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Revealing the Disruptive Potential of New Technologies at Early Stages in the Innovation Process

A Master's Thesis submitted for the degree of
"Master of Business Administration"

supervised by
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Vienna, August 2018

Affidavit

I, **DORIS WINKLER**, hereby declare

1. that I am the sole author of the present Master's Thesis, "Revealing the Disruptive Potential of New Technologies at Early Stages in the Innovation Process", 101 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and

2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Preface

The *PMBA of Entrepreneurship and Innovation* was a perfect completion to my preceding studies of Technical Mathematics at the TU Vienna by giving a holistic view of indispensable economic foundations and opening up to me the incredibly fascinating world of technological innovation and entrepreneurship. Throughout the studies, I found myself permanently outside my personal comfort zone, and it was this outstanding crowd of enthusiastic professors, inspiring entrepreneurs, great mentors, brilliant colleagues and untiringly supportive program managers who encouraged me in an unprecedent way and whose personalities, passion and brains for their business made the MBA journey a unique pleasure. I am convinced that this experience will positively influence my further life in several aspects - it already changed it in an incredible fashion.

The end of this impressive two-year MBA era taught me once more about the worth of people and the enormous power of an awe-inspiring environment, wherefore it is time for a token of my deepest esteem to those I had the pleasure to work and be with closely and I was allowed to learn from– personally and professionally.

I would like to take this opportunity to express my deep gratitude to **Professor Keinz**, whose expert knowledge in innovation theory and quick-wittedness in capturing complex subjects I highly appreciate.

Furthermore, my perfect esteem goes to **Bernhard Graser**, a phenomenally talented colleague who captivates with his intelligent spirit, and sparked the idea in me for this MBA, **Manfred Fellner** and **Thomas Bogensperger**, my incredible mentors of the last eight years, whose permanent excellent support was my personal backbone especially in tough times.

I also pay tribute to **Johanna Hofmann**, my intimate group of ingenious MBA colleagues and friends, on whom I could rely *at any time*, *every day* of the last years – unforgettable their daily motivation calls and encouraging messages.

And most important, once more I learned that I am blessed to have such a **loving family**, who gave me strong roots and made this amazing adventure possible, and who has always been compassionate when time was scarce. You are the essence of my life.

In Love for the Being, in Loving Memory for Those Who have been

Abstract

Technology is key. The current digital era is characterised by the unique co-evolution of disruptive technologies, fostering the incredible pace of change in information system and in algorithm-driven decision-making. The intelligent integration of emerging technologies to new technologies through open innovation will collectively remove obstacles of adoption and induce striking paradigm shifts in nearly every business by generating disruptive innovations in form of highly competitive products, processes, services, or the development of new markets reinventing the rules of business of centennial industry sectors.

The present thesis puts the development of a conceptual integrated process framework for the strategic and early detection of new technologies in the form of technically feasible, sufficiently mature and superior product concepts with high disruption potential centre stage. These novel technologies are assumed to emerge from the smart recombination or unification of promising technologies. A taxonomy based on the interaction of technologies, defined as bundles of value chains, allows the designing of subprocesses in this *New Product Development Process.* The proposed framework incorporates (a) tools for *strategic market opportunity identification (Technological Competence Leveraging,* the *Technology-Push Lead User Concept,* and the *Method for Technology-Push Roadmapping),* (b) tools for the *conceptualization* and *strategic solution of technical systems* and *ignition of creativity in the problem-solving process,* and (c) *Artificial Intelligence* and *Virtual Reality* methodologies for enhancing the preceding techniques and the communication in collaboration processes in order to account for the people's global dispersion due to increased mobility. The presented framework intends to contribute to the theory of technological innovation management by providing a clearly structured and technologically powerful procedure for steering a company's future technological landscape with regard to optimally placed technological investments. It aims to primarily address SMEs and independent research centres due to its strong orientation towards technology-push concepts and pronounced involvement of strategic collaboration networks, although strong market-pull aspects are included to synthesize respective advantages of both approaches. As the thesis remains on a conceptional level, empirical validation of the process framework through implementation in distinct organisational structures is indicated. Moreover, its application needs to be seen and discussed in a broader context through the inclusion of relevant key enablers of innovation like organisational structure, company culture or innovation promoters of the focal company which is recommended to be subject of further research.

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List of Acronyms and Abbreviations

AI:	Artificial Intelligence
AR:	Augmented Reality
CAE:	Computer-Aided Engineering
CAGR:	Compound Annual Growth Rate
CAI:	Computer-Aided Innovation
CBR:	Case-Based Reasoning
C-K:	Concept-Knowledge Theory
DL:	Deep Learning
IDC:	International Data Corporation
IDM:	Inventive Design Method
IFR:	Ideal Final Result
IoT:	Internet of Things
IP:	Intellectual Property
GUI:	Graphical User Interface
KCP:	Knowledge-Concept-Propositions Design Process
MDAO:	Multidisciplinary Design-Analysis and Optimization
MCDA:	Multiple-Criteria Decision Analysis
MCDM:	Multi-Criteria Decision Making
ML:	Machine Learning
MR:	Mixed Reality
MTP:	Method for Technology Push
NPDP:	New Product Development Process
QFD:	Quality Function Deployment
SME:	Small and Medium Enterprise
ROI:	Return on Investment
S&T:	Science and Technology
SOI:	Sources of Innovation
TAK:	Title, Abstraction and Keywords
TCL:	Technological Competence Leveraging
TIPS:	Theory of Inventive Problem-Solving
T-PLUC:	Technology-Push Lead User Concept
TRIZ:	Teorija Resehnija Izobretateliskih Zadatch (Russian acronym of TIPS)
TRM:	Technology Roadmapping
VR:	Virtual Reality
WoS:	Web of Science
xR:	Describing VR, AR or MR

1 INTRODUCTION

In the current era of globalisation and liberalised markets, increasingly reduced high-tech product lifecycles, innovation-related industry dynamics, and data- and information system-associated trends setting the pace with which technologies are evolving and becoming redundant and substituted by others, organisations and entrepreneurs are finding themselves under tremendous pressure to proactively and—in particular—strategically create and commercialise innovations, e.g. to leverage existing technologies across industries or to invent radically new technologies with high disruption potential in order to ensure continued profits and the survival of the company in the mid- to long-term. Faced with highly-dynamic markets with increased complexity and disruptive changes in communication networks, the minimisation of the development cycle time, paired with early technological robustness and maturity and increased organisational agility, has become essential for taking advantage of open-market opportunity windows by conquering the *maturity* and *time gap* (Schulz et al., 2000, p. 182), and thus, achieving and keeping competitive advantage (Appendix Figure 34).

Beyond, an increased strategic linkage between effective networks of *Sources of Innovation (SOI)* (Schilling, 2017, p. 15-42) constituting silos of relevant market and technology knowledge needs to be complemented by the intelligent, industry-transcending use, recombination and transformation of new technologies into *smart, connected products* (Porter and Heppelmann, 2014) This will offer companies the opportunity to realise better financial as well as non-financial results along with high cost-efficiency, which in turn increases the probability of outperforming competitors. Therefore, enterprises are asked to utilise appropriate resources (Danneels, 2007) to effectively perform *technological innovation management* (Wolfrum, 2013, 1991b) based on a systematic approach.

1.1 Phenomenon Formulation

Early phases of the technological innovation process—known as the *fuzzy front-end of innovation* (Lüthje and Herstatt, 2004, p. 553)—exhibit a high degree of market and technology-related uncertainty. But these phases also offer the unique opportunity to decide on the future technology landscape of a company, hence sowing the seeds to drive future business success (Herstatt and Verworn, 2007). At this innovation stage, the commercial relevance of identified opportunities is difficult to ascertain (Gehringer, 2013, p. 82). Lüthje (2007, pp. 39–60) supports the preceding assumption by pointing out the urgent necessity to involve *lead users* (Von Hippel, 1986, p. 791) who have due to their present strong needs which they seek to meet peculiar expertise for creating cutting-edge product features already in this phase of the innovation process where investment decisions are undertaken and where the negligence of customer needs can be critical to the success of the innovation process. Apart from the compelling merits of their integration in forecasting future user needs and in the creation of customer-centric product concepts, the involvement of lead users provides the additional convincing advantage to generate initial demand (Von Hippel, 2005; Von Hippel et al., 2009, 1999).

Figure 1 describes the innovation process given by Herstatt and Verworn (2007, p. 9) and its early stages—mentioned as *fuzzy front-end*—where the dashed line indicates the scope of the present thesis. The proposed innovation process framework developed herein aims to benefit from the unique knowledge of the lead users, not only in the idea generation and concept generation phases, but also in the subprocess of idea evaluation.

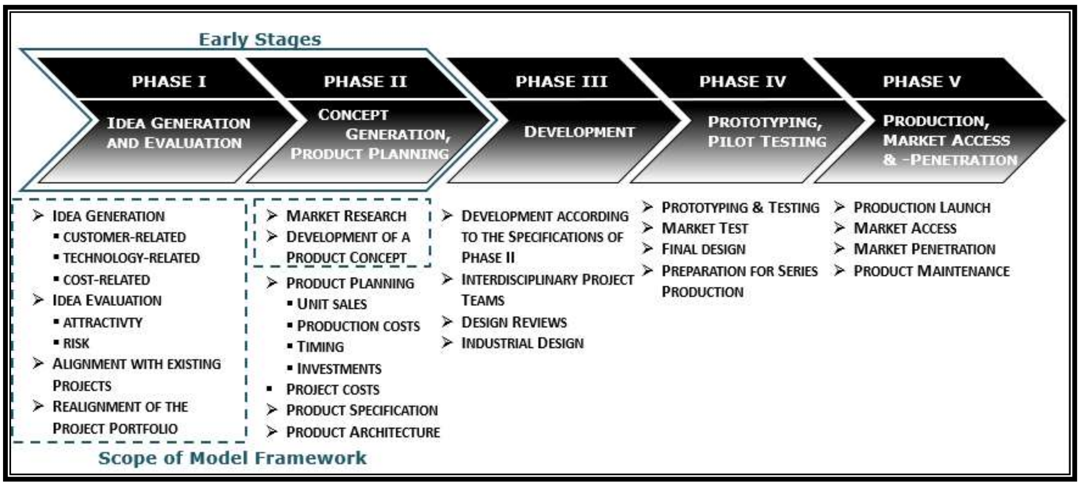

Figure 1: Model of the Innovation Process (Herstatt and Verworn, 2007, p. 9) and Scope of the Thesis Process Framework

To exploit technological and other trends in company-related or other markets and link them to a company's internal business, technology and innovation strategies for the relevant time period, appropriate tools for the strategic search for experts, forecasting and evaluation of trends from *technology intelligence* and *technology forecasting* (E. Lichtenthaler, 2008; Moehrle and Isenmann, 2007; Wolfrum, 2013, 1991b), and empirically proven search strategies like *pyramiding* (Von Hippel et al., 2009) and *broadcasting* (Grubhofer, 2008) for accumulating functionally, contextually, or geographically dispersed knowledge (Schilling, 2017, pp. 15–37) to overcome the problem of *local search behaviour* (Keinz & Prügl, 2010) are indispensable aside efficient solution techniques for the tacitly emerging complex systems of technologies (Cavallucci, 2017).

1.2 Scope and Objective of the Master's Thesis

On that score, the prevalent thesis focusses on the strategic development of an integrated model framework for a technological innovation process for merging novel technologies and addressing the initial stages of the innovation process by combining elements of *technology-push* product integration (Danneels, 2007; Henkel and Jung, 2009; Herstatt and Lettl, 2004; Keinz and Prügl, 2010; Souder, 1989) and *lead user* concepts (Gehringer, 2013; Lüthje and Herstatt, 2004; Von Hippel, 2005, 1986; Von Hippel et al., 1999) to incorporate aspects of a *market-pull* product integration strategy, *technological roadmapping (TRM),* and systematic approaches for inventive problem-solving *(TRIZ).* The targeted deployment of *Artificial Intelligence (AI)* and *Virtual Reality (VR)* to specific approaches of the nascent framework aims to optimise methodological specifics with regard to efficiency, performance, lead-time, robustness, and maturity of technologies, and to account for the increase in people's mobility and market liberalisation in order to connect people globally and to facilitate and drive the associated communication processes. In the following section, it is assumed that strategically chosen co-working partners share innovation-project-specific content on web-based platforms or receive virtual training sessions for innovation-project-relevant methodologies. Figure 2 illustrates the final integrated process with its underlying, delineated methodologies, which are used to overcome the *opaque* and *permeable boundary* between technology systems and market opportunities, using the layer of collaboration networks communicating via platforms for bridging knowledge gaps on both sides of the boundary. Apart from these technical aspects, the framework's implicitly strong inclusion of effective collaboration networks of professional excellence and the systematic approach of collaboration partners purport to further increase the probability of revealing market opportunities with high likelihood of breakthrough for systems of mutually supportive—*symbiotic*—technologies (Coccia, 2018, 2017; Odum and Barrett, 2005; Sandén and Hillman, 2011;) like blockchain, *Artificial Intelligence (AI)*, and *Virtual* and *Augmented Reality*

(VR/AR)[1] in order to unlock the implicit value of the technology combination to its full potential.

