Sure, we have already used SLM [selective laser melting] but this deposition method was new for us and we had almost no experience with the process and its production equipment. So, they helped us to elaborate the concept and to refine the specification. (Non-managerial employee, interviewed on 02 April 2014, translated by the author)

Having defined the process architecture, the purchasing department is involved to perform the standardised tendering process and to select appropriate suppliers. In short, the knowledge and skills to plan and define the process architecture are institutionalised through acquisition mechanisms to incorporate external know-how into the conceptual process design.

Detail and Describe Process Components (Node Reference A22.2)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

The selected production equipment suppliers detail each process component of the conceptualised process architecture and elaborate relevant manufacturing drawings and the associated bill of materials. As soon as preliminary results are available, the project teams check, among others, kinematic or accessibility aspects of the process components and their interface compatibility. For example, in case #14 (*mechanical welding process for polymeric materials*), the responsible 'process planner' described this activity as follows:

So the first step will be that the design is detailed on CAD [computer aided design] basis which includes in our case the prototype tooling with all welding components and mechanical parts. We have already defined the interface to the robot; so, we have just announced it in the tender documents and passed the interface descriptions on to the selected suppliers. When they have outlined the detailed design, we can simulate any mechanical processes. Depending on the scope and complexity, this will take around 6-8 weeks until the CAD is ready for evaluation. (Non-managerial employee, interviewed on 10 April 2014, translated by the author)

After completing several iterative improvement cycles, the process components are described and their interfaces comply with the interface descriptions. In the next step, the detailed design of the process components is released and their fabrication is triggered.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

A common practice is to standardise the used process components in order to facilitate their integration into existing manufacturing systems. Therefore, newly designed process components for pilot plants should comply with BMW's design standards and already try to use commercial off-the-shelf solutions. For example, in case #14 (*mechanical welding process for polymeric materials*), the new process components were designed to given standards as follows:

Our pilot plant in the test area is already designed in a way that we can easily deduce the series equipment from it because one of our requirements was to use standard components which we also use in the series production. This included standard clutches, standard pneumatic components, standard tool changer and tool stations and so on just to approximate as close as possible the potential series configuration of the plant. (Non-managerial employee, interviewed on 10 April 2014, translated by the author)

The utilisation of standardised process components according to established design catalogues is essential to ensure cost-effectiveness during the industrialisation stages later on. In short, the knowledge and skills to detail and describe process components are institutionalised through rules and guidelines for the design of process components to ensure cost-effective solutions.

Implement and Test Process Components (Node Reference A22.3)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

The fabricated process components are usually assembled according to the conceptualised process architecture at the supplier's site where they can be verified whether they meet the specified requirements. When the assembled pilot plant is accepted, the equipment is installed in one of the production department's test areas to produce functional prototypes. For example, in case #8 (*laser-based rapid prototyping process*), the pilot plant was put into action as follows:

The supplier delivered a 'turnkey ready' pilot plant. So, in principle, the delivery also included standard STL [Surface Tessellation Language] files so that we could immediately test the process components. In addition, a technician from the supplier spent one week with us to introduce the software, the control unit and so on. So, he provided a training and demonstrated how the different components work. (Non-managerial employee, interviewed on 02 April 2014, translated by the author)

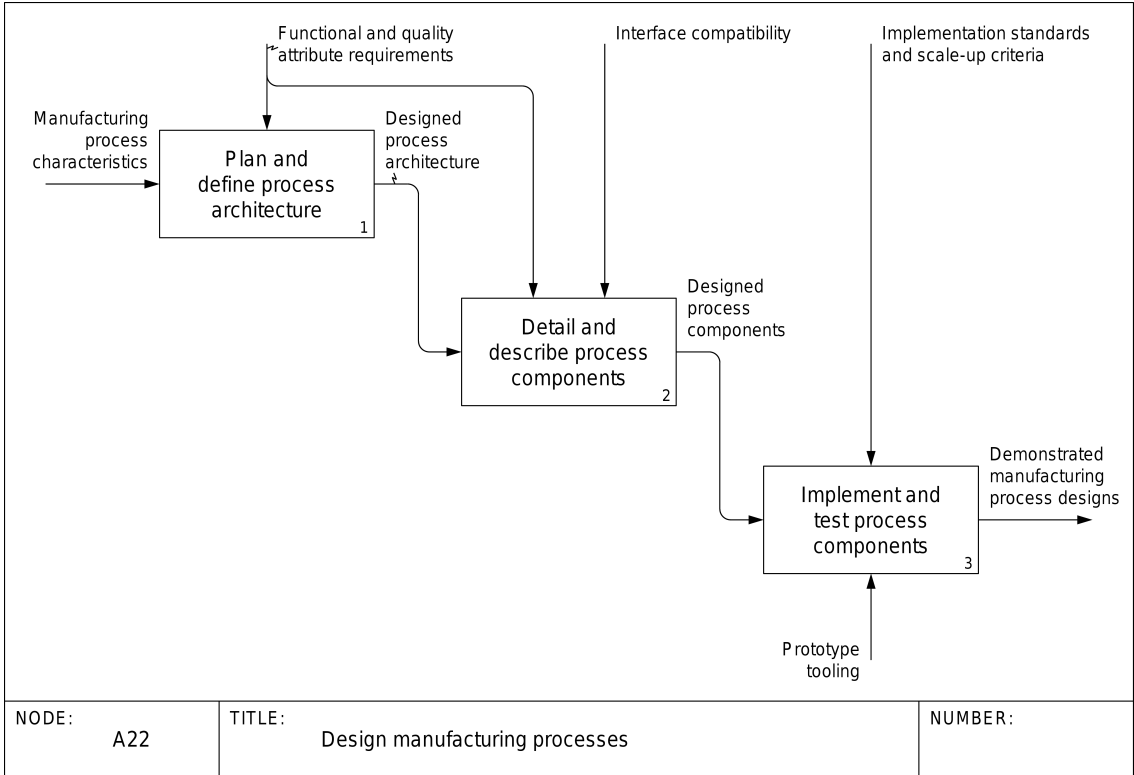
Having installed the modified prototype tooling and adjusted the determined processes characteristics, a third 'test series' with functional prototypes in reasonable quantity is performed. As a result, the designed manufacturing process demonstrates the capability to produce prototype (sub) systems in a production relevant environment.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

The purpose of the third 'test series' is to learn about the behaviour of the designed manufacturing processes in a production relevant environment and to optimise their process characteristics regarding the target applications. This activity is usually performed in-house in one of the production department's test areas and includes plant operators and maintenance workers who incorporate their production know-how. For example, the production manager of a series production body shop described the involvement of his technical staff as follows:

This initial prototype testing is extremely important, yes, I definitely need to be there with my team not only that we can give our input from the perspective of production or maintenance but also to learn what kind of processes are coming, what training is necessary, what should I do to prepare my staff, what comes to us as the operator [i.e. process end-user] and the responsible producer. So, when the new processes are somewhere available, I am already involved. (Middle-level manager, interviewed on 07 November 2014, translated by the author)

As soon as functional prototypes of the target applications are tested, existing production capabilities become increasingly important. Their co-ordination with technological development capabilities needs to be carefully managed in order to prepare the manufacturing processes for the pilot/serial line environment. In short, the knowledge and skills to implement and test process components are institutionalised through production workforce involvement to consider practical implications of manufacturing processes.



Source: The author

Figure 28: The IDEFo diagram - Node A22

Table 23: The strategies, practices or tactics regarding MRL 6

Manufacturing Readiness Level 6	
Strategies, Practices or Tactics	<ul style="list-style-type: none">• Establish and maintain acquisition mechanisms to incorporate external know-how into the conceptual process design• Establish and maintain rules and guidelines for the design of process components to ensure cost-effective solutions• Establish and maintain production workforce involvement to consider practical implications of manufacturing processes

Source: The author

4.3.3 Perform Trial Production Runs (Node A23)

A summary can be found at the end of this subsection (see Figure 29 and Table 24).

Develop and Maintain Technical Data Packages (Node Reference A23.1)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

After the third 'test series', a technical data package for the manufacturing process is developed. This package contains, among others, the concept of the process architecture, the description of the process components and the documented process characteristics. For example, in case #1 (*CFRP adhesive bonding process*), the developed 'process instruction' was described as follows:

Well, such a 'process instruction' is so to speak a kind of controlled document and its development basically starts as soon as you know, okay, we have a target application and want to produce a functional prototype. In our case, the document described in a step-by-step logic the pretreatment of the CFRP parts, the cleaning of the substrates, the application of the activator and the bond line and so on. In its original draft version at the very beginning, it was even more detailed, we literally depicted all bond lines with images to guide the operators, look here, if you take the part then you have to grind this point, you need to clean this point and here you need to put your adhesive on. So, the colleagues actually printed the document and put it beside the equipment. (Non-managerial employee, interviewed on 12 March 2014, translated by the author)

In general, the developed technical data package is a collection of all relevant documents or manuals and determines the standard of the designed manufacturing process. At that point, the manufacturing processes are sufficiently robust so that they can leave the 'incubator' and be transferred to a production representative environment.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

The gained process know-how of the previous three 'test series' is condensed and comprehensively documented in order to make it available to other organisational units and subunits. A central document management system stores the developed technical data packages and links them with associated standard document classes. The underlying purpose of those process asset libraries was described as follows:

We also try to ensure that the new manufacturing process is anchored somewhere so that the next one who deals with a similar subject in a new product development project can easily find this solution for his design problem. This means that the solution is documented in a 'process instruction' or in a database on which developers, planners and so on have access. So, when they start a new project and think about joining two components that they can find appropriate answers to their questions. (Lower-level manager, interviewed on 23 July 2014, translated by the author)

The stored documents are periodically reviewed and revised as needed in order to keep track of the latest technological development in the production department. In short, the knowledge and skills to develop and maintain technical data packages are institutionalised through controlled standard document classes to codify the acquired/developed process know-how.

Install and Operate Manufacturing Processes (Node Reference A23.2)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

After sufficient testing in one of the production department's test areas, a trial production run is set up so that the manufacturing processes can be applied in a production representative environment. In most cases, this 'pilot' is performed at the production site where either user test models of the target application are produced or potential end-users want to integrate the manufacturing processes later on. For example, in case #2 (*human-robot co-operation*), the project team operated the 'pilot' in the door assembly line of the series production as follows:

We performed a two-week long 'line trial' in the door assembly line. In the first week, we waited until the door was in front of the robot and then we pushed the button to start the process. Then, the robot performed the process because we knew that the door will stand there for one minute and after completion we removed the robot again; this semi-automatic mode happened in the first week. In the second week, we synchronised the robot with the assembly line so that the robot received a signal and started the process automatically. (Non-managerial employee, interviewed on 11 June 2014, translated by the author)

At this stage, the manufacturing processes are already equipped with pre-production tooling which is iteratively modified in order to resolve arising problems during the trial production run. The successful completion of the 'pilot' or the fourth 'test series' triggers the industrialisation of the designed manufacturing processes.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

A trial production run is often one of the first opportunities to demonstrate the manufacturing processes outside of the production department's test areas which are normally located at the R&D site. Therefore, the 'pilot' is set up and performed by the project teams together with manufacturing line supervisors, plant operators and maintenance workers from the series production. This shift from a production relevant environment to a production representative environment requires careful planning as follows:

I provide the team an 'incubator' and I protect the innovation project from the volatile environment and the everyday business. But after a while, with increasing maturity of the manufacturing process, the project team needs to leave the 'incubator'. But to manage this transfer, you need to expand your team stepwise with more and more specialists from the organisation; otherwise, the innovation gets lost in the large organisation. And at some point, you start a 'pilot' to test the process in the real world. (Middle-level manager, interviewed on 01 August 2014, translated by the author)

Depending on the degree of innovativeness, the 'pilot' is also used to increase the acceptance of the manufacturing processes—or to prevent the not-invented-here syndrome—and to provide initial training for individuals. In short, the knowledge and skills to install and operate manufacturing processes are institutionalised through pilot plants located at the production site to perform trial production runs with potential end-users.