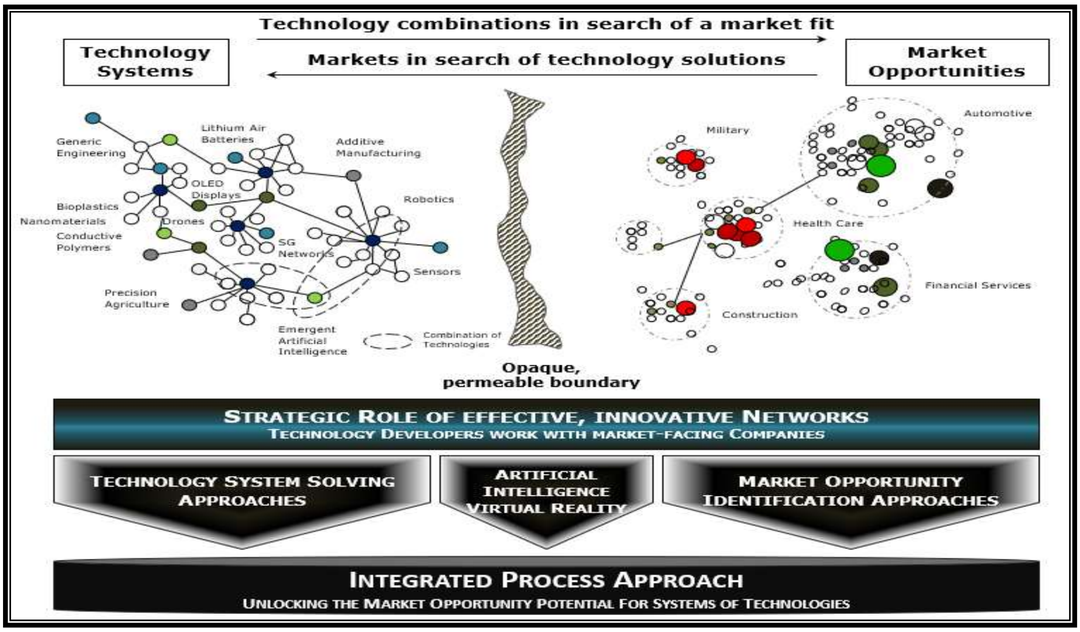

Figure 2: Overcoming the Boundary Between Technology Systems and Potential Market Opportunities with an Integrated Model Framework (Figure Adapted from Ed Morrison et al., 2015)

In the subsequent course of this thesis, the following research questions are addressed that are assumed to be the most significant for the prevailing problem and that are aimed to be sequentially answered:

Central Research Question:

RQ0: 'Which model framework of an innovation process can increase the likelihood of detecting application fields with a high innovation level for the recombination of technologies—both existing and company-extraneous—at an early stage of the innovation process?'

Research Sub-Questions

RQ1: 'What developments and coincidences *promote the symbiotic relationship* of emerging technologies?'

RQ2: 'How can technologies be *classified*?'

[1] It is hereinafter referred to as VR, although the degree of immersion depends on the type and purpose of collaboration, the information or documents that need to be visually shared, how collaboration partners are interacting, and whether VR training and collaboration platforms are used.

RQ3: 'What techniques and approaches exist to *combine technologies* and how can this *combination be classified*?'

RQ4: 'According to what principles does a *system of technologies evolve* in time?'

RQ5: 'What techniques and approaches exist for the *discovery of novel application areas* for technology combinations?'

RQ6: 'The synthesis of technologies results in a system of technologies: What techniques and approaches exist for the *discovery of conflicts in this technical system that can be solved solely with innovative approaches* and with what tools can these contradictions be removed?'

RQ7: 'What techniques *broaden the innovation problem's solution space* by overcoming psychological inertia, and hence, increase the *market opportunity set prior to market entry*[2] (Gruber et al., 2012) with regard to its size and variety?'

RQ8: 'What *user-communities* best support the detection of highly disruptive innovations and how can they *be found*?'

RQ9: 'Is it possible to integrate *both product integration strategies*—voice of the market (market-pull) and the voice of technology (technology-push)—into one innovation process framework?'

RQ10: 'Is it possible to *accelerate the maturity level of a novel technology* and to *increase its degree of robustness* at such an early stage in the innovation process?'

RQ11: 'Selection from a range of novel technologies: What evolution pathways of novel technologies promise *world-class competitiveness in a short time* by exhibiting low failure risk and high market potential? How can the latter parameters be assessed?'

RQ12: 'What tools enable efficient communication in collaboration groups from a cost and time perspective?'

RQ13: 'What are the main challenges and obstacles in adopting this model framework?'

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[2] Chapter 2.1.3. is dedicated to this powerful concept.

1.3 Course of Investigation

As the objective of thesis is to develop a conceptual innovation process framework leading to highly innovative product concepts, a *literature review* has been conducted, focusing on the methodologies relevant to identifying novel market opportunities, solving technical systems, and collaborating in the era of *Web 2.0* (Newman et al., 2016), primarily by screening the '*World Wide Web*', '*Springer Online*', '*Google Books*', '*Google Scholar*', '*IDC*' (a global market intelligence provider), the academic libraries '*TU Wien University Library*' and '*Vienna University of Economics and Business Library*', and scientific databases like '*Web of Science*' and '*ScienceDirect*'. The latter has been chosen to be the primary source of performing a subsequent in-depth scientific paper search for TRIZ, AI, and VR. Although it does not offer the possibility to do a quantitative citation analysis, the results seem to be more plausible and reliable with regard to search settings compared to '*Web of Science*'. Subsequently, for each search result, the respective bundles of papers have been analysed with regard to their applicability in the context of the intended process framework and for consolidating the formation of the process structure. From the results of the literature studies, scientific fields of rapid growth according to increasing public interest were identified, indicating trends and dynamics to show how the focal methodologies are currently used in combination and where persistent gaps still emerge. The interpretation of these insights has led to the final process framework presented in this work.

This semi-structured quantitative (Table 2, Table 4, Table 5) information-seeking process has been carried out to filter the most recent academic developments in order to ensure that the research is up-to-date, as this is considered to be essential for further research (Pontis et al., 2015).

1.4 Structure of the Master's Thesis

The present work is structured as follows, starting with **Chapter 1** which introduces the topic of the thesis.

Chapter 2 highlights the context of the thesis topic and illustrate the promising co-evolution of scientific developments and technological trends, followed by definitions and classifications of technologies according to their interrelation, and the non-random evolution of pathways of the technologies' relationship deduced therefrom. The chapter also reveals the importance of these approaches for the development of the process framework by giving a methodological indication of how the presented techniques are feasibly combined. Subsequently, reviews and analyses of existing methodological approaches and concepts relevant for technology forecasting, which increase the novelty degree of inventions and enable cost- and time-efficient collaboration, are presented. Further, strengths and weaknesses of each method and the communalities and differences between approaches are discussed. Figure 3 illustrates the outlined structure of Chapter 2.

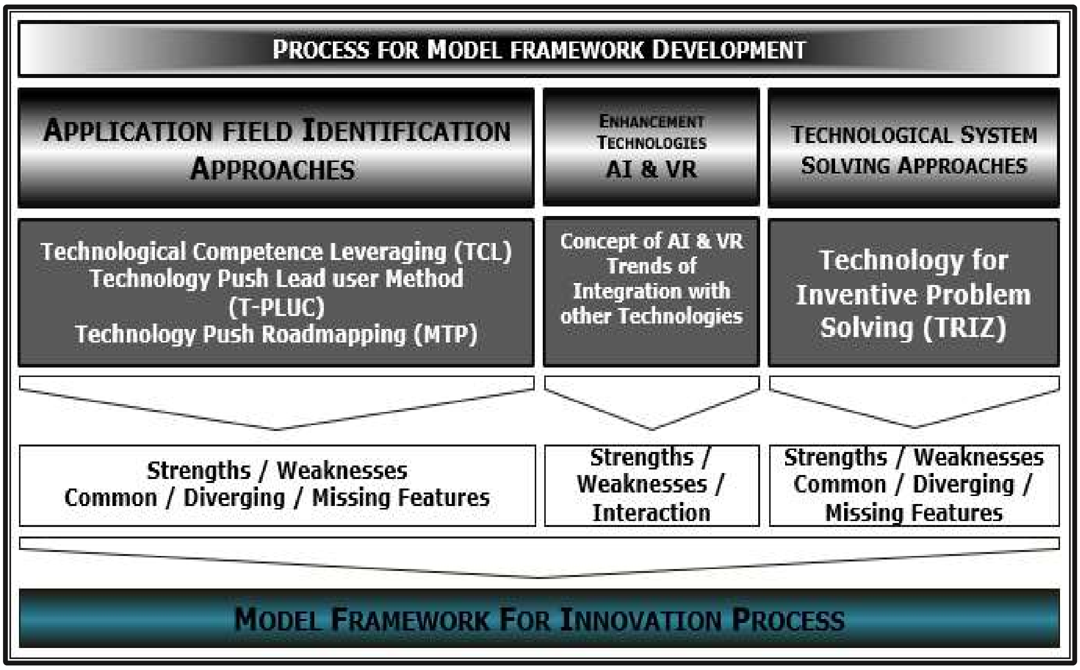


Figure 3: Process Structure of Chapter 2

Chapter 3 applies the new definition and taxonomical concept of interaction of technologies for identifying viable combinatorial arrangements in order to best integrate the presented methodologies into one common model framework for an innovation process, the aim of which is to fill the gaps of the methods with regards to a priori enacted factors assumed to be key for the detection of highly disruptive innovations by synthesising the advantages of each and getting rid of their specific drawbacks. The framework itself is divided into four phases, of which only the first three are in the scope of the thesis and described in detail. Each phase is structured into workshops for the purpose of increasing the transparency of process flow to give a holistic approach by allocating collaboration groups as well.

Chapter 4 discusses the presented conceptual process framework, provides recommendations for a corresponding implementation, and gives an outlook of future relevant research related to innovative approaches for new product development.

2 THEORY

Open innovation has triggered a paradigm shift in the way companies foster the invention and commercialisation of new customer-centric products, services, and optimised processes. It is already an inevitable and established trend (Chesbrough, 2006) requiring multidisciplinary and multi-intelligence efforts as well as a well-thought-out future technology planning with regard to respective selection, timing, and role, embedded in effective innovation management. Companies are feeling the need to develop new and educate the existing workforces and to allocate adequate resources to the open innovation process to propel the development of novel combinations of pre-existing components and leading-edge innovations.

2.1 Framework

This subsection provides the frame for uncovering the potential of technology combinations by discussing important theories and concepts constituting important prerequisites for the methodologies driving open innovation introduced hereinafter.

2.1.1 Current Coevolution of Technologies

The prevalent industrial epoch is an era of technological change, and thus, economic growth, and exhibits the unique coevolution of technologies opening the door to unprecedented innovations capable of conquering the global market (Coccia, 2018, p. 3).

'*Convergence is a deep integration of knowledge, tools, and all relevant activities of human activity for a common goal, to allow society to answer new questions to change the respective physical or social ecosystem. Such changes in the respective ecosystem open new trends, pathways, and opportunities in the following divergent phase of the process*' (Roco, 2002, Roco and Bainbridge, 2002, cited by Bainbridge and Roco, 2016, p. 1).

Bainbridge and Roco (2016, p. 1) promote certain principles and methods that enable *science and technology convergence* and create a *'[n]ew universe of discovery, innovation and application opportunities'.* They refer to 10 increasingly coalescing theories using—apart from historical developments—elements of social, economic, physical, and cognitive science, whose emerging technologies-driven progressive interrelation the authors believe to converge *'[t]oward a transformative socioeconomic ecosystem'* (Bainbridge and Roco, 2016, p. 7) (Appendix Figure 35).

Analogous to Bainbridge and Roco's (2016) nanotechnology-associated convergence examples, the theories introduced in conjunction with the presented principles try to answer questions like *'if emerging trends in information technologies are actually able to wipe out jobs, can a technology—in convergence with other emerging technologies—fill the emerging gap in employment by generating new applications and—as a feasible consequence—new markets?'*

2.1.2 Technology Classifications and Pathways of Evolution

In addition to this convergence of science and novel technologies, consistent terminologies are imperative for the revelation of technology-based synergies and the derived pathways of common technical system evolution, conjointly occurring patterns in market opportunity, and technology evaluation tools assignable to the specifics of the company. Therefore, in the present thesis, *technology* is defined as science of technique, which includes knowledge of scientific and technical interrelationships of effects (Wolfrum, 2013, p. 4), in accordance with Burgelman et al. (2008; cited by Stig, 2013, p. 919):

'[T]echnology refers to the theoretical and practical knowledge, skills, and artifacts that can be used to develop products and services, as well as their production and delivery systems. Technology can be embodied in people, materials, cognitive and physical processes, plant, equipment and tools.'

Accordingly, *technology* is also the abstract existence of technical objects in the form of models, operations, and processes, with abstract technical and functional principles (Rautenberg, 1991; cited by Kröll, 2007, p. 24). In distinction thereto, *technique* is the concrete material application of technologies, which is a science leading to action or offering possibilities for action based on theoretical knowledge (Wolfrum, 2013, p. 4).

In times of strong competition for the leading market position and the development of a *dominant design* (Beise, 2012, p. 30; Suárez and Utterback, 1995), the avoidance of dysfunctional technological locked-in systems (Sandén and Hillman, 2011, p. 412) is a major topic of concern for companies, making the understanding of the fundamental rules of interplay of technologies the crux of a firm's innovation management. Regarding the classification on single-technology basis, Spur (1998) and Pfeiffer (1992) (cited by Kröll, 2007, p. 27) classify technologies according to their (a) competition effect, (b) competitive potential, (c) application range, (d) complexity, and (e) development stage (Appendix Figure 36). Sandén and Hillman (2011) expand this classification concept by defining technology more precisely as being a *'system of socio-technical elements organised in bundles of value chains'* (Sandén and Hillman, 2011, p. 405), and by implication, adding new dimensions of material, organisational, and conceptual aspects while highlighting the advantages of a technological innovation system framework for technology diffusion.

Consequently, the *interaction between two technologies* in a complex system (Coccia, 2017) is another possible source of technology classification. By following a community ecology approach in the field of biology, Odum and Barret (2005) identify nine different two-technology interaction modes, while Coccia (2017) and Sandén and Hillman (2011) distinguish six slightly different interaction modes whose aligned and adapted summary is presented in Figure 4 supplemented by Sandén and Hillman's (2011, p. 407 ff.) statement that *'[i]nteraction [of technologies] emanates from overlaps, i.e. shared elements in different parts of the value chain'*. The authors define the terms *quasi-static* and *dynamic interaction* of technologies as prerequisites for their subsequent taxonomic allocation. They argue that *quasi-static interaction* between technologies refers to a *'[f]ixed overlapping part of the [bundles]'* (Sandén and Hillman, 2011, p. 407), which is the case for a presumed constant resource flow used by two technologies or a presumed fixed size of the common market of the two technologies. This is the case for the symmetric interaction variants of *competition* (for markets or resources)*, neutralism, mutualism,* and *symbiosis*. On the other hand, *dynamic interaction* between technologies implies that the interaction happens *'[v]ia structural change in overlapping parts of the [bundles]' due to '[c]hanging demand, production* systems and knowledge pools' (Sandén and Hillman, 2011, p. 407).

Coccia (2018, p. 3) sets a first milestone in advanced concepts of the development of technological systems by addressing the non-trivial problem of designing a *technometric,* which tries to measure the evolution of technologies in technological systems. This is exemplified by host-parasite systems and is based on the works of Sahal (1981, cited by Coccia, 2018, p. 32), which examines the *'systems innovations based on integration of two or more symbiotic technologies',* and Arthur (2009, cited by Coccia, 2018, p. 32), who highlights the *'[s]elf-creating process […] combinatorial evolution[, which] is about things creating novel things by combinations of themselves'* by clarifying that technologies, as well as human and technological necessities, have the capability to generate *opportunity niches* that, in turn, evoke other technologies (Arthur 2009).

TAXONOMY OF TECHNOLOGIES' INTERACTION

GRADE	TYPOLOGY	DESCRIPTION Relationship between two technologies T1 and T2 in a complex system S[1] where:	SOURCE / EXAMPLES / IMPLICATIONS	SHORT NOTATION
1	**Technological competition**	Inhibition when common resource or market is in short supply	**Source: Sandén and Hillman (2011, p. 407-409)** based on Odum and Barrett (2005)	**T1: - T2: -**
2	**Technological amensalism**	One technology T1 is inhibited, whereas T2 is not affected	**Source: Sandén and Hillman (2011, p. 407-409)** based on Odum and Barrett (2005)	**T1: - T2:0**
3	**Technological neutralism**	Neither technology affects the other	**Source: Sandén and Hillman (2011, p. 407-409)** based on Odum and Barrett (2005)	**T1: 0 T2: 0**
4	**Technological parasitism**	One technology T1 benefits (+) from the interaction with T2, whereas T2 has a negative side (–) from interaction with T1	**Source: (Coccia, 2017, p. 12)** **Examples**: Parasite technologies can function, if and only if (iff) associated with other technologies. In Information and Communication Technologies, host technology decreases its energy from interaction with parasitic technologies, such as electric power of battery	**T1: + T2: -**
5	**Technological commensalism**	One technology T1 benefits (+) from the other without affecting it (0).	**Source: Coccia (2017, p. 12)** **Examples:** A commensal technology relation is the connection of a single mobile device to a large WiFi network **Note:** The commensal relation is often between a larger host or master technology and a smaller commensal technology; host or master technology is not impacted by the interaction, "[w]hereas commensal technologies may show great structural adaptation consonant with their systems	**T1: + T2: 0**
6	**Technological mutualism**	Technological mutualism is a relationship in which each technology benefits from the activity of the other technology.	**Source: Coccia (2017, p. 12)** **Examples**: the interrelational link between battery and mobile devices is one example of mutual technologies **Note:** Sandén and Hillman (2011) call the mutualism 'symbiosis' and do not incorporate Coccia's definition of symbiosis in their technological interaction typology	**T1: + T2: +**
7	**Technological symbiosis**	**Long-term interaction** between two technologies (T1, T2) that evolve together in a complex system S. Symbiotic technologies have a **long-run interaction** that generates continuous and mutual benefits and, as a consequence, **coevolution of complex systems in which these technologies function and adapt themselves**.	**Source: Coccia (2017, p. 12)** **Examples:** Symbiotic technologies are Bluetooth and mobile devices continually enhancing each other's technical efficiency. "[T]his technological evolution of Bluetooth technology is associated with new generations of mobile devices [...] in order to better interact with this and other technologies and generate coevolution of complex systems in which these technologies function."	**T1: ++ T2: ++**

[1] Note: "[+](Plus) is a positive benefit to technology Ti from interaction with technology Tj in a complex system S (i=1,..,n; j=1,..,m); (minus) is a negative benefit to technology Ti from interaction with technology Tj in S; 0 (zero) indicates a neutral effect from interaction between technologies Ti and Tj in S; ++ is a strong positive benefit from long- run mutual symbiotic interaction between technologies Ti and Tj in S (i.e., coevolution of Ti and Tj in S)"(Coccia, 2017, p. 12).

Figure 4: A Taxonomy of Technologies in Complex Systems Based on the Work of Sandén and Hillman (2011) and Coccia (2017)

The relevance of this taxonomy for the predominant work becomes apparent, since the determination of those technology combinations is aimed at, which influence each other positively on the short-term and have a mutually positive effect on the long-term as well, triggering constant, reciprocal improvement of products or processes due to their intrinsic hierarchical and recursive structure (shaded areas in Figure 5).

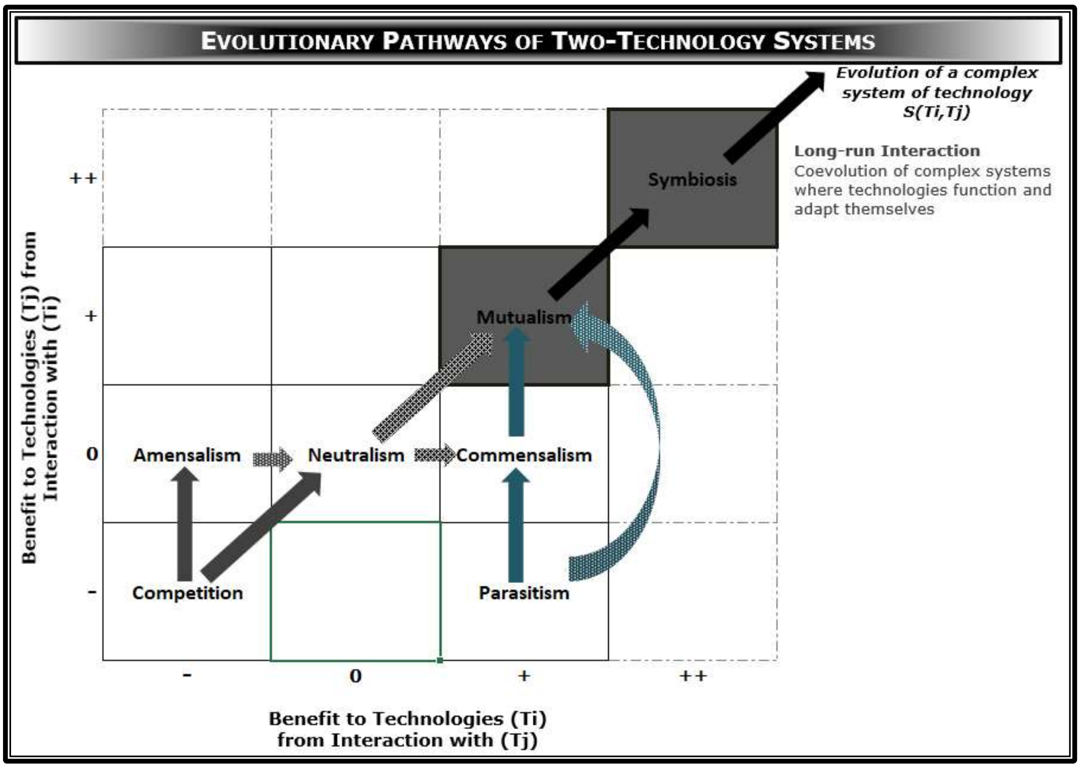


Figure 5: Types and Evolutionary Pathways of Interactive Technologies in a Complex System S[3] Based on the Works of Sandén and Hillman (2011) and Coccia (2017)

Since the utmost goal of the intended conceptual model framework is the discovery of *use cases* infused into potential product concepts for combinations of technologies, whose application scope is not yet fully explored due to the poor data and knowledge available, the term *use case* will address a *system use case,* reflecting the business function and system functionality classification following the framework of the taxonomy specification of Goldman and Song (2005) of six diverse use case classification schemes (Appendix Figure 38). The

[3] *'[T]he notions of positive, negative, and neutral benefit from interaction between technologies Ti and Tj in S are represented by mathematical symbols +, –, and 0. ++ is a strong positive benefit from long-run mutual symbiotic interaction between technologies Ti and Tj in S (i.e. coevolution of Ti and Tj in S). Thick solid [or patterned] arrows indicate the probable evolutionary route of interactive technologies in a complex system S: the possibilities for parasitic technologies to become commensals, mutualists, and symbiotic; [patterned arrows originating from neutralism] show other possible evolutionary pathways of Technologies Ti and Tj during the interaction in a complex system S (∀i=1,…,n; ∀j=1,…,m)'* (Coccia, 2017, p. 12).

presented use case organisation has the potential to facilitate the project management through appropriate resource allocation and use case prioritisation by answering questions according to a proposed scheme given by Goldman and Song (2005, p. 45 ff.) (Appendix Figure 40).

Since concepts for technology classification and technical system evolution are identified, the next subsection focuses on a concept that boosts the likelihood of diversification into new markets, and thus, increases the probability of long-term business success.