Interpret and Assess Trial Production Runs (Node Reference A23.3)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

Drawing on the experiences from the trial production run, the equipment of the manufacturing processes is iteratively modified and adjusted to meet the performance targets. Simultaneously, collected machine and process capability data are interpreted and specifications for the production tooling are derived. For example, in case #2 (*human-robot co-operation*), the improvement cycles as part of the assessment were described as follows:

After the initial 'line trial', we repeated this one or two times until we could install the modified robot which met all requirements of the door assembly line in October 2012. Then, we multiplied the equipment four times because we started the series production with four robots in December 2012. So, the robots have already been there since October, but the start of production was end of 2012 and now, in May 2014, after a 18-months long trial production run, we have finally received the 'green sheet'. This means that production and maintenance have accepted the robot and that they are now responsible for the equipment. (Lower-level manager, interviewed on 26 June 2014, translated by the author)

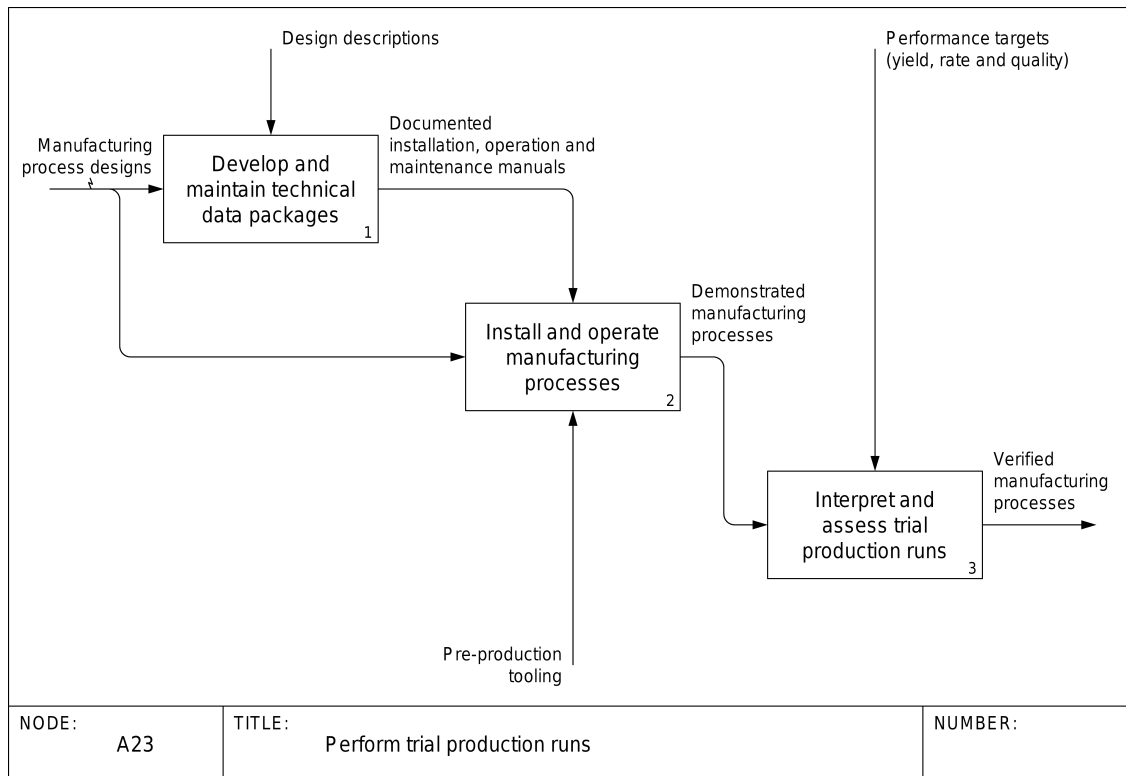
Having successfully achieved the performance targets, the manufacturing processes are verified and hence officially released by the production department. As a result, the designed manufacturing processes demonstrate the capability to produce (sub) systems or components in a production representative environment.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

The fourth 'test series' comprises the evaluation of the initial process architecture and its process components in a production representative environment. Performance targets such as yields, rates and quality measures are established for the trial production runs and their results which are stored in production department's measurement repositories feed improvement plans. For example, in case #1 (*CFRP adhesive bonding process*), the machine capability analysis was performed as follows:

After our trial production run became reasonably stable, we said, okay, now the adhesive system looks like this, the cleaning system looks like this and so on. So, now we can perform the machine capability analysis and we built 50 prototypes in succession without altering any settings and evaluated the results against the targets. (Non-managerial employee, interviewed on 28 July 2014, translated by the author)

The established process quality assurance practices such as machine/process capability analyses which are performed in a production representative environment are described in standard documents and linked to the acceptance criteria in the technical data packages. In short, the knowledge and skills to interpret and assess trial production runs are institutionalised through statistical and other quantitative techniques to systematically improve the process performance.



Source: The author

Figure 29: The IDEFo diagram - Node A23

Table 24: The strategies, practices or tactics regarding MRL 7

<i>Manufacturing Readiness Level 7</i>	
<i>Strategies, Practices or Tactics</i>	<ul style="list-style-type: none"> • Establish and maintain controlled standard document classes to codify the acquired/developed process know-how • Establish and maintain pilot plants located at the production site to perform trial production runs with potential end-users • Establish and maintain statistical and other quantitative techniques to systematically improve the process performance

Source: The author

4.4 EXPLOIT MANUFACTURING SYSTEMS (NODE A3)

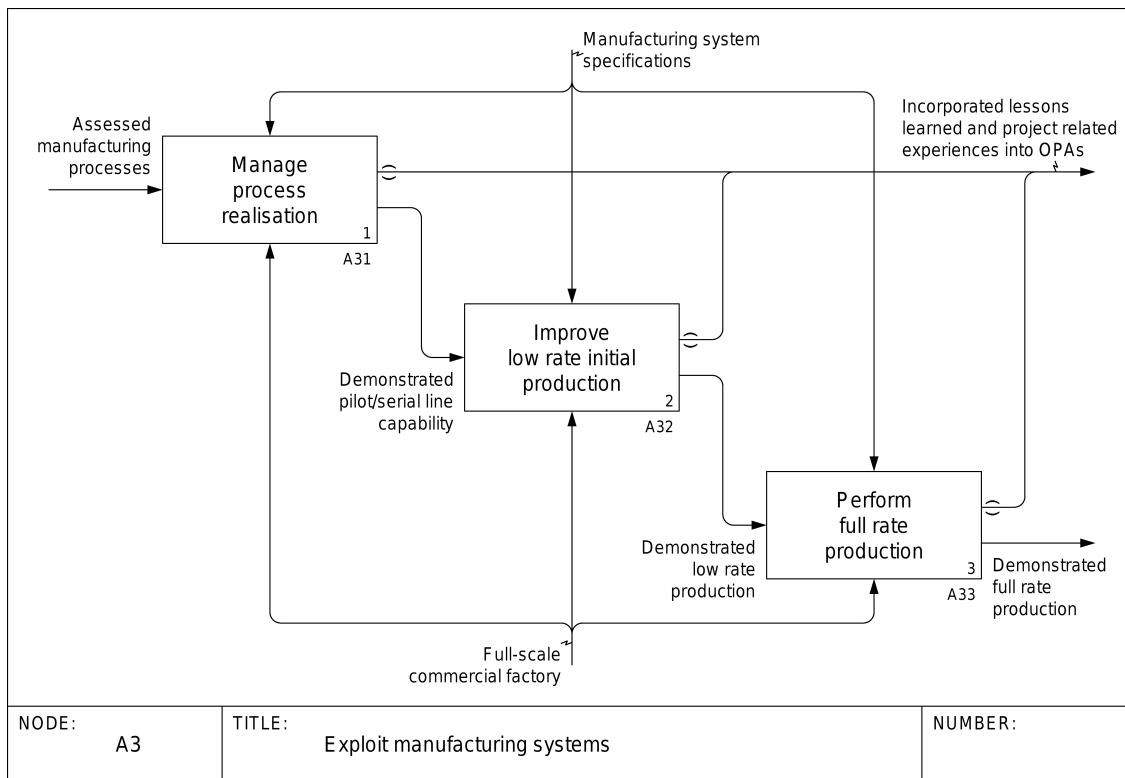
The top-level learning routine *exploit manufacturing systems* reintegrates the 'newstream organisations' or 'incubators' into the main organisation in order to unlock the full potential of the technical process innovations. For example, the industrial-scale manufacture of CFRP—referring to case #1 (*CFRP adhesive bonding process*) and case #3 (*advanced composite forming process*)—was accomplished by industrialising the manufacturing processes as follows:

As the first premium electric vehicle, the BMW i3 rises to the social, ecological and economic challenges of our times. With its groundbreaking vehicle architecture, the concept calls for the use of modern lightweight construction materials as well as innovative production processes. [...] The use of CFRP on the scale required for the BMW i models is without parallel in the automotive industry worldwide and the BMW Group has also assumed a leading role in this area. [...] Over more than 10 years, the BMW Group's specialists have steadily refined and automated the CFRP production process so that it is now possible to volume-produce CFRP body components cost-efficiently, to a high quality and with high process stability. In doing this, the manufacturing costs for CFRP body components over this period have been cut by around 50 per cent. [...] The CFRP process is no longer comparable with conventional sheet steel manufacturing. This industrialised manufacture of CFRP is extremely economical and makes the production of large CFRP composite components for the automotive industry a feasible proposition for the first time. [...] At 20 hours, the total processing time in the body shop and on the assembly line is only half of what be required in a conventional production process. (BMW, 2013d, pp. 2, 4-5, 11)

During the exploitation phase of the technical process innovation projects, the following manufacturing readiness levels (MRLs) are achieved (see Figure 30):

- pilot line capability demonstrated; ready to begin low rate initial production (MRL 8),
- low rate production demonstrated; capability in place to begin full rate production (MRL 9) and
- full rate production demonstrated and lean production practices in place (MRL 10).

As soon as the manufacturing systems are approved in a full-scale commercial factory, the technical process innovations are deployed throughout the production network. In order to maintain the new knowledge and skills, the used organisational process assets (e.g. plans, processes, policies, procedures and knowledge bases) are revised by the project teams throughout the exploitation phase as necessary.



Source: The author

Figure 30: The IDEFo diagram - Node A3

4.4.1 Manage Process Realisation (Node A31)

A summary can be found at the end of this subsection (see Figure 31 and Table 25).

Plan and Define Manufacturing Workstations (Node Reference A31.1)

- What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?

In general, a manufacturing workstation represents a cell equipped with production tooling to produce (sub) systems or components of the target application. Its design is influenced by functional and quality attribute requirements which are derived from the manufacturing system specifications. The dimensioning and structuring of the cell's layout determines the 'quantity structure' of the required production tooling. For example, in case #1 (*CFRP adhesive bonding process*), the planning stage of the manufacturing workstations was described as follows:

I started with a draft layout in which I positioned all my robots, jigs, tool stations and so on according to the joining sequence of the product and the takt time diagram. Then you check the distances from the robots to the dispenser of the stationary adhesive system or when the adhesive system is mounted on a robot head you need to check the accessibility of your parts. Usually you start planning with a 2-D layout and later on you convert it into a 3-D layout to check all accessibilities in more detail to prevent any collisions. It is a very iterative process and you refine the

cell design step by step. Since all process components are already standardised and hence available in our digital layout library, you can design the cell simply by drag and drop and the software creates and calculates all relevant data. (Non-managerial employee, interviewed on 10 June 2014, translated by the author)

After completing the layout, relevant production equipment suppliers are selected to detail and simulate the production tooling. Lastly, the detailed design of the manufacturing workstations is reviewed and change requests or corrective actions are addressed as needed.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

The design activities of the production equipment suppliers are usually initiated with kick-off meetings and followed by several design inspection meetings in which the design drafts and results are reviewed. When the detailed design deviates from the supplier agreement or does not meet the functional and quality attribute requirements from the manufacturing system specifications, appropriate corrective actions are determined to resolve those issues. For example, in case #1 (*CFRP adhesive bonding process*), a design inspection meeting was described as follows:

Depending on the production tooling, this is often a complex and time-consuming task. In most cases, each tool must be discussed several times because necessary design changes are recorded in our database to discuss it in the next meeting again. Literally, you must check every single part of the tooling that it complies with our requirements and standards; otherwise, when you install the tool and it does not work then it is your problem and subsequent design changes are costly. As soon as the tooling is released, the procurement starts and we place an order. At this time, many activities are going on simultaneously. (Non-managerial employee, interviewed on 27 May 2014, translated by the author)

An established configuration management and change management system enables the project teams to track and control any changes to the process components during the early industrialisation stages. In short, the knowledge and skills to plan and define manufacturing workstations are institutionalised through configuration management and change management systems to control supplier agreements.

Build and Integrate Manufacturing Workstations (Node Reference A31.2)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

In most cases, the design and fabrication of the production tooling is performed by the same production equipment supplier. Any nonconformity issues regarding the functional and quality attribute requirements or interface compatibility are communicated and resolved before the equipment is accepted. For example, in case #4 (*adhesive injection bonding process*), the preliminary acceptance testing of the plant was described as follows:

When the project runs smoothly, it is usually the case that the supplier, who has made the whole planning and design for you, also puts the plant into operation. So, the supplier is responsible to manufacture and assemble the process components and to put it into operation. It is up to the supplier to integrate other subcontractors as needed. Then you check the 'preassembly' at the supplier's site; we have simply tested the functionality without adhesive. If the plant meets the specifications, the supplier can start to deliver the plant and to put it into operation at our site. (Non-managerial employee, interviewed on 10 September 2014, translated by the author)

When the plant and all its process components comply with the defined specifications, the different cells are build up in the pilot/serial line and put into operation. As soon as the manufacturing workstations are installed, they are ready to perform another 'test series'.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

Depending on the innovation projects and the plant sizes, the in-house plant engineering unit takes on the role of the general contractor. This enables BMW to monitor and control the planning and execution processes needed to maintain the given standards. At this stage, the innovation projects are fully reintegrated into the main organisation in order to use all their resources and established standard processes. For example, the reintegration of the 'project i' in which case #1 (*CFRP adhesive bonding process*) was embedded, was described as follows:

A very significant lever for promoting innovation and maybe the most important ever to make a real 'step change' is to detach teams from the main organisation, from the daily business and the daily concerns, I think this is essential. And then, I think it would be stupid not to use the possibilities of the core unit such as test stands, laboratories, all that services that do not question the idea itself but add value just as an extended workbench, which I think is good because this also helps to protect the information. 'Project i' is for me the example no. 1 and a role model. However, like most things, it has a package insert because at some point it has to be reintegrated into the organisation and so you have to wait for the right time. When you do it too early, then it will be interred in the integration, if you do it too late, then perhaps the maturity of the innovation will not be where it should be. Regarding the 'project i', it was probably a little bit too late or there is just always pain in the reintegration and some repulsion effects, but if you do it too early, the idea is strangled. Nevertheless, in the future, I think, we will apply more often the working model of the 'project i'. (Top-management level, interviewed on 30 September 2014, translated by the author)

Clearly defined responsibilities and organisational interfaces facilitate the transition from innovation projects into conventional development projects in which manufacturing workstations are integrated or replaced in a pilot/serial line. In short, the knowledge and skills to build and integrate manufacturing workstations are institutionalised through support mechanisms to reintegrate the innovation projects into the main organisation.

Operate and Test Manufacturing Workstations (Node Reference A31.3)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

After the manufacturing systems are completely installed in a full-scale commercial factory, a fifth 'test series' is performed in order to prove the correct set-up of their workstations. The production tooling of the cells is evaluated against the pilot/serial line performance targets. Since the fifth 'test series' is usually performed without any pilot/serial line articles or demonstration units, this procedure is often labelled as 'dry-run'. For example, in case #1 (*CFRP adhesive bonding process*), one of the 'process planners' explained the purpose of a 'dry-run' as follows:

In my opinion, the ideal case would be to achieve the planned takt time with automatic mode because at that point you do not have any external influences on your process. Most noises or disturbances are caused by the product components, deviations, etc. Therefore, the objective is to achieve the takt time with a 'dry-run' configuration of your equipment so that you can say, okay, the process works. So, you test all your processes and you try to confirm the takt time. (Non-managerial employee, interviewed on 24 June 2014, translated by the author)

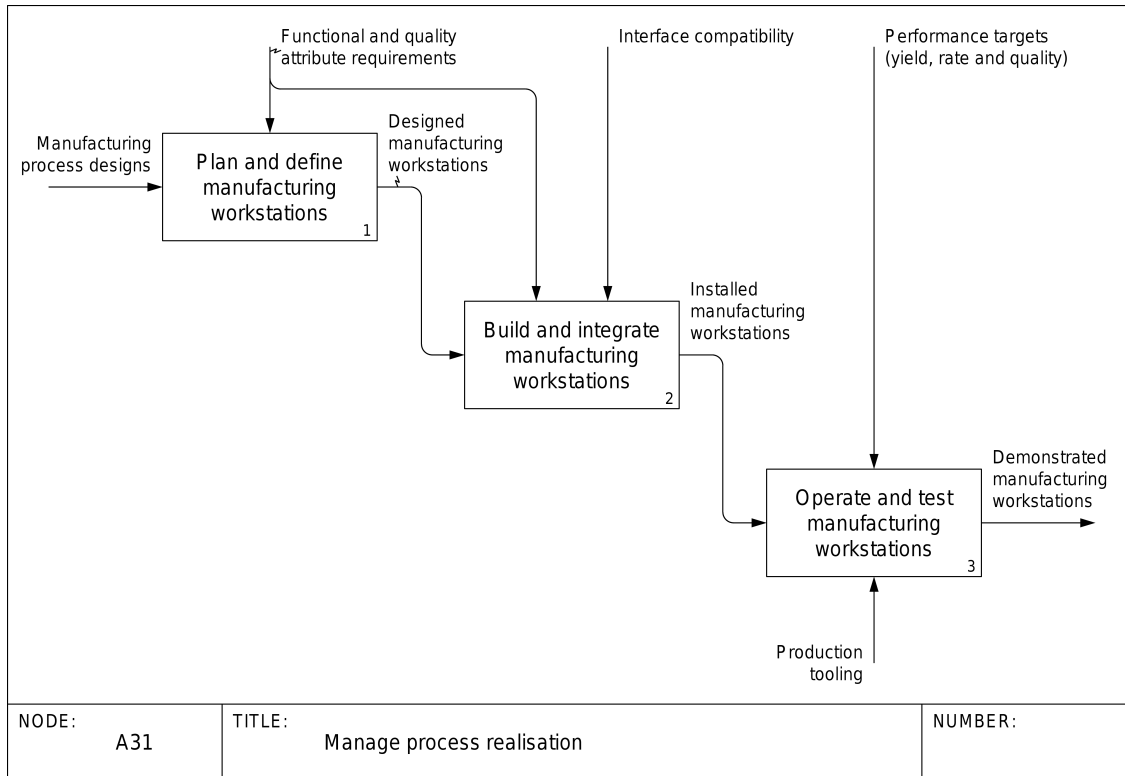
The learnings of the 'dry-run' feed modification plans with the objective to further increase the degree of automation and to resolve any identified quality issues. As a result, the installed manufacturing workstations achieve the pilot line targets and demonstrate the required pilot/serial line capability.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

Drawing on experiences from previous 'test series' in the production relevant/representative environment, the pilot/serial line workforce is trained on the installed manufacturing workstations. Moreover, specific technical and operational trainings are provided for plant operators and maintenance workers to perform their roles effectively and according to the developed 'process instructions'. For example, manufacturing personnel of a series production press shop was trained for new processes as follows:

The new servo press technology you have seen out there, we were not the first site who implemented it. And when you know that another site has already implemented it then you contact the authorities of the other site and usually they support you with production workforce and train your workers. On the other hand, we send our workers to the next site again in order to train and support their workforce. (Middle-level manager, interviewed on 03 November 2014, translated by the author)

'Process planners' document in their 'open items' lists any comments of the production workforce to improve the standardised process components and the installed manufacturing workstations. In short, the knowledge and skills to operate and test manufacturing workstations are institutionalised through an organisational training capability to prepare and qualify the manufacturing personnel.



Source: The author

Figure 31: The IDEFo diagram - Node A31

Table 25: The strategies, practices or tactics regarding MRL 8

<i>Manufacturing Readiness Level 8</i>	
<i>Strategies, Practices or Tactics</i>	<ul style="list-style-type: none"> • Establish and maintain configuration management and change management systems to control supplier agreements • Establish and maintain support mechanisms to reintegrate the innovation projects into the main organisation • Establish and maintain an organisational training capability to prepare and qualify the manufacturing personnel

Source: The author

4.4.2 Improve Low Rate Initial Production (Node A32)

A summary can be found at the end of this subsection (see Figure 32 and Table 26).

Plan and Organise Low Rate Initial Production (Node Reference A32.1)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

After completing the 'dry-run', the manufacturing workstations are fully integrated into the pilot/serial line. This incorporates, among others, the adjustment of the production tooling to mature demonstration units (e.g. system models) of the target application. For example, in case #1 (*CFRP adhesive bonding process*), the preparation of the low rate initial production in the body shop was described as follows:

Between the 'dry-run' and the 'production forerun' [i.e. the low rate initial production] we use pilot line articles also referred to as 'pipe cleaners'. These parts do not need to be passed on to the assembly line and we use them only to adjust our tooling and the processes. Because the expectation of the subsequent 'production forerun' is that the assembly line gets vehicle body structures from us even when they are not yet 100% OK regarding their bond strength or dimensional accuracy. So we have pilot line articles which we can crash in our test rooms to adjust the process parameters or we can use them simply to pass them on from workstation to workstation in order to test the handling; as I said before, 'pipe cleaners'. (Non-managerial employee, interviewed on 24 June 2014, translated by the author)

In addition, the manufacturing workstations are interlinked and required production work environment standards (e.g. cleanliness, maintenance, material supply, logistic, supplier quality, etc.) are established. In consequence, the manufacturing systems are prepared to perform a low rate initial production.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

In order to prepare the organisation to perform the low rate initial production, the standard operating procedures for plant operators are described in 'work instructions' and the interlinked manufacturing workstations are fully integrated into the production control system. Moreover, an appropriate maintenance strategy is elaborated with the maintenance workers and the developed risk mitigation plans are revised as needed. For example, in case #2 (*human-robot co-operation*), the performed risk assessment regarding security standards was described as follows:

Simultaneously to the various 'line trials', we have performed the risk assessment with safety experts from an external company. So, we did the risk analysis at the Spartanburg site and looked at potential issues regarding the direct interaction of operator and robot in order to get the equipment approved from a safety perspective. At the end, we received the certificate so that we can operate this application in the series production door assembly line. (Non-managerial employee, interviewed on 11 June 2014, translated by the author)

At that point, the responsibility and authority for performing the manufacturing processes is step by step assigned to the local series production units. In short, the knowledge and skills to plan and organise a low rate initial production are institutionalised through work environment standards to ensure workplace safety and security of the manufacturing systems.

Perform and Analyse Low Rate Initial Production (Node Reference A32.2)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

The project teams start together with the trained production workforce the low rate initial production which is labelled as 'production forerun' or 'pre-series o' and produces the target application itself instead of any demonstration units. Depending on the manufacturing processes, this sixth 'test series' is usually performed in a manual or semi-automatic mode of the individual manufacturing workstation in order to ensure work safety and to prevent any collisions during the process handling. For example, in case #1 (*CFRP adhesive bonding process*), the sixth 'test series' performed in the body shop was described as follows:

When we started the 'production forerun', we usually produced 2-3 serial line parts in a row with the same settings [i. e. process and system parameters]. Then we passed on the parts to the measuring room where they were evaluated. Drawing on the measurement results, we adjusted our settings and tried to produce the rest in a row in order to get a feel for the achieved takt time and technical availability when we run our process with parts. Having produced the defined quantity of serial line parts, we had a 4-week long time period to reconfigure or optimise the workstation for the next 'test series'. (Non-managerial employee, interviewed on 24 June 2014, translated by the author)

As soon as the low rate initial production is completed and all formal requirements are met, the ownership of the manufacturing processes is formally handed over from the innovation project teams to the series production sites. This means that all safety related issues of the manufacturing processes must be resolved before the degree of automation and the production rate is further increased.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

At this stage of the innovation projects, the responsibility and authority for performing the manufacturing processes is largely assigned to the local series production units. Therefore, organisational rules and guidelines supplemented by standardised 'transfer check-lists' are established which define the responsibilities of the different roles involved and the tasks needed to be accomplished. For example, a subject matter expert for joining processes described existing 'transfer documents' as follows:

Then we have so-called 'blue lists' which describe the phase in the production site—so from the 'production forerun' onwards—very detailed in terms of what to do and when to do it. Those worksheets exist for each joining process we have. [...] Right, and then we also have check-lists, at the moment we have a check-list for each process in which is written down what things of your equipment you actually need to test in order to say that this plant is OK. But this is very detailed and operational, I always say this is like 'tattooing ants'. In addition, there are official release documents which are then filed and controlled in our central document management system. (Lower-level manager, interviewed on 05 February 2014, translated by the author)

By-products of the low rate initial production such as process capability data or ideal equipment settings are systematically stored in the production department's measurement repositories and feed improvement plans. In short, the knowledge and skills to perform and analyse the low rate initial production are institutionalised through systematic procedures with standard documents to accomplish the process industrialisation.