2.1.3 The Importance of the Market Opportunity Set Prior to Market Entry

Innovation is created when the knowledge of unfulfilled customer needs coincides with the knowledge of technological solutions and when a company has the ability to identify and transform the merits of this typically external information to commercial success (Cohen and Levinthal, 1990, p. 128). Factors influencing this *absorptive capacity* (Cohen and Levinthal, 1990) have been studied by Mowery (1983), who compares the respective impacts of inhouse R&D vs sourcing in industrial knowledge from external parties on contractual basis and claims that the stronger are a company's inhouse research activities, the stronger is the capability to recognise the value of information that comes from outside the company or an extra-domain and to relate it to the firm's business scope. In line with this argument, Lüthje et al. (2005) draw a direct connection between the *local* information of lead users who reportedly possess need and solution knowledge and the innovation outcome—a relationship that can be purposefully applied for steering innovation results by providing lead users with a specific type of knowledge that matches their needs. Schweisfurth and Raasch (2018) supplement Cohen and Levinthal's (1990) conventionally used term *absorptive capacity* by referring to *solution absorptive capacity*—primarily pertaining to technical solution knowledge—by (customer) *need absorptive capacity* (Von Hippel, 1994). The results of their research on implied causalities of prior intra- and extra-domain knowledge, absorptive capacity mode, and innovations show that precognitions for solutions and prior need knowledge positively affect need absorptive capacity (*cross-pollination effect*), whereas previous proficiencies of market needs diminish the solution absorptive capacity (*attenuation effect*).

Extending the research scope to the influence of knowledge types on the innovation outcome associated with the focal company's economic growth power, Gruber et al. (2012) argue that a decisive factor for achieving sustainable firm growth is the identification of the *market opportunity set prior to market entry,* and thus, the drivers for its components of count and variety as these propelling forces hold the inherent potential to increase the likelihood of diversification in new markets after first entry. Focusing on the essential factors impacting the *variety of market opportunities prior to market entry* the most, the study reveals the importance of external-knowledge-sourcing relationships and the team's industrial experience. It suggests a very high significance of technological experience, whereas entrepreneurial and market experience seem to have no noteworthy influence. Alongside this, there exists a positive moderating effect between the technological expertise of the (founding) team and its industry expertise and the breadth of external knowledge-sourcing. In comparison to these insights, and regarding the *count of market opportunities prior to market entry*, Gruber et al.'s (2012) study discovers a high degree of importance of the team's industry and entrepreneurial experience, a very high degree of importance of the number of external-knowledge-sourcing relationships, and a highly significant but negative impact of market experience. Both market opportunity count and variety are significantly positively related to the likelihood of later diversification into new markets whereupon its inverted u-shaped relationship to the later indicates that the likelihood only increases to a certain point with respect to economies of scope (Appendix Figure 39).

The implication of these research outcomes for the present work is to focus on concepts that broaden the solution space and increase the variety and size of the product concept range. The next subchapter presents a formal definition of open innovation and—closely related thereto—the importance of establishing networks of professional excellence across relevant domains.

2.1.4 Open Innovation and the Strategic Role of Effective Collaboration Networks in the Era of Web 2.0

'[O]pen innovation [is defined] as a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with the organization's business model. These flows of knowledge may involve knowledge inflows to the focal organization (leveraging external knowledge source through internal processes), knowledge outflows from a focal organization (leveraging internal knowledge through external commercialization processes) or both (coupling external knowledge sources and commercialization activities) […]' (Chesbrough et al., 2014, p. 17).

Figure 6 illustrates this open innovation funnel and its commercialisation streams (Herzog, 2011), as described by Chesbrough et al. (2014) which gives an indication of how open innovation supports the unveiling of new revenue streams. According to (Teece, 1986), capturing returns from innovation is affected by three fundamental components: the *appropriability regime*, i.e. non-company or market-related factors referring to the efficacy of legal intellectual property rights protection or technology characteristics, complementary assets, and the *dominant design paradigm* (Teece, 1986, p. 287). The latter relates to the scientific maturity and acceptance of technologies as industrial standards and incorporates the preparadigmatic stage, where no universal conceptual treatment of the phenomenon yet exists, and the paradigmatic stage, when the phenomenon is conceptually accepted by science.

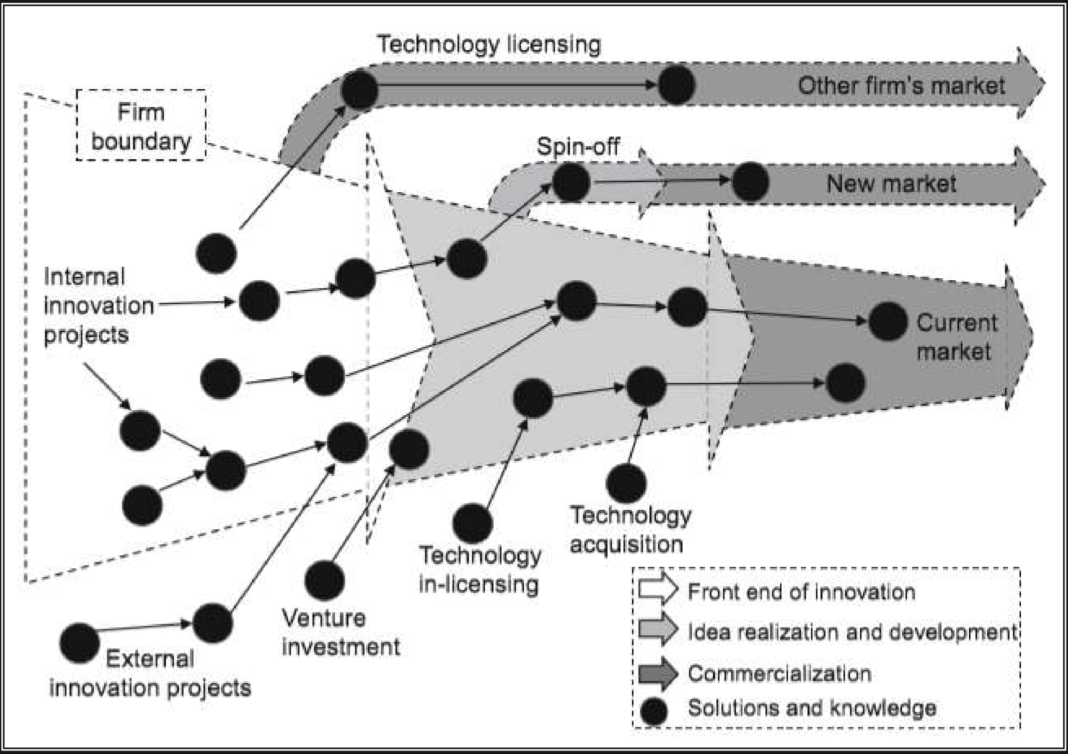


Figure 6: Open Innovation Model (Herzog, 2011, p. 23)

At this point, it needs to be mentioned that open innovation in large organisations differs substantially from open innovation in traditional *Small and Medium-Sized Companies (SMEs),* often relating to high-tech start-ups, and small entrepreneurial firms, according to Chesbrough et al. (2014). In the latter, the role of the founder resembles that of an entrepreneur with a strong stake in shaping the company's innovation process, which is why Chesbrough et al. (2014) recommend linking innovation in SMEs with insights of entrepreneurial literature. Due to their company structure, their lack of internal

R&D power, and their strong dependency on external knowledge carriers such as collaboration or cooperation (Caetano and Amaral, 2011) networks and strategic alliances that play an evident role in the performance of SMEs, the proposed process framework addresses primarily this company type without loss of generality as the presented methodologies focus on technology-push product integration strategies in the first stake. In addition, a strong market view is incorporated early and extensively in the process through the involvement of lead users, and as the proposed framework can be applied as well on technologies new to a company, it also attempts to enhance its attractiveness for large corporations.

The questions which decide whether open innovation is indicated and what collaboration forms are the most appropriate comprise the characteristics of the present problem, i.e. its degree of *ease of delineation and transmission* and its *modularizability*, as well as the characteristics of the required knowledge to solve the problem, i.e. the *effective distance* and the *complexity and tacitness of the knowledge* that the company is forced to assess (*Afuah & Tucci, 2012*). These factors determine the type of innovation—closed or open—and the related governance choice (Felin and Zenger, 2014; Figure 7), ascribing social networks and underlying personal ties with a pronounced strategic role in the innovation-related management process. Concerning the learning process in social networks, Borgatti and Cross (2003) explain the impact of relational characteristics, like the type of personal ties, on information retrieval, whereas Nooteboom (2000) supplements these research by focusing on the effects of organisational structures on the learning process, and hence, its influence on innovation.

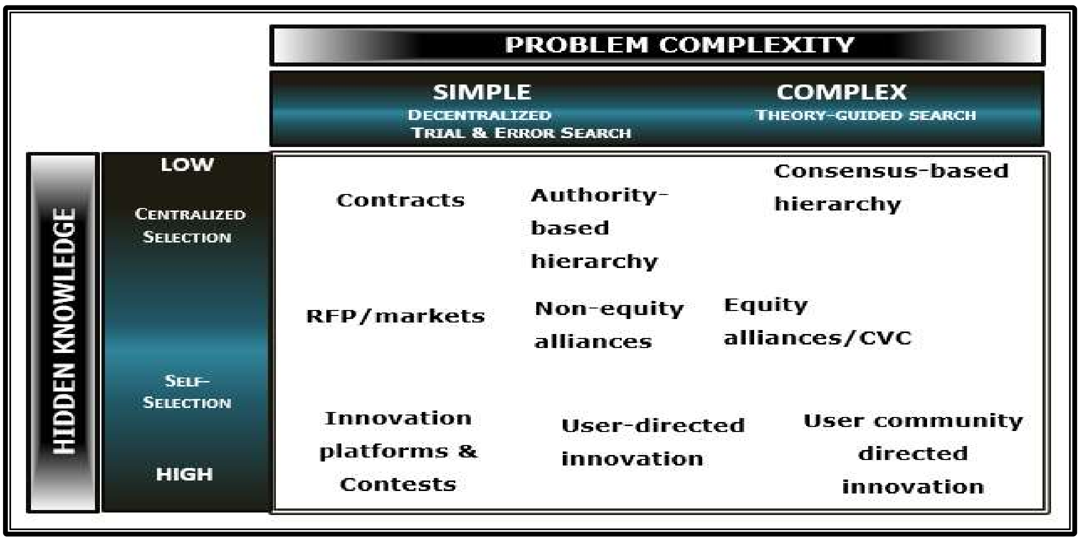


Figure 7: Solution Search vs Problem Complexity (Felin and Zenger, 2014)

According to Satell (2016a) and Gulbrandsen (2009), establishing an organisation coping with the contemporary pace of technological developments only will not guarantee a firm's preservation due to improved long-term sustainability and profitability but would necessitate *'[a] new breed of innovative organizations which integrates the efforts of government agencies, academic institutions and private companies'* (Satell, 2016a) to overcome the *Valley of Death*—i.e. the gap between academic discoveries and their commercialisation. The success of enterprises increasingly working in unexplored terrains is crucially dependent on the capability of the organisation to create a *'[s]hared vision and a collaborative spirit among world-class scientists from a wide range of organizations'* (Satell, 2016b)—an approach that will be the decisive success factor for companies to transcend technology cycles due to fundamental discoveries by integrating specific elements of Silicon Valley characteristics into the company's DNA in order to set the seeds for an intrapreneurial mind-set and spark the intrinsic enthusiasm of employees, while profiting from strong collaborations with institutions at the edge of innovation (Schilling, 2017).

Regarding the concrete *collaboration in groups*, Gabriel et al. (2017) present a multi-agent system for increasing the creativity in workshops by assigning each participant a different role (in its simplistic form: organiser, decision-maker, ideator, facilitator, evaluator, and expert), different responsibilities (problem analysis, ideation, idea evaluation, and implementation and communication) and by characterising creativity through six independent factors *'[i]ntellectual ability, knowledge, type of thought, personality, motivation, and environment'* (Gabriel et al., 2017, p. 264) seen from three different viewpoints:

(I) **The Individual Perspective**: relating to motivation, expert knowledge, and cognitive abilities. Subdivided into three systems:
   - (a) *Personality/Motivation:* the system that fosters creative activity,
   - (b) *Education/Environment:* the system that determines and controls creative activity
   - (c) *Knowledge/Information* related to problems and tools: the resource system of creative activity

(II) **The Collective Perspective:** relating to the interaction and impact of characteristics of individuals on the team, with the prominent collaboration phenomena of *production blocking, judgement fear,* and *social loafing* (Ray and Romano, 2013; Warr and O'Neill, 2005; cited by Gabriel et al., 2017).

(III) The Organisational Perspective: relating to adaptation of the organisational management policy, communication style, company culture, and management of processes to create an environment that fosters creativity.