Operate and Improve Production Ramp-Up (Node Reference A32.3)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

Having handed over the ownership of the manufacturing processes, the interplay of the manufacturing workstations is systematically optimised to achieve the pilot/serial line performance and automation targets. This process is often divided into three 'test series' labelled as 'pre-series 1', 'pre-series 2' and 'start-up production' which contain different performance tests. For example, in case #1 (*CFRP adhesive bonding process*), one of the 'process planners' described the 'pre-series 1' performance test as follows:

So you have organised a large number of parts for your performance test and then you try to produce them in one pass. We agreed, I think, on a time period of one morning or even a whole day and then you have produced everything what was there and, in parallel, we have documented every single error, interruption and plant shut-down. At the end, we figured out, okay, we have produced so and so long, we had this downtime and we produced this quantity. Because you do such performance tests mainly to improve the plant. After it, you reprogram the robots, adjust the tooling and so on. The ultimate goal is to achieve the takt time and to increase the technical availability of your process. (Non-managerial employee, interviewed on 10 June 2014, translated by the author)

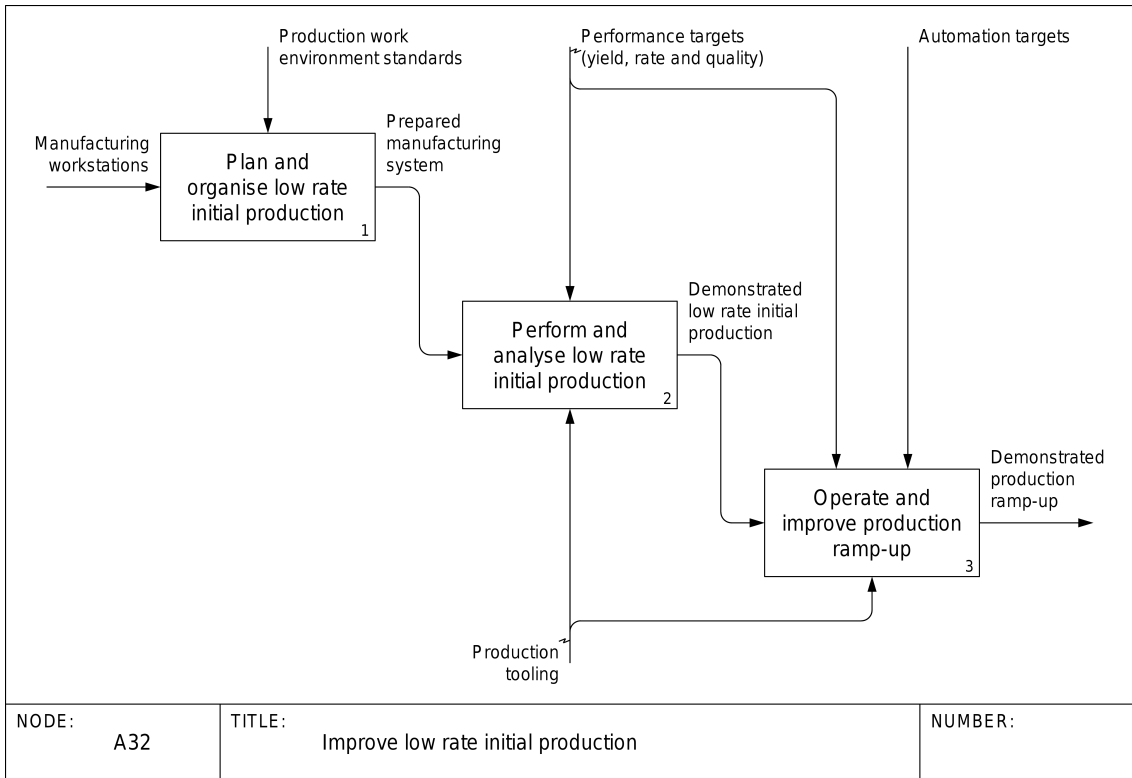
The 'retrofitting window' after each 'test series' is used to modify the manufacturing workstations and to deal with corrective actions as needed. As a result, the manufacturing processes are reasonably stable and ready to begin the full rate production of the target application.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

The three sequential 'test series' represent produce-test-feedback-and-retrofit iterations. Since the work content is completely compartmentalised and allocated to various parties and stakeholders, this activity is co-ordinated by means of standardised work outputs in terms of specified performance and automation targets. For example, in case #1 (*CFRP adhesive bonding process*), the objective of the 'pre-series 1' short time test was described as follows:

There is a milestone with release criteria between 'pre-series 1' and 'pre-series 2' which is described in our standard document *General Specifications for Body-in-White Production and Conveyor Equipment*. At that point we must achieve a technical availability of 60% proven by a short time test which runs 5 days and 8 hours each. (Non-managerial employee, interviewed on 24 June 2014, translated by the author)

Any issues and deviations are systematically addressed to all relevant stakeholders and corrective actions needed to resolve the problems are managed according to the established 'production-oriented quality management' system. The causal analysis of problems and the associated resolution data are documented in 'problem recognition sheets' and stored in the production department's process asset libraries. In short, the knowledge and skills to operate and improve the production ramp-up are institutionalised through quality management practices to resolve non-compliance issues of the manufacturing systems.



Source: The author

Figure 32: The IDEFo diagram - Node A32

Table 26: The strategies, practices or tactics regarding MRL 9

Manufacturing Readiness Level 9	
Strategies, Practices or Tactics	<ul style="list-style-type: none">• Establish and maintain work environment standards to ensure workplace safety and security of the manufacturing systems• Establish and maintain systematic procedures with standard documents to accomplish the process industrialisation• Establish and maintain quality management practices to resolve non-compliance issues of the manufacturing systems

Source: The author

4.4.3 Perform Full Rate Production (Node A33)

A summary can be found at the end of this subsection (see Figure 33 and Table 27).

Perform and Analyse Full Rate Production (Node Reference A33.1)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

When the manufacturing systems are completely integrated into the wider production system with all its support processes, the full rate production of the target application is started. The 'process planners' from the innovation project teams begin to hand over their responsibility to the 'production system support analysts' from the production sites. This hand over was described as follows:

In order to receive the final acceptance certificate for the manufacturing process, all non-compliance issues must be resolved and 100 % of the performance targets must be achieved. This contains usually the takt time and technical availability. Additionally, the documentation and all manuals of the process and the plant must be completed. Workplace safety and security standards are important prerequisites to start the full rate production but they are checked again and again. (Non-managerial employee, interviewed on 24 June 2014, translated by the author)

The obtained process capability data are systematically analysed and used to adequately control the manufacturing processes and to feed any quality improvements. With the start of the full rate production, the manufacturing systems are completely embedded in the wider production system and use the capacity and support mechanisms of the production sites.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

The developed 'process instructions' and other relevant descriptions are used to evaluate the performed manufacturing processes. Due to the achieved overall maturity of the manufacturing processes and the production tooling, occurring quality issues are resolved with standardised quality assurance activities at the production site. For example, in case #2 (*human-robot co-operation*), the process reliability of the roller heads was ensured as follows:

A major concern when you start full rate production is process reliability. So, in order to check that the flange or roller head always applies the correct force, we installed a simple weighing measurement system. Once a day, the robot moves to the weighing instrument to measure the counter-pressure. The flange presses with 50N and the scale measures approximately 5 kg. We [the innovation project team] have not done that. This was implemented by the maintenance workers of the series production, they adjusted the display and the interface to the BMW control standards and exchanged the sensor of the calibration process [...]. This was all done at the Spartanburg site. At that point, we accompany them only and share our ideas but we do not own the process any longer. (Non-managerial employee, interviewed on 11 June 2014, translated by the author)

The technical process performance data which are managed by means of statistical and other quantitative techniques are then incorporated into the production department's measurement repositories. In short, the knowledge and skills to perform and analyse the full rate production are institutionalised through central measurement repositories to monitor and control the results of process improvements.

Improve and Assess Manufacturing Processes (Node Reference A33.2)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

A continuous improvement process which includes 'lean production' practices as well as statistical and other quantitative techniques such as statistical process control and process capability analysis is initiated to optimise the manufacturing systems. Particularly the long-term process capability plays a key role to ensure stable manufacturing processes. For example, in case #1 (*CFRP adhesive bonding process*), one of the 'process planners' described the process capability analysis as follows:

The 'BMW Group procedural instruction' [controlled document class] defines short-term and long-term analyses. So far, we have only accomplished the short-term process capability analysis where we produced about 70 parts within 1-2 weeks. For the long-term process capability analysis we obtain a much larger sample size because we pass on several parts from the full rate production to the measuring room every week. This is done for at least three months in order to see whether the process is stable or not. (Non-managerial employee, interviewed on 24 June 2014, translated by the author)

In addition, suggested improvements from plant operators, maintenance workers, manufacturing line supervisors or 'production system support analysts' are evaluated for their impact on the process capability targets and implemented. In consequence, the manufacturing risks are largely mitigated and the manufacturing processes are sufficiently controlled.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

The improved manufacturing processes are usually defined as new standards and implemented in all relevant production sites if applicable. In order to support the deployment of improvements throughout the production network, various exchange platforms using different channels of communication are established. For example, a central process asset library to exchange success stories was described as follows:

In the production department we have established a central 'good practice sharing' platform. This is a valuable platform in which each technology [i. e. press shop, body shop, paint shop and assembly line] can look up proven methods or practices from other production sites to further improve its own manufacturing processes. This includes suggestions for cost or capital investment reductions, quality improvements and so on. (Middle-level manager, interviewed on 03 November 2014, translated by the author)

While conventional structures such as different ‘centres of competence’ formally preserve the know-how of subject matter experts, the established digital ‘information hub’—comparable to social networks or social media platforms—facilitates the informal exchange of process know-how between organisational units and subunits. In short, the knowledge and skills to improve and assess manufacturing processes are institutionalised through exchange platforms to share and deploy ‘best practices’ throughout the production network.

Evaluate and Approve Final Acceptance (Node Reference A33.3)

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*

After the performance targets and process capability targets are achieved in the pilot/serial line, a final acceptance review of the manufacturing processes is conducted with the process end-users. The verification criteria are generally defined in the manufacturing system specifications and documented as a ‘BMW Group Standard’. For example, in case #1 (*CFRP adhesive bonding process*), the project manager described the final acceptance procedure as follows:

Most often, the verification of the manufacturing process is performed after three months of full rate production. This final acceptance is the last milestone for the project team. Since we have installed multiple workstations with the same process in the body shop, we agreed with the operator [i. e. process end-user] to verify only one complete workstation with a stationary adhesive system and another one in which the adhesive system is mounted on a robot head. Then we have checked the mechanical and electrical installation and the workplace safety and security standards according to our check-lists. (Lower-level manager, interviewed on 05 June 2014, translated by the author)

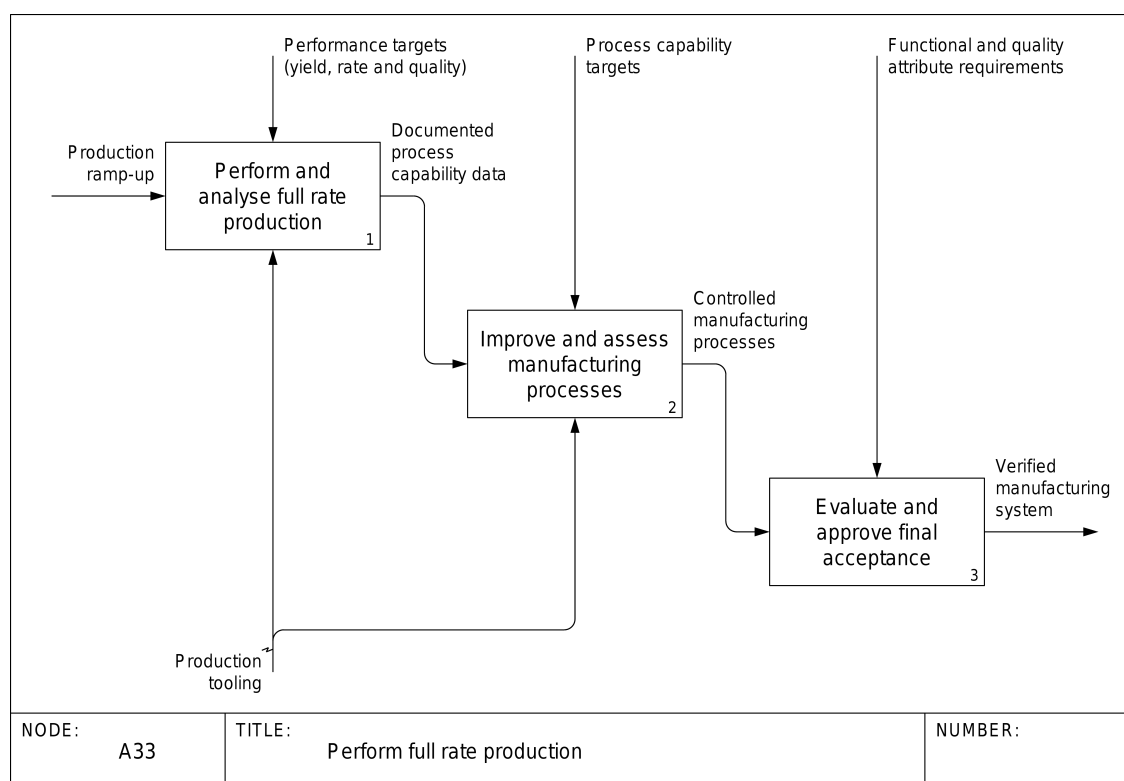
When the manufacturing processes are formally accepted by the ‘local’ series production and the verification report is signed, the manufacturing processes meet the defined specifications and fulfil their intended use in the pilot/serial line. As a result, the technical process innovation projects can be formally closed.

- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

At the end of the technical process innovation projects, it must be ensured that all used organisational process assets are updated and the project related experiences are incorporated into process asset libraries. This includes, among others, the documentation of lessons learned and improvement suggestions for subsequent innovation projects as well as the completion of project records and documents. For example, in case #1 (*CFRP adhesive bonding process*), the project closure was described as follows:

At the end of the project, you organise face-to-face meetings with your project team members and all relevant stakeholders to elaborate lessons learned or any strengths and weaknesses of the innovation project. For this procedure, I followed the process description 'TKB 9.1' which outlines the step: 'ensure project closure and transfer project related experiences'. Then, I finalised and distributed the project documentation which included the project schedule, all premises of the project, performance targets and so on. (Lower-level manager, interviewed on 05 June 2014, translated by the author)

Systematic procedures guide the administrative closure of the projects and the release of their resources such as project team members and remaining budgets. In short, the knowledge and skills to evaluate and approve final acceptance are institutionalised through administrative guidelines to modify standards with lessons learned and project experiences.



Source: The author

Figure 33: The IDEFo diagram - Node A33

Table 27: The strategies, practices or tactics regarding MRL 10

<i>Manufacturing Readiness Level 10</i>	
<i>Strategies, Practices or Tactics</i>	<ul style="list-style-type: none"> • Establish and maintain central measurement repositories to monitor and control the results of process improvements • Establish and maintain exchange platforms to share and deploy 'best practices' throughout the production network • Establish and maintain administrative guidelines to modify standards with lessons learned and project experiences

Source: The author

4.5 SUMMARY

The purpose of this case study-based dissertation is to *explore* and *describe* in what way the *technical process innovation capability* is built and maintained by R&D and production departments at a world leading motor vehicle manufacturer. To reiterate, the major research question was decomposed into the following two subsidiary research questions which point to what should be studied and where to look for relevant evidence:

- *What are the activities, mechanisms and controls of technical process innovation projects employed by R&D and production departments?*
- *What are the strategies, practices or tactics to institutionalise the knowledge and skills of technical process innovation projects?*

In seeking answers to the stated set of research questions, data from 15 examples of current or recent technical process innovations within the Bayerische Motoren Werke Aktiengesellschaft (BMW AG) were obtained and processed as described in the previous chapter. The results described in this chapter address primarily the two subsidiary research questions as follows:

The first subsidiary research question is answered by means of a hierarchical series of IDEFo diagrams which gradually illustrate increasing levels of detail. At the beginning, the top-level 'context diagram' (i. e. Node A-o) presents the immediate environment of the IDEFo function model including its purpose and viewpoint. Subsequently, the top-level 'child diagram' (i. e. Node A0) links the function being modelled—*build and maintain technical process innovation capability*—with the associated top-level learning routines. Their corresponding 'child diagrams' (i. e. Nodes A1, A2 and A3) partition the learning routines into their components and align them with the associated manufacturing readiness levels (MRLs). At the end, the lower-level 'child diagrams' (i. e. Nodes A11, A12, A13, A21, A22, A23, A31, A32 and A33) display the activities, mechanisms and controls of technical process innovation projects in sufficient detail. As a result, the hierarchical exposition of detail illustrates in large part a concrete example of the adopted resource and capability architecture.

The second subsidiary research question is answered by means of a sequential series of tables which contain established and maintained activities along the manufacturing readiness levels (MRLs). These activities reveal strategies, practices or tactics with which R&D and production departments identify, (externally) acquire, (internally) develop, share/distribute and protect/preserve the new knowledge and skills. Moreover, the reported strategies, practices or tactics refer directly to the activities being described in the lower-level 'child diagrams' (i. e. Nodes A11, A12, A13, A21, A22, A23, A31, A32 and A33) of the IDEFo function model. This interdependency enables cross-referencing between the two subsidiary research questions at the same level of detail. As a result, the sequential representation of strategies, practices or tactics which institutionalise the knowledge and skills exemplifies in large part co-ordination mechanisms of the adopted resource and capability architecture.

DISCUSSION

*Truth is ever to be found in simplicity,
and not in the multiplicity and confusion of things.*

—Isaac Newton

Appendix A: 'Fragments from a Treatise on Revelation'
(Manuel, 1974, p. 120)

THE MAIN OBJECTIVE OF THIS DISCUSSION CHAPTER IS TO INTEGRATE AND INTERPRET THE INSIGHTS FROM THE DETAILED ACCOUNT TO ANSWER THE STATED MAJOR RESEARCH QUESTION.

5.1 OVERVIEW

This discussion chapter draws on the results from 15 examples of current or recent technical process innovations within the Bayerische Motoren Werke Aktiengesellschaft (BMW AG). It synthesises the 'constructed' IDEFo (Integration DEFinition language o) function model with the identified strategies, practices or tactics and expounds general conclusions arising from the data. In order to accomplish these major tasks, the following three subjects are discussed in more detail: (1) *Findings Emerging from Evidence*, (2) *Contributions and Implications* and (3) *Limitations and Future Research*. According to the first, the main findings of the present research are summarised and mapped to existing research. The second notes the contributions to knowledge and highlights potential implications for managers of technical process innovations. Finally, shortcomings and limitations of the present research are outlined and possible directions for future research concerning the strategic management of process innovations are recommended. Thus, the chapter integrates and interprets the insights and hence answers the major research question of this dissertation.

5.2 FINDINGS EMERGING FROM EVIDENCE

The scope and direction for the present research was provided by the following major research question:

- *In what way does a world leading motor vehicle manufacturer build and maintain its technical process innovation capability?*

In order to enable concrete observations of the central research phenomenon—*technical process innovation capability*—an operational definition was elaborated. To reiterate, the synthesis of reviewed categorical taxonomies suggested the following theoretically grounded and practically relevant definition for the present research:

A TECHNICAL PROCESS INNOVATION CAPABILITY is the power or ability of manufacturers to explore, transform and exploit in a co-ordinated multi-stage process knowledge and skills into new or significantly improved production methods implemented in a socio-technical transformation system, in order to advance, compete and differentiate themselves successfully in their marketplace.

This section answers the major research question through integrating and interpreting the insights from 15 examples of current or recent technical process innovations within the Bayerische Motoren Werke Aktiengesellschaft (BMW AG).

As shown in the top-level 'context diagram' and the top-level 'child diagram' (i.e. Nodes A-o and Ao; see on page 82), the learning routines update and add to BMW's process asset libraries and measurement repositories. These libraries and repositories contain process assets related to *values and norms*, *managerial systems* and *knowledge and skills* which are modified through learning mechanisms and, in turn, control the learning/operating routines. The corresponding 'child diagrams' (i.e. Nodes A1, A2 and A3; see on pages 84, 101 and 117) illustrate the incorporation of lessons learned and project related experiences into such process assets as a critical output of each performed activity. This identified closed-loop control "[...] is a learned and stable pattern of collective activity through which the organization systematically generates and modifies its operating routines in pursuit of improved effectiveness" (Zollo and Winter, 2002, p. 340). In other words, the R&D and production departments of BMW employ not only technical process innovation projects per se but also reflect simultaneously on their operating routines and utilise learning mechanisms such as experience accumulation, knowledge articulation and knowledge codification. Consequently, without this cognitive effort, BMW's existing stock of knowledge and skills would decay over time since technological development knowledge becomes obsolete and production skills decline due to attrition of workforce.

This finding of a closed-loop control supports the following observation from Pisano (1997, p. 32): "Projects also generate opportunities to understand and improve the way projects are organized and managed, which further enhances development capabilities". Moreover, Lawson and Samson (2001, p. 388) arrive at a similar conclusion, saying that "[i]nnovation capability itself is not a separately identifiable construct. The capability is composed of reinforcing practices and processes within the firm". Apart from that, a growing body of literature investigates the social phenomenon of *inter-project learning* in the context of capability building (Bakker et al., 2011; Newell and Edelman, 2008; Prencipe and Tell, 2001; Schindler and Eppler, 2003) which concurs with Macher and

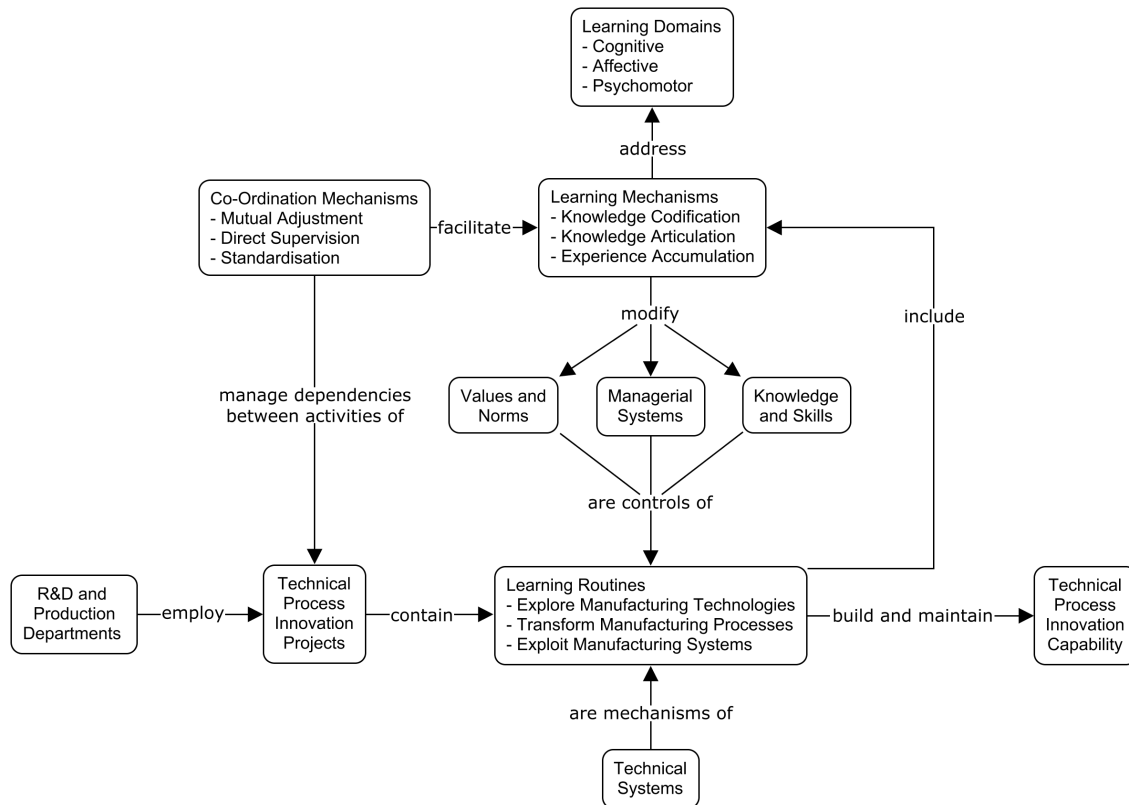
Mowery (2009, p. 60) who highlight in their empirical analysis “[...] the importance of deliberate, rather than passive, learning for the development of dynamic capabilities”. In conclusion, BMW makes a substantial investment in this reflection through learning routines and associated learning mechanisms not only to avoid a ‘lossy’ system but also to build its technical process innovation capability.

The lower-level ‘child diagrams’ (i.e. Nodes A11, A12, A13, A21, A22, A23, A31, A32 and A33; see Chapter 4) display the natural progression of manufacturing maturity along the innovation stage-gate model. In particular, experimental hardware models, laboratory tooling, prototype tooling, pre-production tooling and production tooling exemplify indispensable means of the learning routines to absorb or create new technological development knowledge and production skills. The acquisition of new technologies embodied in machinery or engineering artefacts from industrial agents such as production equipment suppliers is a common external knowledge-sourcing strategy to generate and adopt technical process innovations (Piening and Salge, 2015; Reichstein and Salter, 2006; Vega-Jurado et al., 2009). These *technical systems* are embedded in different work environments (e.g. laboratory environment, production relevant/representative environment and pilot/serial line environment) which require context-specific approaches to institutionalise the knowledge and skills. The identified strategies, practices or tactics reveal that mutual adjustment and standardisation are the two dominant co-ordination mechanisms through the life of the projects. For example, during the exploration phase with distinct technological development capabilities, knowledge articulation is facilitated through open exchange platforms and information hubs. On the other hand, during the exploitation phase with strongly marked production capabilities, knowledge codification is facilitated through increasingly standardised work processes, outputs and skills. Direct supervision comes to the fore only when the production department’s central innovation unit reviews the project’s accomplishments and results according to the innovation stage-gate model and corrective actions need to be taken by the project team. Consequently, the alignment of the applied strategies, practices or tactics with the different work environments ensures an adequate institutionalisation of knowledge and skills since the attention turns with increasing manufacturing maturity from technological development towards production.