Fan (2011) completes this elaboration on aspects that foster creative activities in co-working teams by emphasising the importance of integrating non-technical people as a natural corrective into the creative collaboration process.

With regard to the *communication in collaboration groups*, enhancements in information technologies like virtualisation in cloud computing and global increase in bandwidth *(*Newman et al., 2016, p. 593) have triggered the so-called social Web 2.0 which involves linking people online to one another or to interest groups. According to Newman et al. (2016), the next generation of social web or Web 3.0, which integrates the emerged technologies of *'[C]loud computing, Big Data, Internet of Things and security' (*Newman et al., 2016, p. 591) into existing web features, is already on its way to disrupt the world's future communication with regard to how people will stay connected and communicate with each other.

The take-away from this section is the importance of strong collaboration groups and the crucial necessity of building these teams by accounting for the individual's specific characteristics in order to create high-performance teams. The preferable communication form to be chosen would involve at least using web-based tools and platforms—if not even VR methodologies—for sharing content to overcome global dispersion of knowledge.

2.2 Tools for Application Field Identification

The exploration of new applications for novel technologies provides propulsion for a firm's economic growth (Herstatt and Lettl, 2004) wherefore the adjacent identification of the most promising use cases covering essential market needs and leaving the focal company's product portfolio with a balanced score of breakthrough vs incremental innovations is an art per se (Morris et al., 2014, p. 14). It requires thoughtful portfolio management and the evaluation of the potential innovation projects with regard to the predefined criteria for innovativeness and competitiveness (Mutanov, 2015), as only a healthy proportion of radical to incremental innovation projects and a business-compatible number of related projects ensure the firm's long-term agility.

A highly dynamic and uncertain environment has a direct influence on the feasibility of an innovation project, which blocks business planning and typically leads to nonviable entrepreneurial strategies. Under such conditions, the application of the *concept of effectuation* (Sarasvathy, 2009) is dissected with regard to its potential impact and applicability on the prevailing innovation project by analysing how existing resources are optimally employed to generate the highest possible value—i.e. what effects can be created based on the fixed resource bundle by setting a hypothesis and then testing it as soon as possible in the market. Furthermore, the *concept of effectuation* encourages entrepreneurs to build strong partnerships with external entities in order to reduce competitive orientation according to research results of Sarasvathy (2009) who emphasises that there is a statistically significant positive relation between collaboration approaches and new-venture performance.

As already mentioned in a previous section, according to Gruber et al. (2012), the size and variety of the *market opportunity set prior to market entry* positively influence, with statistical significance, the likelihood of later diversification into new markets triggering sustainable firm growth. Therefore, instead of an alertness-based search process (Kirzner, 1985, Kaish and Gilad, 1991, cited by Henkel and Jung, 2009, p. 2), an explicitly systematic approach is utilised in the proposed framework due to its higher ability to detect a comparably greater number of market opportunities (Fiet et al., 2007, p. 329–344). In order to find applications for radical technological developments that are leading edge, the focus is on *technology-push* concepts, as related innovations tend to have higher failure rates due to the comparably higher uncertainty, but at the same time a higher disruption potential compared to *market-pull* approaches, whose innovations tend to be rather incremental (Brem, 2008, p. 48 ff.). Furthermore, in contrast to the latter, whose underlying process starts from the market, technology-push inventions start from the technology and are transformed into *innovations* only after the identification of potential markets and successful commercialisation (Henkel and Jung, 2009, p. 2). Apart from the targeted high innovation level of the envisaged market opportunities and the aspired early phase of innovation process and technology-readiness level, Von Hippel (2005) proposes the involvement of *lead users* (Von Hippel, 2005) found by a community-based knowledge-search strategy (Von Hippel et al., 2009) in order to map the demand side in the process (Mowery and Rosenberg, 1979) and to create the preconditions for a potential later market-pull effect (Figure 8). Hereinafter, the term *lead users* is used to mean future consumers, i.e. users with unsatisfied demand but being ahead of relevant market trends. Figure 8 gives an overview of the focal concepts that are known up to now and need to be integrated into the model framework with regard to the objective of the research study.

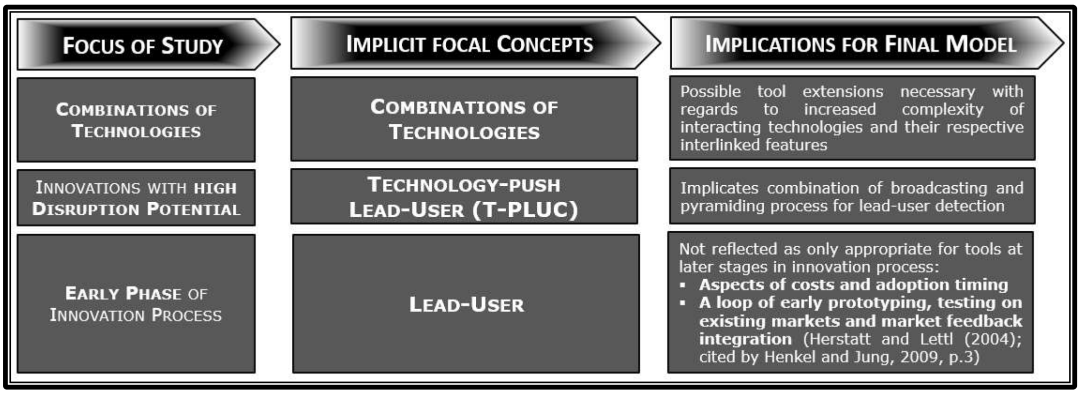


Figure 8: Focal Elements of Model Framework (I)

2.2.1 Technological Competence Leveraging (TCL)

One enabler for detecting new applications in other markets for existing technologies to fully explore the technologies' intrinsic value (Thomke and Kuemmerle, 2002) is the structured search process of *Technological Competence Leveraging (TCL)* (Danneels, 2007; Keinz and Prügl, 2010) by breaking up knowledge silos that hinder the growth of a company. Gruber et al. (2012), in their research, support the work of Danneels (2007) by revealing the types of experiences that can promote or hinder the discovery of market opportunities and should therefore always be taken into account when assembling coworking communities involved in the TCL process. In particular, the highly significant negative relationship with marketing experience, as detected by Gruber et al. (2012), goes in line with arising issues related to the process of TCL (Danneels, 2007) identifying local market knowledge as one possible trap that companies can be caught by not searching globally for new market opportunities due to the marketers' prior experiences—which is referred to as the *customer competence trap* (Danneels, 2007; Debruyne, 2014, p. 212). The paper emphasises the contemporaneous existence of both first-order customer competence, i.e. the knowledge to serve current customers, and second-order marketing competence, which allows the identification of new markets, building and assigning market-related resources, enforcing infrastructural prerequisites like organisational ambidexterity, installing the right management with the appropriate mindset for innovation to get access to markets and customers that are not yet targeted. Customer competence causes companies to be caught in the trap of expecting immediate returns from innovation and therefore being unable to resist the strong impetus towards resource allocation to technology development in effective markets that already incur revenues once viable opportunities are ascertained, classified, and rated with regard to risk exposure and return potential (Danneels, 2007).

2.2.1.1 Procedure and Steps

TCL provides a strategic four-step approach, as described in Figure 10, for the identification of commercially highly attractive applications of existing technologies by first following Danneels' (2007) suggestion of *delinking* the technology from its products to *'[r]ecognize technological competence in its own right*'. Danneels (2007) reasons further that the formulation and degree of formalisation of the problem statement and whether it needs to offer a *'job to be done for customers'* are dictated by the goal of the innovation. An iterative process of innovation goal and the triple problem, possible solution, and testing drive the repeated revision of the problem statement, particularly in case of ill-defined innovation problems (Spradlin, 2012). Ackoff (1981) states that each individual's past experience shapes his world-view, and thus impacts the way problems are phrased and approached. This can result in a *dilemma* that he defines as *'[a] problem, which cannot be solved with the current world view'* (Ackoff, 1981; cited by Pourdehnad et al., 2011, p. 2). To create a framework to escape this trap and support the extraction of the right innovation-problem definition, Watanabe et al. (2017) and Pourdehnad et al. (2011) both combine methodologies of *design thinking* and the *concept of systematic wholeness (*Pourdehnad et al., 2011, p. 3). They instruct managers to see their organisation as an interplay of individual parts and to optimise it as a whole enclosed under *system thinking*. Depending on the used platform and the addressed crowd, additional considerations about using a storytelling style of problem-framing to package the information can be considered (Smith, 1998, p. 84 ff.). Ejdelind and Karlsson (2015) suggest, that in order to not limit the creativity of the employees by curtailing the market scope of the innovation to serve current markets only—and hence falling into a sort of *customer competence trap* (Danneels, 2007)—careful deliberations about the framing of the problem statement need to be attended. This means, that depending on the objective of the innovation and the respective focal crowd, either a *domain-specific* or a more abstract *deep-structure* problem formulation has to be preferred in order to overcome the communication impediments between employees with intra-domain knowledge and external stakeholders with extra-domain knowledge. In line with the latter approach, Keinz and Prügl (2010) go a step further by abstracting the characteristics of the prevailing technology and associating costumer benefits in collaboration with the focal company's research group.

The second step relates to systematising the sourcing of external knowledge in the form of innovative application options from (particular focus) groups, since the technological knowledge of experts of the company might prohibit the full detection of new markets but can establish the in-house *absorptive capacity* (Cohen and Levinthal, 1990; Schilling, 2017, p. 72; Schweisfurth and Raasch, 2018) to assess the knowledge's novelty and quality and recognise feasible technological application possibilities, as provided by *lead users* (Von Hippel, 2005) or other external stakeholders (Gruber et al., 2012, 2008). In this context, there is empirical proof that a chronologically coordinated sequence of *pyramiding* (Von Hippel et al., 2009) and *broadcasting* approaches for gathering multi-intelligence knowledge from relevant interviewees from other application fields increases the efficiency of the search. Further, user-community groups relevant to the survey of individual knowledge carriers should be preferred in the search for alternative application fields for the focal technology (Keinz and Prügl, 2010; Von Hippel et al., 2009). Results of empirical tests of analogous market effects exhibit a statistical significance of more novel solutions that are particularly strong in the upper tail of the novelty distribution, i.e. ideas with strong innovative breakthrough potential, and recommend searching far-distant analogous markets that do not compete with the target market of the company and that already have a solution in place due to internal necessity, *Return on Investment (ROI)* due to the size of the target market, or its competition environment (Keinz and Prügl, 2010).

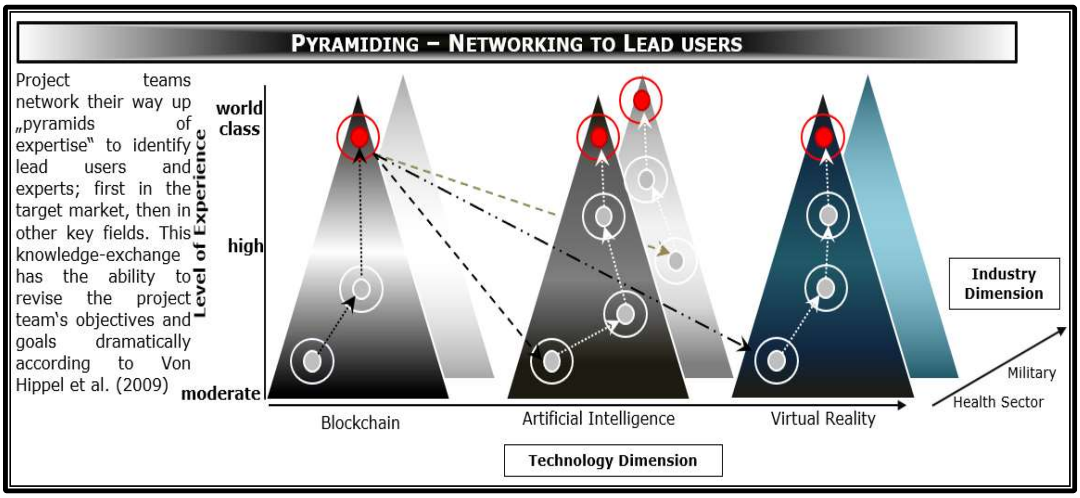


Figure 9: Pyramiding Networking Scheme for Lead User Identification Based on the Work of Von Hippel et al. (2009)

The counter-argument for implementing innovative novelties from analogues markets is that the usefulness of proposed ideas might be sometimes limited by not being in line with the target company's business strategy or IT landscape or the like and requires the establishment of in-house *absorptive capacity*, e.g. a team with high knowledge of the existing technology to evaluate the applicability, i.e. feasibility of implementation, of alternative solutions. If rare, very unique know-how needs be found in a sparse search space, Von Hippel et al.'s (2009, p. 5-7) sequential *pyramiding* search approach—corresponding with regards to underlying aspects to a mathematical global optimization methodology—has proven itself relative to the more cost-intensive parallel-performed *screening* search method by giving systematic guidance to overcome the *local search bias* (Afuah and Tucci, 2012) through the exploitation of social and professional ties between targeted people to accelerate the search process (Figure 9). Moreover, Von Hippel et al. (2009, p. 14) have invented a *reputation metric* that places the number of connectors between actors with relevant tie strength in relation to the maximum possible tie strength and the size of the social network.