This finding of changing dominant co-ordination mechanisms throughout the technical process innovation projects is in good agreement with Mintzberg’s (1979b, p. 7) rough continuum of complexity: “As organizational work becomes more complicated, the favored means of coordination seems to shift [...] from mutual adjustment to direct supervision to standardization, preferably of work processes, otherwise of outputs, or else of skills, finally reverting back to mutual adjustment”. Moreover, mutual adjustment as the prime co-ordination mechanism during the exploration phase compares well with the perceived ‘fuzziness’ at the front-end phase of innovation projects (Frishammar et al., 2011; Khurana and Rosenthal, 1997; Koen et al., 2001; Kurkkio et al., 2011; Reid and de Brentani, 2004). In conclusion, BMW orchestrates different strategies,

practices or tactics not only to sufficiently manage the dependencies between activities of technical process innovation projects but also to institutionalise the knowledge and skills and hence to maintain its technical process innovation capability.

These two main findings emerging from the evidence represent the major component parts used by BMW to build and maintain its technical process innovation capability.



Source: The author

Figure 34: The graphical concept map

The graphical concept map (see Figure 34) synthesises the identified elements contributing to the formation of a firm's technical process innovation capability. As depicted, technical process innovation projects are undertaken by R&D and production departments through routinised activities which start with a stimulus for innovation (e.g. problem or idea) and proceed through various stages of design and industrialisation to an innovation introduced into practice. Depending on the manufacturing maturity, exploratory, transformative or exploitative learning routines are performed simultaneously with the operating routines. Technical systems (i.e. machinery or engineering artefacts) are the physical means that are used to perform these activities. On the other hand, values and norms, managerial systems and knowledge and skills control them. Moreover, the learning routines include learning mechanisms such as experience accumulation, knowledge articulation and knowledge codification which are utilised in order to modify the controls. Depending on the learning objectives, this process addresses the cognitive, affective and/or psychomotor domain of learning. The

co-ordination mechanisms which manage dependencies between activities of technical process innovation projects facilitate the utilisation of learning mechanisms and hence the inter-project learning. Overall, cumulative learning through a closed-loop control and an appropriate interplay of co-ordination and learning mechanisms is understood by a world leading motor vehicle manufacturer as the underlying key to build and maintain its technical process innovation capability.

5.3 CONTRIBUTIONS AND IMPLICATIONS

The present research contributes to knowledge in three important ways. First, it extends the innovation literature concerning the strategic management of process innovations by shedding light on the central research phenomenon of *technical process innovation capability*. In order to enable concrete observations, an operational definition of this phenomenon was elaborated and a process approach, in contrast to an outcome approach, was applied. This approach allows the investigation of involved resources, activities and (higher-order) capabilities within a firm. The 'constructed' IDEFo (Integration DEFinition language o) function model and the identified strategies, practices or tactics provide a thorough and coherent description of empirical knowledge. Furthermore, a graphical concept map synthesises the integrated and interpreted insights into a world leading motor vehicle manufacturer. In short, this dissertation addresses the call from two recent systematic literature reviews for further research on how firms can strategically manage the generation and adoption of process innovations (Frishammar et al., 2012; Keupp et al., 2012).

Second, the present research operationalises and interlinks substantial theoretical foundations in the domain of strategic management such as the resource-based view (Wernerfelt, 1984), organisational routines (Feldman and Pentland, 2003), dynamic capabilities (Teece et al., 1997), absorptive capacity (Cohen and Levinthal, 1990) and co-ordination mechanisms (Mintzberg, 1979b).

RESOURCE-BASED VIEW: The IDEFo diagrams enrich the resource-based view by making strategically relevant resources more tangible. For example, technical systems (i. e. machinery or engineering artefacts) exemplify physical means that are used to generate and adopt process innovations. Furthermore, organisational process assets (e. g. plans, processes, policies, procedures and knowledge bases) represent mechanisms which contain knowledge components such as factual knowledge, conceptual knowledge, procedural knowledge and meta-cognitive knowledge. These tangible and intangible assets constitute the building blocks for socially complex firm resources such as 'technological development knowledge' and 'production skills'. As a result, the present research sheds light on critical resource bundles which are needed to build and maintain a firm's technical process innovation capability.

ORGANISATIONAL ROUTINES: The detailed account of the operational practice elucidates organisational routines by focusing on regularities from 15 examples of current or recent technical process innovations. While the narratives—including the strategies, practices or tactics to institutionalise the knowledge and skills—describe the performative aspects, the IDEFo diagrams illustrate the ostensive aspects of organisational routines. Depending on the underlying purpose, these aspects constitute either learning routines or operating routines. In short, the learning routines utilise associated learning mechanisms to generate and modify the operating routines which must be accomplished by the project teams to carry out technical process innovations into practice. As a result, the present research provides insights into two different ways a firm utilises its critical resource bundles.

DYNAMIC CAPABILITIES: The graphical concept map illustrates a dynamic capability by indicating the cumulative learning through a closed-loop control. Learning mechanisms such as experience accumulation, knowledge articulation and knowledge codification are embedded in learning routines and modify the organisational process assets which, in turn, control the learning/operating routines. Thus, the closed-loop control balances the focus on both productivity improvements and innovation and hence maintains the stability of a system. This capacity to renew organisational routines by changing the existing stock of knowledge and skills enables a firm to respond to its volatile environment. As a result, the present research highlights the importance of learning routines with which a firm can reconfigure and deploy its resource base.

ABSORPTIVE CAPACITY: The IDEFo diagrams exemplify the concept of absorptive capacity by displaying the natural progression of manufacturing maturity along the innovation stage-gate model. For example, technology intelligence processes capture relevant information about basic technology research, emerging technological trends and the competitive environment to identify manufacturing concepts. Subsequently, machinery or engineering artefacts which embody new technologies are acquired from industrial agents such as production equipment suppliers to develop a manufacturing proof of concept and to demonstrate the capability to produce the technology in a laboratory environment. These activities which identify, assimilate and apply new or outside knowledge and skills constitute absorptive capacity routines. As a result, the present research shows a firm's exploratory, transformative and exploitative learning routines.

CO-ORDINATION MECHANISMS: The strategies, practices or tactics exhibit co-ordination mechanisms by composing additional activities needed to manage dependencies between activities of technical process innovation projects. In particular the interplay of organisational process assets and organisational routines which identify, (externally) acquire, (internally) develop, share/distribute and protect/

preserve the new knowledge and skills is emphasised. Furthermore, mutual adjustment and standardisation as the dominant co-ordination mechanisms through the life of the projects facilitate the utilisation of learning mechanisms and hence the inter-project learning. This understanding is important to avoid co-ordination problems between existing mainstream (i.e. production) capabilities and new-stream (i.e. technological development) capabilities. As a result, the present research illuminates the crucial nexus between a firm's strategically relevant resources, activities and (higher-order) capabilities.

In short, by seeing a concrete example of the adopted resource and capability architecture in its real-life context, the reader/reviewer has a much easier time imagining how the proposed conceptual framework and the associated graphical concept map might actually be applied to other empirical settings (Mills et al., 2003; Siggelkow, 2007).

Third, the present research expands existing qualitative methods by applying a well-tested and proven systems engineering technique in the domain of strategic management. The 'constructed' IDEFo (Integration DEFinition language o) function model is seen as an integral part of the thematic (coding) analysis. Normally, the development of IDEFo diagrams is done 'top-down' by decomposing a modelled function into its component functions (NIST, 1993, pp. 4, 66). However, in the context of the present research, the obtained data were used in a 'bottom-up' manner (1) to generate initial codes, (2) to identify potential themes, (3) to construct networks and matrices and (4) to integrate and interpret the findings. This synthesis (i.e. condensing and displaying the data) according to the rigorous syntax and semantic rules of IDEFo diagrams is in line with the selected inductive research strategy. Furthermore, while Fairlie-Clarke and Muller (2003); Li (2009); Shahidipour et al. (2000) utilise IDEFo diagrams to illustrate the design or innovation model itself, this research utilises them to exemplify the adopted resource and capability architecture in its real-life context. In short, to the authors knowledge this is the first descriptive model of its type—a collection of IDEFo diagrams and associated narratives arranged in a hierarchic manner—which illustrates the strategic management of process innovations.

Beyond the outlined contributions to knowledge, three potential implications for managers of technical process innovations are highlighted. First, the results seem to indicate that the existence of a high-quality innovation stage-gate model and a balanced portfolio of technical process innovation projects constitute an appropriate foundation for building and maintaining a firm's technical process innovation capability. The former is suggested to be guided by the manufacturing readiness levels with tough go/kill decision points and the latter is suggested to be guided by the production department's innovation strategy with translated competitive priorities. In order to set up these foundations, it is essential to understand that a process innovation is complete only after it is carried out into practice and hence the innovation management comprises more than merely the generation/conception of new ideas (Fagerberg et al., 2005; Knight, 1967).

Second, the research reveals that a formal system of reflection (i. e. cumulative learning through a closed-loop control) appears to facilitate the incorporation of lessons learned and project related experiences into organisational process assets. It might be fruitful to integrate these activities into the innovation stage-gate model and to link them with the acceptance criteria of the go/kill decision points (Schindler and Eppler, 2003, pp. 225-227). Drawing on Cooper (1999, p. 127), saying that “[n]o process, no matter how well designed and needed it is, will ever implement itself. It needs someone to make it happen”, the additional installation of a ‘capability manager’ to oversee the inter-project learning might be conceivable.

Third, the empirical data tend to support the idea that context-specific co-ordination mechanisms promote the institutionalisation of knowledge and skills. For this reason, managers of technical process innovations should carefully consider which co-ordination mechanisms they use in a particular work environment, not only to avoid co-ordination problems but also to improve the effectiveness of organisational routines. The examined process and project management activities may provide promising support to accomplish this task.

5.4 LIMITATIONS AND FUTURE RESEARCH

The scope of this research has been very broad involving the exploration of manufacturing technologies, the transformation of manufacturing processes and the exploitation of manufacturing systems. It was largely determined by the elaborated operational definition of the central research phenomenon, the selected unit(s) of analysis and the underlying theoretical foundations in the domain of strategic management. Due to the breadth of the scope, the present research resulted in a thorough and coherent description of the operational practice a world leading motor vehicle manufacturer adopts in building and maintaining its technical process innovation capability. Nevertheless, some issues could not be investigated in depth and hence limit the level of detail in the descriptive model. In short, this dissertation has its shortcomings and limitations; some of which can provide the basis for promising future research.

As one might expect, the applied single-company design of the present research limits the transferability of the findings. In order to transfer or even generalise them across industry group, size of organisation and type of manufacture, it would be beneficial to broaden the empirical basis by replicating this research in multiple forms. Accordingly, this should be done with large multinational manufacturers and/or small and medium sized manufacturers (SMMs) within and outside the automotive industry.

Apart from this, due to the breadth of the investigated innovation stage-gate model and the exploratory and descriptive purpose of this research, some areas remain not sufficiently studied and the findings fall short of explaining causal inferences. For this reason, a possible direction is to focus on elements of the graphical concept map and to explain and understand their interaction in greater detail. This interesting path could

be used to systematically structure the associated antecedents and/or 'success factors' of process innovations from existing research (Aravind et al., 2014; Frishammar et al., 2012; Lawson and Samson, 2001; Piening and Salge, 2015; Ramm et al., 2012; Terziovski, 2007).

Notwithstanding these shortcomings and limitations, this dissertation provides a detailed account which illuminates the central research phenomenon and hopefully encourages further conceptual and empirical research on the strategic management of process innovations.

5.5 SUMMARY

This research explored and described in what way the technical process innovation capability is built and maintained by R&D and production departments at a world leading motor vehicle manufacturer. After providing background information regarding the addressed problem area and articulating the research motive and goal in the introduction chapter, the literature review chapter has positioned the research itself and illuminated the foundations upon which the present research is based. Then, the methodology chapter has described how the present research was done and what assumptions and decisions were involved. Subsequently, the results chapter has 'constructed' a complete picture and provided a detailed account for building and maintaining a technical process innovation capability. At the end, and perhaps most importantly, the discussion chapter has integrated and interpreted the insights from the detailed account to answer the stated major research question.

Emerging from the evidence, cumulative learning through a closed-loop control and an appropriate interplay of co-ordination and learning mechanisms is understood by a world leading motor vehicle manufacturer as the underlying key to build and maintain its technical process innovation capability. The summarised main findings contribute to knowledge by extending the innovation literature concerning the strategic management of process innovations and by operationalising and interlinking substantial theoretical foundations in the domain of strategic management. In addition, the present research expands existing qualitative methods by applying a well-tested and proven systems engineering technique as an integral part of the thematic (coding) analysis. From an practitioners perspective, managers of technical process innovations should establish and maintain a high-quality innovation stage-gate model and a balanced portfolio of technical process innovation projects. Furthermore, a formal system of reflection and context-specific co-ordination mechanisms facilitate the incorporation of lessons learned and project related experiences into organisational process assets.

Last, but by no means least, shortcomings and limitations of the present research, due to the applied single-company design and the breadth of the investigated innovation stage-gate model, were outlined and possible directions for future research concerning the strategic management of process innovations were recommended.

APPENDIX

THE MAIN OBJECTIVE OF THIS ADDENDUM CHAPTER IS TO DESCRIBE THE TWO INITIAL CASES IN MORE DETAIL AND TO PROVIDE A CROSS-CASE ANALYSIS REFLECTING ON THE KEY FINDINGS.

A.1 OVERVIEW

This addendum chapter offers a rich description of the two initial cases and compares their points of similarity/difference which form the basis for a thorough discussion of the identified themes in the main document (see Chapter 5). In order to accomplish these major tasks, the following three subjects are outlined in more detail: (1) *Case #1—CFRP Adhesive Bonding Process*, (2) *Case #2—Human-Robot Co-Operation* and (3) *Cross-Case Analysis*. According to the first, a demand-induced technical process innovation driven by recognised needs is presented. The second reports a supply-induced technical process innovation driven by discovered opportunities. Finally, these polar type cases are examined regarding similarities and differences in order to facilitate the discussion of the insights. Thus, the addendum chapter supports the illumination of the central research phenomenon—technical process innovation capability—by shedding light on the two initial cases.

A.2 CASE #1—CFRP ADHESIVE BONDING PROCESS

This section describes a demand-induced technical process innovation driven by recognised needs. In so doing, the case description is divided into five subsections. At the beginning, the case background is described. This subsection is followed by core narratives on the three top-level learning routines (i.e. explore manufacturing technologies, transform manufacturing processes and exploit manufacturing systems). Finally, the case description concludes by drawing together the main findings and highlighting their potential implications for managers of technical process innovations.

Introduction

Case #1 is inseparably connected to the case company's new all-electric motor vehicle (BMW i3) whose start of production (SOP) in a new production facility was imminent (BMW, 2010, 2013a,c,d). This revolutionary new all-electric motor vehicle required,

among others, revolutionary new processes in carbon-fibre-reinforced plastic (CFRP) body manufacture. An excerpt from a published press kit is used to briefly introduce¹ case #1—CFRP adhesive bonding process:

The CFRP composite components are bonded together in the new body shop in Leipzig. This is where the basic structure of the Life module takes shape. A high level of geometric integration means that the CFRP structure requires only a third of the number of body components used in a conventional steel body; the Life module's basic CFRP structure comprises around 150 CFRP parts in total. There is no noise from bolting or riveting and no sparks from welding in the manufacturing process for a CFRP body. Instead, only the latest bonding technology is used, which is 100 per cent automated. In this unique, BMW-developed assembly process, the individual components are positioned at a precisely defined bond line gap in order to ensure the resulting joint is as strong as possible. The bonded joints of each BMW i3 measure a total of 160 metres in length. In order to minimise hardening times for volume production of the BMW i3, BMW has greatly accelerated the hardening process. Significant advances in the development of the adhesive mean it is now workable for only 90 seconds after being applied to a component and before adhesion begins. An hour and a half later it has fully hardened and achieved its full strength. This represents a tenfold acceleration of conventional adhesive hardening times. In order to further reduce the hardening time below 10 minutes, BMW has developed a supplementary thermal process. This involves heating specific points on the CFRP parts which are to be bonded, thereby accelerating the hardening process even further. (BMW, 2013d, p. 5)

The case study is based on fifteen semi-structured interviews with three lower-level managers (i.e. motor vehicle project manager for body shop and subject matter experts for joining processes) and twelve non-managerial employees (i.e. project team members) at the R&D and production departments of BMW AG. Furthermore, four 'non-case-specific' interviews with two top-level managers (i.e. Senior Vice President of Technical Planning and Senior Vice President of Research, New Technologies and Innovations) and two middle-level managers (i.e. Head of Innovation Works and Head of Production Concept BMW i) contributed to the case study. In addition, a series of press kits/releases, intranet articles and project documents as well as numerous visits of the process R&D laboratories, pilot plants and full-scale commercial factories located in Munich, Landshut, Dingolfing and Leipzig complemented the interview data and ensured data triangulation (Eisenhardt, 1989; Miles and Huberman, 1994; Yin, 1989).

Explore Manufacturing Technologies

In mid-2007, the BMW Group presented its new corporate strategy called 'Number One'. The mission of one of the company's strategic initiatives, namely 'project i', was articulated as follows:

[P]roject i, launched in late 2007, is an initiative to develop sustainable and pioneering mobility concepts. There must also be a collateral transfer of know-how from this project to the company as a whole and to future vehicle projects. The long-term

¹ A video published by the BMW Group can be found online at <https://www.youtube.com/watch?v=q2nFKkbV63Y> (BMW, 2014b).

goal of project i is to bring fresh thinking to the company's technologies, processes and vehicle concepts, whether in production, development or sales. The concrete mission is to develop new, pioneering products geared closely to future challenges and customer requirements in the field of urban mobility. (BMW, 2010, p. 11)

In order to provide a work environment with sufficient freedom, the BMW Group's project i transcended the existing organisational structure and brought together in a 'newstream organisation' expertise and critical mindset across functional silos. At the same time, this established think tank worked with the full support of the core unit—the main organisation. This working model resulted in a culture of open and transparent knowledge-sharing and in an entrepreneurial spirit as follows:

It's a great experience for me to be able to work in a project like this, with colleagues who are all on a similar wavelength. From the start, we were given every freedom we needed. The result was a mood, an atmosphere you would normally only encounter in a start-up company. (Peter Ratz, project manager of 'project i', BMW, 2010, p. 12)

The starting point for case #1 was formed by an assessment of all manufacturing systems along the process chain (e.g. press shop, body shop, paint shop and assembly line) whether existing technologies were satisfactory or acceptable to meet the initiative's high sustainability goals or whether optimisations or redesigns of them were required. For example, due to the innovative use of CFRP in the passenger cell, the manufacturing processes in the body shop were entirely new developed. However, the development of the CFRP adhesive bonding process was not starting completely from scratch, because a remarkable CFRP-specific material and process engineering expertise has been built up over the past ten years with extensive technology research work. As a result, the capability to produce the technology in a laboratory environment has already been in place.

Transform Manufacturing Processes

By means of a pilot plant located at the R&D site, process engineers characterised the joining processes and determined the specific bonding parameters (e.g. height and width of an applied/compressed adhesive bead) to achieve the required adhesive cure time and bond strength. In October 2010, the developed technical data package for the new manufacturing processes was finally approved and the designed process components for the pilot plant were tested. Shortly after, the project team established a test area with a cordoned off robot cell—using a protective cage of wood and flax—at the Munich site which was close to the BMW Group's Research and Innovation Centre to produce functional prototypes of the Body-in-White structure in a production representative environment. Until May 2011, the project team was managed as a 'speedboat' which bypassed the administrative units of the R&D and production departments and reported directly to the Chairman of the Board of Management of BMW AG. However, the core unit was divided between sceptics and proponents. For this reason, the HR

department was involved and towards the end of 2011 a roadshow with board members was organised to talk in front of the BMW Group's development engineers and to present them demonstration units from the project with the following effect:

Hardware talks! If you put a part on the table, you can forget about PowerPoint. Suddenly they are excited about it. (Martin Arlt, Head of Planning and Steering 'project i', Freitag, 2013, translated by the author)

This positive momentum was then used to carefully reintegrate the 'newstream organisation' into the core unit in order to unlock the full potential of the technical process innovation.

Exploit Manufacturing Systems

At the beginning of 2012, the project team was fully reintegrated into the core unit and used all its resources and established standard processes to ensure a cost-effective industrialisation of the CFRP adhesive bonding process. The Senior Vice President of Research, New Technologies and Innovations described not only the importance but also the criticality of the right reintegration timing as follows:

A very significant lever for promoting innovation and maybe the most important ever to make a real 'step change' is to detach teams from the main organisation, from the daily business and the daily concerns, I think this is essential. And then, I think it would be stupid not to use the possibilities of the core unit such as test stands, laboratories, all that services that do not question the idea itself but add value just as an extended workbench, which I think is good because this also helps to protect the information. 'Project i' is for me the example no. 1 and a role model. However, like most things, it has a package insert because at some point it has to be reintegrated into the organisation and so you have to wait for the right time. When you do it too early, then it will be interred in the integration, if you do it too late, then perhaps the maturity of the innovation will not be where it should be. Regarding the 'project i', it was probably a little bit too late or there is just always pain in the reintegration and some repulsion effects, but if you do it too early, the idea is strangled. Nevertheless, in the future, I think, we will apply more often the working model of the 'project i'. (Top-management level, interviewed on 30 September 2014, translated by the author)

In July 2012, the building site was opened and the installation of the serial line started at the Leipzig site. A fully automated joining process—featuring 173 ABB 6-axis robots—was build up and put into operation step by step to bond together the passenger cell—comprising 16 resin transfer moulded CFRP parts—with a total bonding length of 160 meters (Perry, 2014; Sloan, 2014). Finally, in September 2013, the BMW Group started the series production of the all-electric motor vehicle (BMW i3) in the new 32,000 m² body shop at the Leipzig site. According to a published press release, the innovativeness (i. e. the capacity to create a technology discontinuity in the automotive industry) of case #1—CFRP adhesive bonding process—can be described as follows:

This is the first time that carbon-fibre-reinforced plastic (CFRP) has been used in automotive volume production. [...] By industrialising the manufacturing process for CFRP, the BMW Group has become the first company worldwide to make its use in vehicle production economically viable. (BMW, 2013c, p. 1)

As a last point, with the launch of the sixth generation of the BMW 7 Series and its multi-material body structure in mid-2015, the gained CFRP-specific technology and process know-how was successfully transferred from 'project i' to the first motor vehicle in the BMW Group's core model portfolio (BMW, 2015c, p. 2).

Conclusion

Drawing upon the conceptual framework of the present research, this section describes a demand-induced technical process innovation that results from the interplay of production and technological development activities at the BMW Group. Specifically, case #1 indicates that existing mainstream (i. e. production) capabilities need to be co-ordinated in an integrated fashion with newstream (i. e. technological development) capabilities in order to implement significantly improved production methods. The BMW Group demonstrates how the know-how of a detached project team can be transferred into the core unit and into future vehicle projects to boost the company's innovation performance. Moreover, BMW actively incorporates lessons learned and project related experiences into organisational process assets. This is achieved through a formal system of reflection which is integrated into the innovation stage-gate model.

A.3 CASE #2—HUMAN-ROBOT CO-OPERATION

This section describes a supply-induced technical process innovation driven by discovered opportunities. In so doing, the case description is divided into five subsections. At the beginning, the case background is described. This subsection is followed by core narratives on the three top-level learning routines (i. e. explore manufacturing technologies, transform manufacturing processes and exploit manufacturing systems). Finally, the case description concludes by drawing together the main findings and highlighting their potential implications for managers of technical process innovations.

Introduction

Case #2 is—in contrast to case #1—largely product-independent and exemplifies a special type of technical process innovation because it cannot be classified according to the three process families of (1) shaping, (2) joining and (3) finishing (BMW, 2013b; Knight, 2014). Another excerpt from a published press release is used to briefly introduce² case #2—human-robot co-operation:

At the BMW Group's Spartanburg site, the future has already begun: In door assembly, people and robots work side by side—without a safety fence—in one team. US plant Spartanburg is the first BMW Group production facility worldwide that

² A video published by the BMW Group can be found online at <https://www.youtube.com/watch?v=8oyqTiacyIY> (BMW, 2015d).

has succeeded in implementing direct human-robot cooperation in series production. Four collaborative robots equip the insides of the doors of BMW X3 models with sound and moisture insulation. In a first step, the foil with the adhesive bead is put in place and slightly pressed on by assembly line workers. Prior to the introduction of the new system, workers then carried out the fixing process by means of a manual roller. Today, systems with roller heads on robot arms handle this labor-intensive task, which requires maximum precision. The sealing protects the electronics in the door and the entire vehicle interior against moisture. [...] The direct interaction of man and machine requires top security standards as the robots are placed in the workers' direct surrounding without any protective devices. They run at a low speed within a defined environment and are stopped immediately in case their sensors detect an obstacle in their way. [...] Thanks to the fully automated process, the rolling power applied to the fixing process can be measured exactly. As a result, the processing quality can be monitored on a permanent basis. (BMW, 2013b, pp. 1-2)

The case study is based on three semi-structured interviews with one lower-level manager (i. e. project manager) and two non-managerial employees (i. e. project team members) at the production department of BMW AG. Furthermore, four 'non-case-specific' interviews with one top-level manager (i. e. Senior Vice President of Technical Planning) and three middle-level managers (i. e. Vice President of Body-in-White, Head of Innovation and Head of Assembly Technology) contributed to the case study. In addition, a series of press kits/releases, intranet articles and project documents as well as numerous visits of the production department's annual 'idea exhibition' (2013 – 2015) and the robot laboratory complemented the interview data and ensured data triangulation (Eisenhardt, 1989; Miles and Huberman, 1994; Yin, 1989).