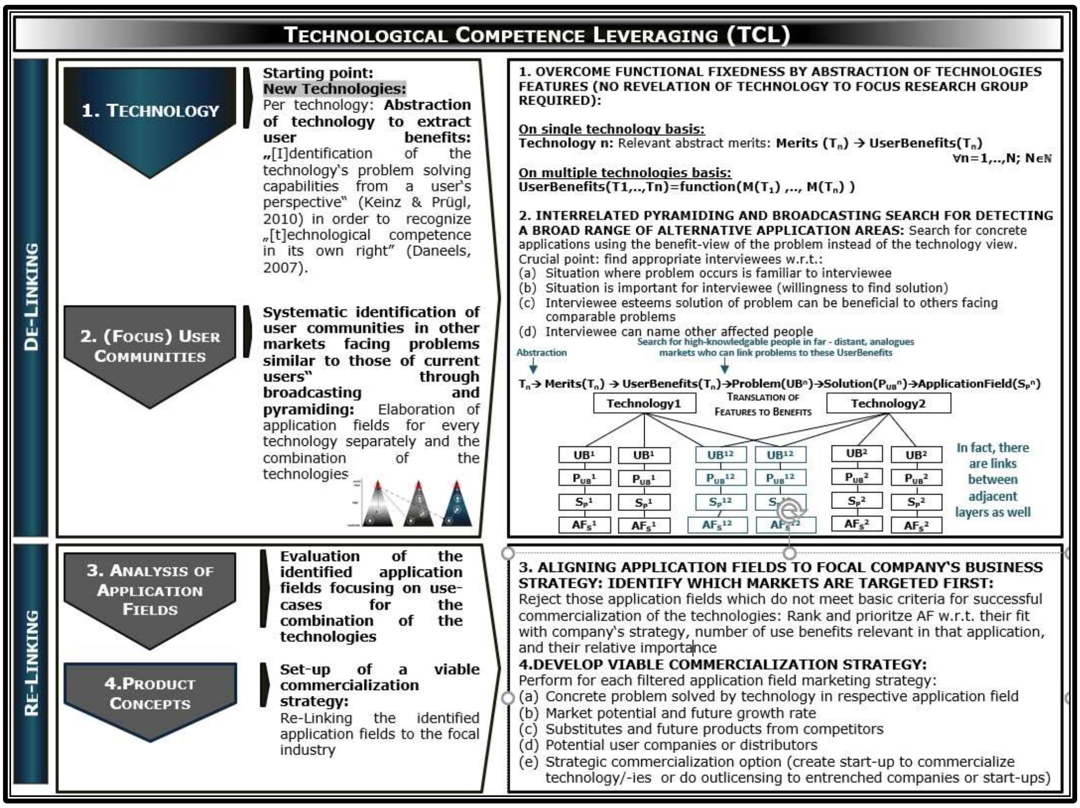


Figure 10: Steps of the TCL Approach Based on the Work of Keinz and Prügl (2010) and Danneels (2007)

Subsequently, after having identified a wide application spectrum for the focal technology supported by creativity-stimulating *divergent thinking* processes

(Cropley, 2015, p. 126), the commercially most promising use cases need to be selected by *relinking* (Danneels, 2007) to the firm's business strategies, as supported by *convergent thinking* processes (Cropley, 2015, p. 126) in order to locate new products for not yet addressed markets, which essentially require the aforementioned second-order marketing competence (Danneels, 2007).

Innovation is understood as the commercialisation of implemented inventions engendered by collaborative effort. Hence, the last step in the TCL process—in order to come up with decent product concepts—involves the enactment of a feasible commercialisation strategy through proper market segmentation for every auspicious application field (Figure 10).

2.2.1.2 Strengths and Weaknesses

The convincing arguments for the TCL approach as one variation of technology-push procedure for organisational learning (Argote, 2012; Dixon, 2017; Easterby-Smith et al., 1999; Gephart and Marsick, 2015; Nooteboom, 2000; Sisaye and Birnberg, 2012) are: (a) its non-fixedness to the technology by making its user benefits—instead of technology features—accessible to the focal community which broadens the community scope and fosters creativity; (b) the engagement of lead users in order to set out *local search behaviour* (Afuah and Tucci, 2012, p. 357; Keinz and Prügl, 2010, p. 270); (c) to use a combination of pyramiding and broadcasting to increase the efficiency of related knowledge search (Keinz and Prügl, 2010); and (d) to include the step of relinking potential application fields to the focal company's internal strategies.

Relating to weak points, an independent market trend analysis is not given, and a certain trend and environment development component is considered only in the last step and exceptionally for the determined application fields. This does not include any forecast of evolution path of technology, interacting technologies, or current technological developments on the market placing substantial responsibility on the lead users and experts, and thus, the effectiveness of the knowledge search. In addition, no retropolation starting with a-priori corporate foresight considerations of where the company aims to be in the coming years is accomplished, and thus the company's corporate foresight relies exclusively on the lead user. In conclusion, a certain degree of systematic approach of coming up with new ideas is missing, as the technical component is completely left out.

The next concept shares similar characteristics with the presented approach but extends it by features beneficial the objective of the thesis.

2.2.2 Technology-Push Lead-User Concept (T-PLUC)

Conventional technology-push methods like Souder's (1989) three-step approach focus on static aspects of user needs instead of trend analysis and do not aim at the detection of state-of-the-art use-cases through the deliberate integration of *lead users* (Henkel and Jung, 2009, p. 3). Juxtaposed on these focal methodological aspects, the *Technology-Push Lead-user Concept (T-PLUC)* of Henkel and Jung (2009) targets leading-edge applications by incorporating facets of the Von Hippel's lead-user method (Von Hippel, 2005; Von Hippel et al., 1999) and by amalgamating trend dynamics into its five-step process.

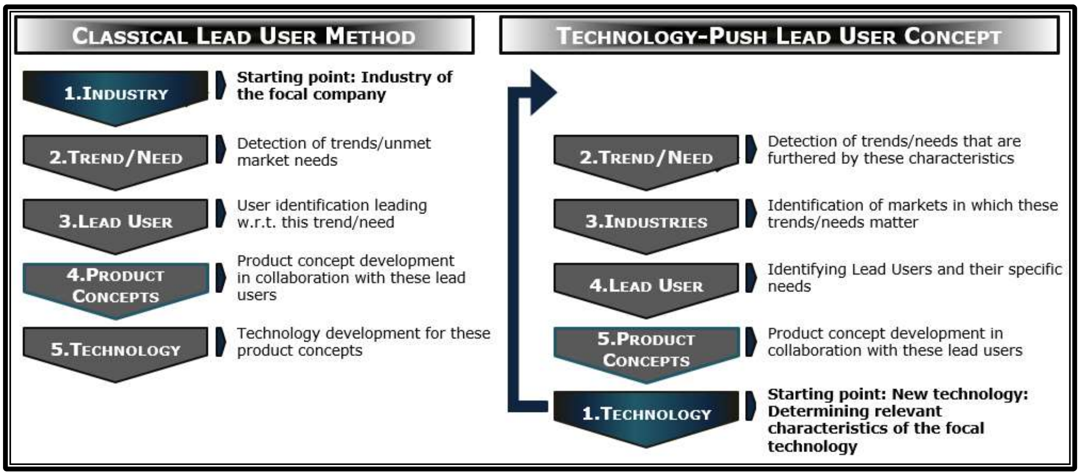


Figure 11: Comparison Between Classical Lead-User Method and Technology-Push Lead-User Concept (Henkel and Jung, 2009)

Compared to the *classical* lead-user method, in which the field of application is known at the beginning and technology plays a subordinate role, T-PLUC originates from core technologies for whose characteristics trends are identified before associated industries are spotted (Figure 11).

2.2.2.1 Procedure and Steps

The underlying five-stage T-PLUC approach of (Henkel and Jung, 2009) reverses the steps of the classical lead user method (industry ➔ trend ➔ technology) by starting with the extraction of the features of a predetermined technology nurturing specific trends. In the third step, industries and market segments are found where these trends play a pertinent role (technology ➔ trend ➔ industry). After these steps, the subsequent lead user approach is consistent with its classical equivalent. Figure 12 gives a picture of these steps of the T-PLUC where the process is assumed to start from two focal technologies and the arrows give indications how the features of technologies can be combined, and that for individual technologies and the combinations of their features, building new technological systems with additional customer benefits, trends are tried to be detected. It also shows how the search space is first narrow through restriction to specific technologies and then broadens with regards to potential applications.

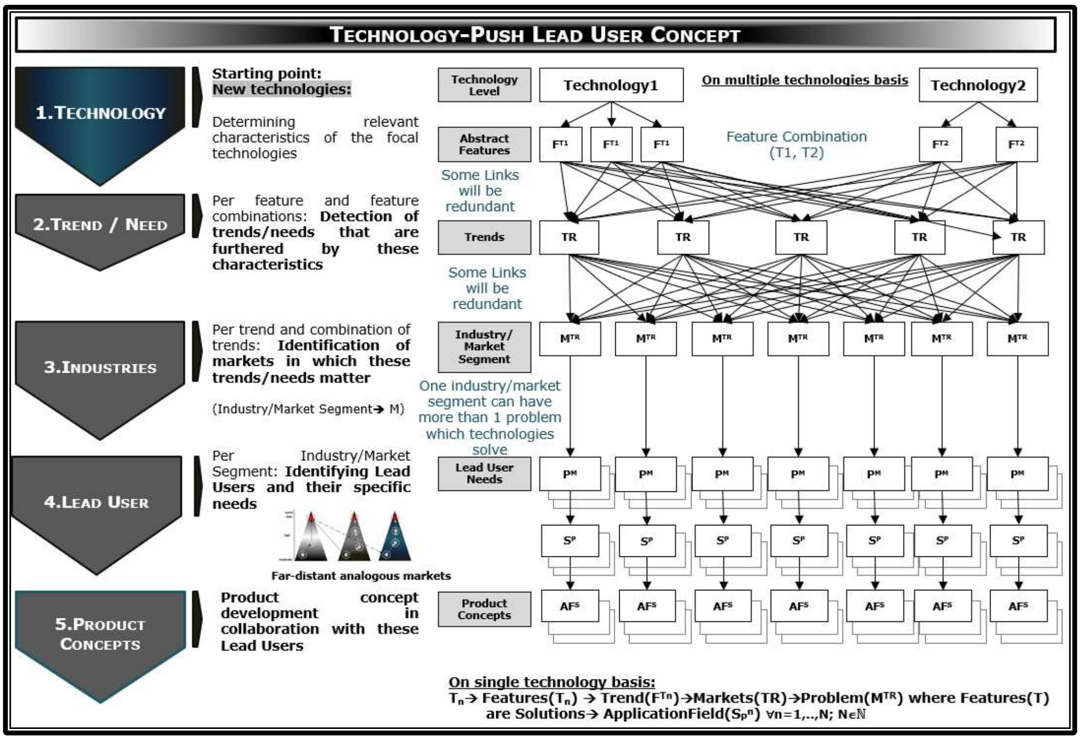


Figure 12: Steps of Technology-Push Lead-User Concept Based on the Work of Henkel and Jung (2009)

2.2.2.2 Strengths and Weaknesses

Compared to the classical lead-user method, this method is limited due to the a priori restriction to certain technologies but increases the range and variety of applications, because this respective search space is not limited right from the start. Moreover, the classical lead-user method transfers the responsibility of developing product concepts to engineers whereas in T-PLUC, these concepts are designed in close collaboration with lead users and the focal firm. Moreover, the methodology’s exceptional advantages are again found (a) in the involvement of lead users, and further, compared to other similar techniques, (b) in the integration of dynamic aspects of demand instead of purely static user needs. Henkel and Jung (2009) hypothesise and, with their research, once more confirm that the strength of this approach is the focus on lead users as the most creative and powerful generators of the most innovative applications, outcompeting technology developers. Furthermore, the translation of the technologies' features into benefits for the customers strengthens the imagination and increases the creativity of all involved cooperation partners as it imitates the TCL step of de-linking (Danneels, 2007). A final relinking step borrowed from the TCL method closes the circle back to the company by creating real-world applications for the focal firm.

Henkel and Jung (2009) admit to the presence of limitations in their empirical search. They state that these should be tackled in further studies when applying the underlying routine: First, if the degree of complexity of the prevalent technologies is too high for the addressed crowd—i.e. they are not deeply familiar with the technologies' underlying characteristics—the probability to come up with appropriate use cases can be tremendously lowered and the range of possibilities constrained. This, in turn, refers to the importance of choosing the right collaboration strategies (Schilling, 2017, pp. 163–177) and Felin and Zenger's (2014) proposed systematics of organisational learning to find the best fit of governance form for sourcing of innovation-related knowledge, i.e. to find the right crowd. This depends on the *prevailing complexity* and the consequent *level of decomposability of the problem* of interest and the level of *hidden knowledge* of the focal firm. It can be concluded that coming up with application fields for complex technologies requires a strategic approach for the collaboration of lead users and technical experts with deep knowledge of the key technologies, who can bridge the obstructive knowledge gap of both sides. The second limitation of T-PLUC described by Henkel and Jung (2009) is of a general nature and applies to other procedures as well: the higher is the commercial potential of an idea, the higher the probability that lead users will not disclose further relevant information to the collaboration group in order to protect their knowledge with regard to future competition, even if the lead-user project is steered by an independent research centre typically working in an open innovation environment (Caetano and Amaral, 2011). The strategic part in the T-PLUC is restricted to using the *pyramiding* approach of Von Hippel et al. (2009) to find lead users, but is missing concrete tools that provide a systematic way of finding use cases in the workshops with these lead users and experts of the focal technologies, who know how to solve abstract systems constructed by features of those technologies as well.

Generally speaking, technology-push routines without previously identified benefits for the consumer can be risky and cost-intensive. These drawbacks are reduced by using TCL or T-PLUC, as it can re-commercialise the already incurred R&D expenditures by identifying untapped markets for existing technologies. Additionally, both concepts include lead-users and the step to relink the identified industry-extraneous use cases to the companies' global business. Hence, they reduce the risk of not addressing the right customer needs or designing non-feasible product ideas that are detached from the focal firm. What both methods are lacking in and what is missing in the process of rapid technology commercialisation is a tool that supports these approaches with a further technique including a temporal component to develop a realistic and detailed technological innovation strategy by visualising time-dependencies of tasks or systems across multiple company divisions and revealing misfits in the alignment of human or other resources as well as technological, environmental, political, or social trends and easing the conscientious assignment of resources.

2.2.3 Technology-Push Roadmapping (MTP)

New product development is a cost factor that cannot be underestimated. This is why tools are in demand that reduce time-to-market and associated costs due to their strategic orientation.

Technology Roadmapping (TRM) includes strategic-level coordination tools to support future-oriented innovation strategies for technology-driven companies for long-term technology and related resource planning based on the improved alignment of the companies' strategic direction and the exploration of best-fitting technology landscape using so-called *roadmaps.* These roadmaps visualise underlying dynamic interactions which are backed by concepts close to *technology foresight* and *technology forecasting*[4] (E. Lichtenthaler, 2008; Moehrle and Isenmann, 2007; Pfeiffer, 1992; Phaal et al., 2004), whose differentiation from other technology-related terms like *technology monitoring* and *technology intelligence*—which comprise operational activities with the objective to detect early, weak signals of important global technological developments—is given through their implicit long-term aspect. The effects and induced economic, social, and individual phenomena associated with the emergence and application of new technologies describe the *technology impact analysis* and *technology assessment* (Moehrle and Isenmann, 2007, p. 6). These exceed the operational-economic dimension and represent an important corrective for business management considerations.

[4] For an overview of the chronology of technology forecasting approaches, kindly refer to Figure 42.

Traditional roadmaps aim to give an optimised *'[c]onsensus view of the landscape of future technology'* (U. Lichtenthaler, 2008, p. 46). They extend over several years and consist of multiple layers that describe market trends, political or environmental developments, the company's business strategy, commercialisable products, processes, and services, the related required technologies, and the resources available to the company, including the respective links of all layers. This structure facilitates the allocation of resources to business goals and to identify knowledge gaps or contradictions, which are solved by aligning the interrelated layers respectively and chronologically (Moehrle and Isenmann, 2007; Probert et al., 2003) (Figure 13). In particular, Phaal et al. (Phaal, 2018; Phaal et al., 2005, 2004, 2001) have done extensive research on TRM where one result is the frequently quoted *'T-plan for fast-start'.* It is composed of four workshops, starting with the identification of market drivers, transition to respective product feature concepts, related technology solutions, and finally the identification of gaps and concatenation of technology resources and future market opportunities, which are designed for a fast implementation in firms adopting a market-pull approach (Phaal et al., 2001).

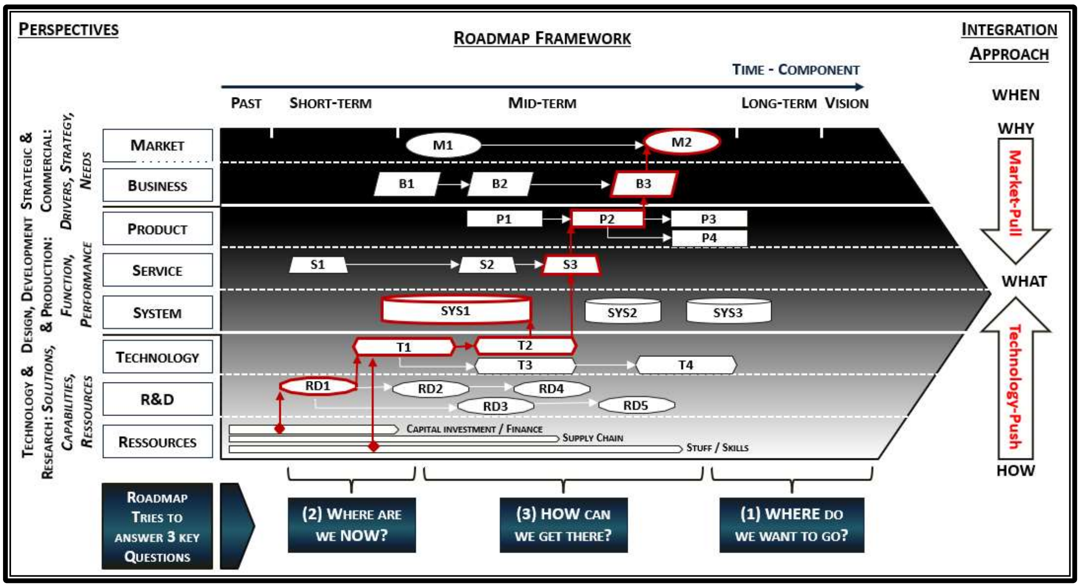


Figure 13: Multi-layer Roadmap Framework for Integration and Alignment of Strategic Plans, Adapted from Phaal and Muller (2009)

Beyond, U. Lichtenthaler (2008, p. 47) underscores the importance of successfully marketing technology assets in order to capitalise pecuniary and strategic opportunities and expands the former TRM concept to include *technology commercialisation roadmaps,* which illustrate the value of internally used or unused technologies for the internal and especially for the external environment, like extraneous industry sectors. They also visualise links between internal and external marketing projects and the prevalent technologies (Figure 14).

To increase the inter-divisional awareness within a company about technologies that are available in order to reuse technologies to their maximum extent and encourage organisational learning, Stig (2013) devised a technology-platform-based methodical approach with the following aims: (a) supporting the strategic planning of technologies by extracting a technology's reusability for other applications via abstraction of its inherent features by classifying in terms of indicators like their *Technological Readiness Level (TRL)* (Eisner, 2011, p. 66) in order to identify a new technology's reusability and interaction with existing core technologies for visualised strategic planning (*'portfolio view'*); (b) creating a technology catalogue to exploit sources of inhouse knowledge (*'catalogue view'*); and (c) providing test reports to deduce the technologies' application scope (*'toolbox view'*).

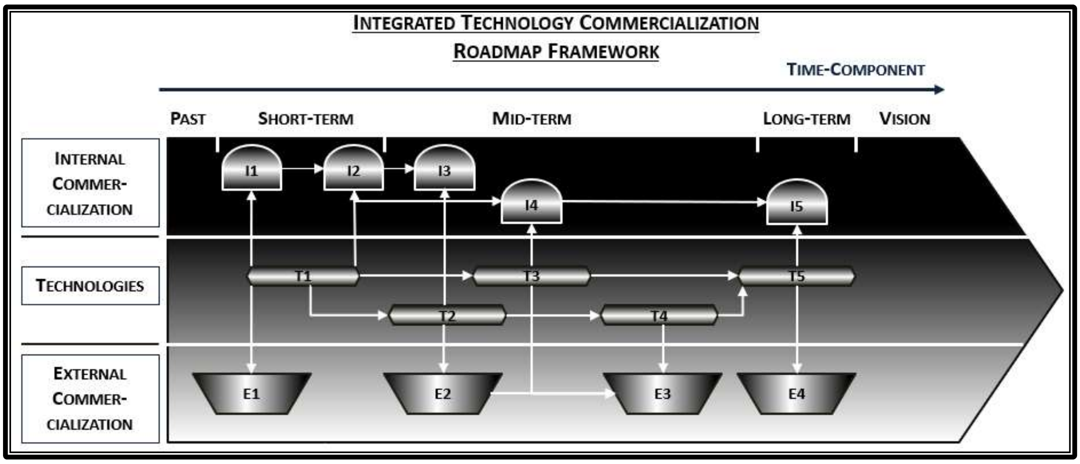


Figure 14: Integrated Technology Commercialisation Roadmap Framework Modified from U. Lichtenthaler (2008)

The literature concentrates almost exclusively on TRM tools that structure the process of integrating a particular technology into products for companies following the *market-pull* approach, which are typically large organisations adopting closed innovation (Phaal et al., 2004). In contrast, Caetano and Amaral (2011, pp. 320–321) present the *Method for Technology Push (MTP)* which links an adapted TRM methodology with the concept of open innovation in order to provide a new approach for technology-based SMEs, independent research centres, and in general for companies working in the technology-push environment. Apart from letting technology-push aspects drive their roadmapping approach, Caetano and Amaral (2011) took up the importance and strategic role of effective networks for systematic technology planning.

They report that literature often lacks a detailed description of how effective collaboration in TRM processes and workshops can be organised and systematised while being the decisive success factor of a TRM project. Due to these circumstances, Piirainen (2015) also started an attempt in his *GRIP method for collaborative roadmapping workshops* that remains on the surface because the high-level instruction for the improvement of group collaboration does not effectively address a systematic search and enactment of external collaboration options. Nurturing the prospects of their MTP concept, Caetano and Amaral (2011) give their work more impetus and depth by adding more systemics to the process via the incorporation of statistical aspects in ranking and prioritisation at every step of the fundamental three-stage process by trying to estimate and evaluate the probability of potential partnerships, and hence, future collaboration and profit aspects and options. These assessments flow into the decision for novel technologies as well and help to prioritize them. A direct analogy to Stig's (2013) technology platform for fostering the diffusion of technologies across the divisional structure of an organisation is the collaboration platform for agile strategies, which functions as a catalyst for innovation. Morrison et al. (2015) promote this with the intention to overcome the communication and knowledge barrier referred to as the *opaque and permeable boundary* between accumulated technology intelligence and market opportunities, whose primary aim is to *'[d]esign [university-driven] innovation ecosystems'* (Figure 2).

2.2.3.1 Procedure and Steps, Strengths and Weaknesses

For the purpose of investigating TRM methodologies to detect whether there are elementary differences in the sequence of process steps and organisation of collaboration workshops or used creativity tools, a literature research was performed, different methodologies were examined, and detailed descriptions of comparatively distinct approaches are summarized in Figure 16. The figure which also includes a strength-weakness analysis and delineates whether the approach considers future partnerships when evaluating market opportunities. The general difference between TRM market-pull and technology-push procedures is illustrated in Figure 15, where the sequence of process steps is again permuted.