Explore Manufacturing Technologies

The fundamentals of case #2 can be found in the mid-2000s when the Board of Management defined the task to restructure the production department's innovation management. Depending on the stimulus (e. g. problem or idea), the improved innovation stage-gate model distinguishes ever since then between demand-induced and supply-induced technical process innovations. The latter are triggered by newly established technology intelligence processes which deliver insights to understand manufacturing opportunities. For example, a developed 'heat map' of emerging technological trends highlighted the cluster of Autonomous Co-operating Systems (ACS) as a 'hot spot'. Subsequently, in 2006, the scouting process with a pre-defined technological search field called ACS was initiated at the BMW Group Technology Offices, among others, in the United States and in Japan (BMW, 2007, p. 19). The consolidated technology roadmap with the initial estimate that human-robot co-operation will become relevant for the BMW Group around 2016 was then presented in the annual strategy workshop to the production department's top-management committee. However, in December 2008, the project manager of ACS and case #2, participated in a robotics conference organised by the MIT Industrial Liaison Program (ILP) and realised that human-robot co-operation

will come considerably faster than originally predicted, because robotics producers have already started to physically build up such collaborative robot systems. As a result, the production department's central predevelopment committee incorporated the new manufacturing approach into the strategic framework and the top-management committee approved the project charter (ID 4599) at the end of 2009 for further development.

Transform Manufacturing Processes

In 2010, the project team acquired lightweight robotic technology from production equipment suppliers and started working on potential use cases in order to get an idea of what a collaborative robot system can be used for in the automotive context and what kind of interaction scenarios are applicable. Since the market was on a basic technology research level (TRL 1-3) and the available lightweight robotic technology was not mature at that time, the project progress was limited. In order to overcome these constraints, the project team decided to rent various robot arms from different leading robotics producers and to intensify the collaboration with scientific institutions such as the Fraunhofer Society and a number of universities. At that point, the production department has established a test area (i.e. robot laboratory) as part of the BMW Group Research and Innovation Centre equipped with laboratory tooling and special test/inspection apparatuses. During a visit of the Automatica 2011 (i.e. International Trade Fair for Automation and Mechatronics), the project manager noticed the Danish robotics producer called Universal Robots and the first certified collaborative robot system UR5 on the market matching Standard³ ISO 10218. In July 2011, the production department's annual 'idea exhibition' took place in the robot laboratory where the results of the initiated technology search field—three different technology concepts for collaborative robot systems—were presented by means of experimental hardware models. Approximately three month later, the group leader of process planning at the Spartanburg site contacted the project team that he has heard from the collaborative robot systems and that the fixing process of the moisture insulation in their door assembly could benefit from the new manufacturing approach. For this reason, the BMW Group and Universal Robots signed in December 2011 a memorandum of understanding for a closer collaboration.

Exploit Manufacturing Systems

At the same time, one of the project team members visited Universal Robots in Denmark with a BMW 3 Series car door from the Munich site to carry out a moisture insulation rolling trial with a prototype of their UR10 industrial robot arm as follows:

³ ISO 10218-1:2011 Robots and robotic devices – Safety requirements for industrial robots – Part 1: Robots
ISO 10218-2:2011 Robots and robotic devices – Safety requirements for industrial robots – Part 2: Robot systems and integration

In December 2011 we visited Universal Robots in Denmark and we constructed a rudimentary test set-up in their laboratory. We mounted a roller head on the robot arm and clamped a car door in a vice. Then, we programmed and demonstrated rolling scenarios and tested the robot arm's force control. So, all in all, we spent two days in Denmark to get a feel for the functionality of the robot arms and to show if our concept is practical. (Non-managerial employee, interviewed on 11 June 2014, translated by the author)

The objective of this experimental proof of concept was to get the feeling that it works and to document the feasibility with a video for internal communication purposes. Back in the robot laboratory at the R&D site, the project team received an original BMW X3 model car door together with an appropriate load handling attachment from Spartanburg and developed the pilot plant further by using an active contact flange from FerRobotics between the roller head and the robot arm to manage the contact force in a reliable way. Members of the process planning group from the Spartanburg site came to the robot laboratory and checked the collaborative robot system before it was transported to the United States. In May 2012, the human-robot co-operation was tested with two one-week 'line trials' in the target environment at the Spartanburg site, hall 52, and the formal risk assessment was undertaken with external support. After the successful 'line trials', the pilot plant and in particular the control unit was modified according to existing BMW Group Standards in order to facilitate the integration of the collaborative robot system into the serial line. At the end of 2012, the modified plant fulfilled all formal requirements and four robot cells could be installed in Spartanburg. Finally, in May 2014, after 18 months of testing, the project team received the 'green sheet' which means that the production and maintenance unit accepted the plant and took over the responsibility for the implemented human-robot co-operation. According to a published press release, the innovativeness (i.e. the capacity to create a technology discontinuity in the automotive industry) of case #2—human-robot co-operation—can be described as follows:

We regard the successful implementation of an ergonomically optimised human-robot co-operation in series production as a major step toward future automotive engineering and the world of Industry 4.0 [...] [and] collaborative robots enable us to create new forms of design in the process layout. (Stefan Bartscher, project manager of 'ACS', BMW, 2013b, p. 2)

In the meantime, lightweight robots have been integrated into series production at other plants in the BMW Group production network such as Regensburg, Dingolfing and Leipzig and further roll-out of collaborative robot systems is currently in the planning stage (BMW, 2015b, p. 2).

Conclusion

This section describes a supply-induced technical process innovation that results from the production department's strategic framework. Specifically, case #2 indicates that the BMW Group's production department pursues an innovation strategy with strategic

themes and objectives and focuses on the identification of internal/external basic manufacturing implications. In so doing, the department's central innovation unit acts as a 'service provider' to the members of the process chain (e. g. press shop, body shop, paint shop and assembly line) and offers new manufacturing approaches which are detected through technology intelligence processes. Moreover, the innovation unit is able to carry out innovation projects and to set up hands-on 'impulse experiments' or 'pilots'. This is achieved through adequate resources in terms of budget and capital investment and established innovation incubators which provide a work environment with sufficient freedom to protect immature work products.

A.4 CROSS-CASE ANALYSIS

This section examines case #1 and case #2 regarding similarities and differences to identify which of those are perceived by the BMW Group as critical to build and maintain its technical process innovation capability. In so doing, the cross-case analysis is divided into five subsections. At the beginning, the context of the analysis is reiterated. This subsection is followed by a brief comparison of the two polar type cases on the three top-level learning routines (i. e. explore manufacturing technologies, transform manufacturing processes and exploit manufacturing systems). Finally, the cross-case analysis concludes by drawing together the main findings and highlighting their potential implications for managers of technical process innovations.

Introduction

In the main document (see Chapter 2), the central research phenomenon—*technical process innovation capability*—was defined and mapped into a conceptual framework which graphically explains the key factors to be investigated and their role in the broader context of competitive advantage. These building blocks, namely resources, activities and capabilities, are linked through co-ordination and grounded in the domain of strategic management. Adopting an intra-organisational perspective, strategically relevant resources such as technological development knowledge and production skills can be reconfigured through the application of learning routines. For this reason, the three top-level learning routines (i. e. explore manufacturing technologies, transform manufacturing processes and exploit manufacturing systems) were used as a construct to identify potential themes which are perceived by the BMW Group as critical to build and maintain its technical process innovation capability. This section addresses the following major research question: *In what way does a world leading motor vehicle manufacturer build and maintain its technical process innovation capability?*

Explore Manufacturing Technologies

The top-level learning routine *explore manufacturing technologies* starts with identified basic manufacturing implications such as recognised problems/needs (case #1) or discovered opportunities (case #2) which are usually linked with the production department's innovation strategy. Moreover, the notion of innovation is deeply rooted in the BMW Group's corporate strategy which consists of four pillars, namely: (1) growth, (2) shaping the future, (3) profitability and (4) access to technologies and customers. While case #1 was initiated by the strategic decision to use CFRP in the passenger cell without having appropriate joining processes in place, case #2 was triggered by the curiosity and persistence of the project manager in charge as well as the newly established technology intelligence processes. Depending on the scale of the technical process innovation projects, flexible organisational structures such as 'newstream organisations' (case #1) or 'incubators' (case #2) are established in order to provide a work environment with sufficient freedom. In addition, the production department's central innovation unit offers systematic ideation services and open exchange platforms to support ideas/solution providers and it collaborates with external partners to access the latest stage of technological development. During the exploration phase, demand-induced (case #1) and supply-induced (case #2) technical process innovation projects achieve the following manufacturing levels (MRLs):

- manufacturing concepts identified (MRL 2),
- manufacturing proof-of-concept developed (MRL 3) and
- capability to produce the technology in a laboratory environment (MRL 4).

The established process R&D laboratories which are most often located at the BMW Group's Research and Innovation Centre (cases #1-2) enable the project teams to explore new manufacturing technologies by means of experimental hardware models and laboratory tooling. In order to maintain the new knowledge and skills, the used organisational process assets (e.g. plans, processes, policies, procedures and knowledge bases) are revised by the project teams throughout the exploration phase as necessary.

Transform Manufacturing Processes

The top-level learning routine *transform manufacturing processes* is the 'transmission belt' between the capability to produce the technology in a laboratory environment and the capability to produce systems, subsystems or components in a production representative environment. In both described cases, the top-management demonstrated strong commitment to the importance of the innovation projects either by supporting a promotional campaign to get the sceptics on board (case #1) or by providing adequate resources to establish the required test area (case #2). Especially supply-induced tech-

nical process innovation projects use vivid communication platforms such as the production department's annual 'idea exhibition' to get in touch with potential end-users and to confirm target applications for the manufacturing processes which is a tough acceptance criteria of the innovation stage-gate model. Through digital 'information hubs' and formally recognised subject matter experts, the BMW Group nurtures a culture of open and transparent knowledge-sharing between organisational members. During the transformation phase of the technical process innovation projects, the following manufacturing readiness levels (MRLs) are achieved:

- capability to produce prototype components in a production relevant environment (MRL 5),
- capability to produce a prototype system or subsystem in a production relevant environment (MRL 6) and
- capability to produce systems, subsystems or components in a production representative environment (MRL 7).

The established pilot plants which are located at the R&D and production sites (cases #1-2) enable the project teams to transform new manufacturing processes by means of prototype tooling and pre-production tooling. In order to maintain the new knowledge and skills, the used organisational process assets (e.g. plans, processes, policies, procedures and knowledge bases) are revised by the project teams throughout the transformation phase as necessary.

Exploit Manufacturing Systems

The top-level learning routine *exploit manufacturing systems* reintegrates the 'newstream organisations' (case #1) or 'incubators' (case #2) into the main organisation in order to unlock the full potential of the technical process innovations. For example, in case #1, the installed pilot plant at the Munich site was used to prepare and qualify the manufacturing personnel in a production representative environment. In contrast, the project team in case #2 used directly the two one-week 'line trials' at the Spartanburg site to involve the local plant operators and maintenance workers. However, both project teams put not only a strong focus on knowledge transfer towards the potential end-users but also towards other product lines (case #1) or production sites (case #2). During the exploitation phase of the technical process innovation projects, the following manufacturing readiness levels (MRLs) are achieved:

- pilot line capability demonstrated; ready to begin low rate initial production (MRL 8),
- low rate production demonstrated; capability in place to begin full rate production (MRL 9) and
- full rate production demonstrated and lean production practices in place (MRL 10).

As soon as the manufacturing systems are approved in a full-scale commercial factory (case #1 at the Leipzig site and case #2 at the Spartanburg site) the technical process innovations are deployed throughout the BMW Group's production network. In order to maintain the new knowledge and skills, the used organisational process assets (e. g. plans, processes, policies, procedures and knowledge bases) are revised by the project teams throughout the exploitation phase as necessary.

Conclusion

Based on the cross-case analysis of the two initial cases, the following preliminary conclusions are outlined with respect to the major research question. Building and maintaining a technical process innovation capability necessitates a concurrent effort:

- realising a high-quality innovation stage-gate model and a balanced portfolio of demand-induced and supply-induced technical process innovation projects,
- developing an innovation strategy based on recognised problems/needs or discovered opportunities and translating it into competitive priorities,
- establishing 'newstream organisations' or 'incubators' to provide the project teams with the leeway for creative thinking and risk-taking,
- demonstrating top-level management commitment to the importance of innovation projects where failure is part of the business and
- having a formal system of reflection in place which incorporates lessons learned and project related experiences into organisational process assets.

A.5 SUMMARY

This addendum chapter offered a rich description of the two initial cases and compared their points of similarity/difference. It began by presenting case #1—CFRP adhesive bonding process—a demand-induced technical process innovation driven by recognised needs. Subsequently, it reported case #2—human-robot co-operation—a supply-induced technical process innovation driven by discovered opportunities. Both case descriptions entail core narratives on the three top-level learning routines (i. e. explore manufacturing technologies, transform manufacturing processes and exploit manufacturing systems). Then it outlined the cross-case analysis of the two initial cases and articulated preliminary conclusions with respect to the major research question which are further discussed in the main document.

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