TRM is a multi-faceted planning process for technology foresight (Barker and Smith, 1995; Hussain et al., 2017) with the objective to create a coherent strategy across all corporate divisions and is used for forecasting, planning, and administration purposes. As such, it is a powerful technique that creates transparency and supports the strategic alignment and communication of needs between functional and organisational domains within the focal firm and with external organisations, if required. With regard to its general benefits, the highly collaborative, time- and resource-efficient TRM process is characterised by (a) a lively exchange of knowledge, (b) a high scalability to other challenges faced by a company, which spotlights at the same time potential barriers like economic uncertainty, (c) supporting in keeping focus and facilitating prioritisation of activities, (d) (as a side product) helping involved people to better understand their and the other participants' roles, and (e) provision of a framework that eases the collaboration with external experts.

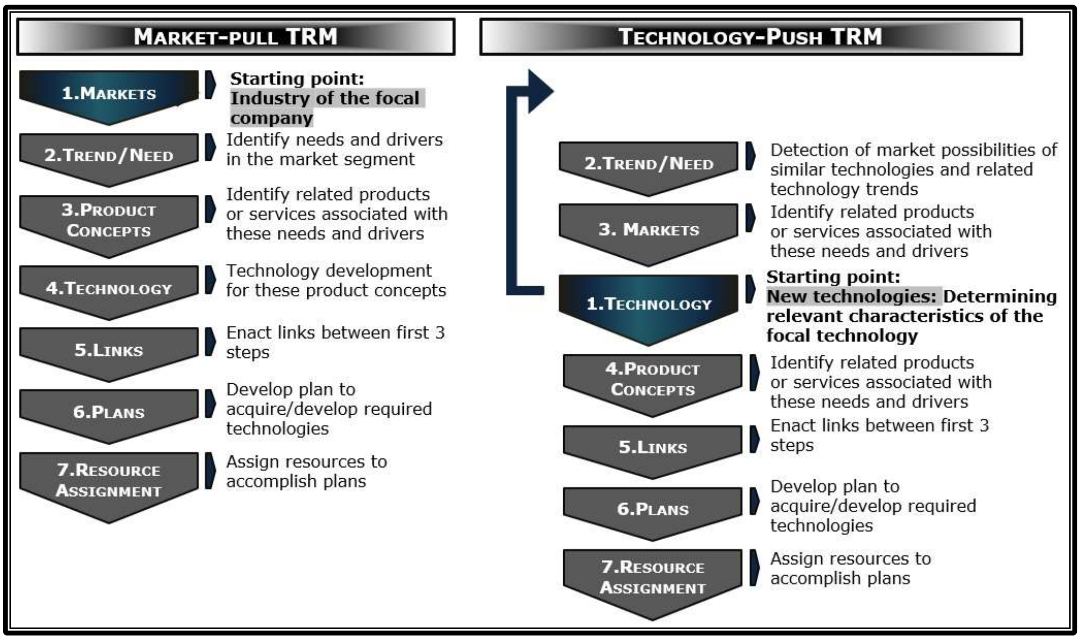


Figure 15: Steps of Market-Pull vs Technology-Push TRM (Modified from Caetano and Amaral (2011) and Daim and Oliver (2008))

Another convincing argument is (f) the increase in speed: with regard to the adjustment to internal or external movements or modifications and arising workshops that tend to be finalisable in one day. Both arguments have the potential to increase the commitment to the process within the enterprise. With regard to additional positive characteristics of specific TRM approaches, MTP (Caetano and Amaral, 2011) does account for partnerships, but solely with regard to future market collaboration or cooperation partners, not including *how* to approach a *peculiar* community of experienced people. However, feedback from TRM project team members of an executed research study go in line with Daim and Oliver's (2008) recommendation to perform antecedent TRM awareness trainings to increase the quality of the workshops.

Although underlying principles show their usefulness when applied to technological innovation management (Daim and Oliver, 2008; E. Lichtenthaler, 2008; U. Lichtenthaler, 2008; Phaal et al., 2004; Probert et al., 2003), TRM is not a cure-all as a stand-alone application wherefore it needs integration with other strategic business plans, a disciplined cross-functional project team with strong communication skills, preferably even external expertise like user-involvement and other tools like scenario analysis (Geum et al., 2014; Hussain et al., 2017; Siebelink et al., 2016), morphology analysis (Yoon et al., 2007), portfolio management techniques (Oliveira and Rozenfeld, 2010), bibliometrics and patent analysis (Wang et al., 2018), or SWOT analyses to enhance the knowledge base for better-informed choices, thus boosting the likelihood of future business success (Ilevbare et al., 2011). As the scope of a roadmap encompasses a multidimensional view of the company, its complexity can soon (a) hamper focus retention, management, maintenance, and presentation of the maps, and as the quality of the map is strongly dependent on the participants, (b) giving a great weight to the commensurate candidate selection. Apart from these apparent deficiencies, (Neill and Jiang, 2017; Strese et al., 2016) accentuate, that the size and level of functional orientation in the focal company can hinder escape from associated silo-thinking due to a prevalent steep hierarchical structure and *cross-function coopetition*, i.e. *'[t]he joint occurrence of cooperation and competition between departments'* (Strese et al., 2016, p.42) implying further pertinent techniques.

Technology roadmap techniques can be clustered according to their addressed application purpose, for example the detection of potential disruptive technologies, the development of new products, or supply chain management to reduce investment uncertainty[5].

[5] For a rough overview of these roadmap clusters, kindly refer to Appendix Figure 44.

TECHNOLOGY ROADMAP APPROACHES

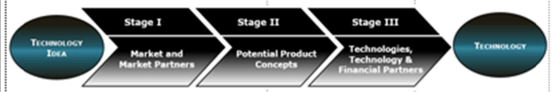
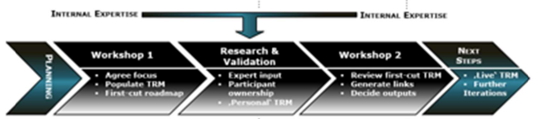
Authors	Addressed Organization Type	Adopted Integration Strategy	Description of TRM Application	Strengths	Weaknesses
(Caetano and Amaral, 2011) 	SMEs, independent research institutes	Technology-push	Method of technology-Push (MTP): T-plan used for group action research **3 Stage Process**: Starting point is a technology idea (incl. functionalities and techn. applications) > Final Result: Technology **Stage I**: Identify & prioritize potential markets and potential market partners based on opportunities for similar technologies via predefined criteria through ranking; link market to organization's business strategy through ranking, weighting grades of criteria **Stage II**: Potential Product Concepts: identify market segments that "can contribute to the idealization of potential products"; assign products to segments, assess (financial) potential of products w.r.t a priori defined performance indicators, rank and prioritize products **Stage III**: Identify and prioritize (core and supplementary) technologies bearing the technology idea, technology and financial partners developed from the identified products **Targeted partnerships**: Financial and non-financial collaboration and cooperation partners	**+Provides strategic approach how to evaluate future collaboration or cooperation partners and build relationships with them early in the technology development process**	**-Does not include users or other external knowledge sources except members from research group** **'-Repeated application of statistical methodologies for prioritization necessary**
(Daim and Oliver, 2008)	Energy service sector	Market- pull	**4 Step process: Step 1**: Survey of organizational, goals, sector and actors, technologies (Detect market drivers and customer needs). Collaboration focus groups: key executives of R&D- and innovation-related departments **Step 2**: Develop and implement **TRM process awareness training** program to educate participants **Step 3**: Collect Data and create roadmap in each department (adopting 4-step T-Plan from Phaal et al. (2001): "(a) identify internal/external drivers for focal technology (brainstorming workshop), (b) identify future products and targeted features w.r.t. cost, operational and technical perspectives, (c) identify related technologies and timing of availability of products, (d) identify R&D requirements for these technologies) **Step 4**: Review and ratification of all roadmaps across organization" (Repeat Step 3 and 4 cyclically) **Targeted partnerships:** Discoverage of technologies that can be sold to partners	**+Brainstorming workshop with external experts from the similar industry field** **'+Awareness training for TRM for the roadmapping team**	**-Missing step: linking resources to prioritized research and development or acquisition** **'-No sytematic approach for establishing the basis for future partnerships**
(U. Lichtenthaler, 2008)	Not specified	Technology-push	External commercialization of inhouse technology assets - unused or used - to grasp out licensing opportunities ("technology licensing");external technology exploitation only through inhouse resources via integrated technology commercialization roadmaps **Targeted partnership form:** Licensees	**+Integrated technology commercialization roadmaps**	**-No sytematic approach for establishing the basis for future partnerships**
(Wells et al., 2004) 	Service organizations	Technology-push and Market-pull	Based on Phaal et al.'s (2001) **T-plan fast start;** **3 Stage Process** closing knowledge gaps with internal SOI and research network based on score- ranking of markets, partners, products, technologies: **Workshop1**: brainstorming tools, grouping techniques for identifying elements within each layer of interest (no link yet between layers) **Research and validation stage**: detect knowledge gaps to be filled by expert information **Workshop2**: build roadmap by linking layers of resources, technology development to business goals and external business drivers, etc **Targeted partnerships:** Not specified	**+Framework for external expert knowledge** (not specified more precisely) **+Research network:** collaboration with university in Cambridge	**-No sytematic approach for establishing the basis for future partnerships** **'+No explicit description of the workshop participants available**

Figure 16: An Excerpt of Technology Roadmap Approaches

2.2.4 Commonalities and Differences of Tools

As shown in Table 1, integration of the technology-push roadmapping approach MTP, T-PLUC and elements of TCL leads to the elimination of deficits in the respective concepts and covers (a) a systematic approach for constituting a visualised sound cross-sectional strategy exhibiting elements of technological foresight, (b) the involvement of lead users in addition to usual stakeholders such as manufacturers, suppliers, and internal or other external experts, (c) the important step of abstracting the innovation problem or technology in order to make the benefits accessible to the research community and facilitate the creativity of the solution-finding process, and (d) to include the essential move to relink the determined solution options to the focal firm's strategies.

GAP DETECTION OF ANALYZED APPROACHES

0=No, 1=Yes, 2=Depends on Method		TCL	T-PLUC	MTP	TRM
Product Integration Strategy	Technology-Push	1	1	1	0
	(Generates) Market-Pull	0	1	0	1
Corporate Foresight / Retropolation	Start with Final Future State	0	0	1	1
Abstraction of Technology	To Technology Features (Link to technology remains)	0	0	1	1
	To User benefits	1	1	2	2
Time- Component	Dynamic Market/User Trends	0	1	1	1
	Environmental / Political Developments	0	0	1	1
	Strategic, chronological Alignment of Processes	0	0	1	1
	Evolution of Technological Systems	0	0	0	0
Lead-User Engagement	Early in Process	1	0	0	0
	Early, but after objective Trend Analysis	0	1	0	0
Strategic Partnerships / Knowledge Search	Pyramiding / Broadcasting	1	1	0	0
	Other systematic Approach of Collaboration/Cooperation Partners	0	0	1	0
	Ranking of Application Fields dependent on future potenial Partnerships	0	0	1	0
	Include Collaboration with external Partners	1	1	1	2
Strategic Solution Search	Strategic Problem solving	0	0	0	0
	Strategic Technological System Solving	0	0	0	0
Technology Classification with respect to Interaction of Technologies	Account for Classifcation, overlapping parts in Supplychain of Technologies	0	0	0	0
Visualization of Results	Includes non-virtual possibility to visualize results / data	0	0	1	1
Include AI or VR Features	AI-driven Problem Solving	0	0	2	2
	VR-supported mobile Collaboration	0	0	0	0

Table 1: Overview of Analysed Approaches and Revelation of Methodological Deficits I

But Table 1 also discloses persisting gaps in these approaches, (1) to account for possible evolutionary pathways of technological systems, or (2) to comprise heterogenous tools for the systematic solution of technological systems applicable, for example, in the collaboration workshops. Most of those exceptionally use brainstorming and grouping techniques for idea generation—techniques that might be enhanced with a combination of design thinking and system-theoretical approaches (Pourdehnad et al., 2011; Watanabe et al., 2017). Apart from fixed technologies Battistella and De Toni (2011), insist that literature falls short of well-conceived, fully-integrated methodologies to determine the coherence between the vision of a company, technological and other megatrends and marketable products; the authors want to close this chasm with the *methodology of future coverage,* which additionally supports the assessment of the *level of future orientation* for comparing companies across industries.

The next section provides approaches with the inherent potential to fill the gap of steered, and hence strategic, problem-solving by accounting for the evolution of technical systems and providing tools that ignite the creativity of people in the innovation design process.

2.3 Tools for Technological System and Problem Solving

As defined in the previous, a technology is a sequence of features, functions, and actions that form a technological system (De Liso and Metcalfe, 1996). The integration of several technologies is a modification or supplementation, translating into another technological system whose elements need to be brought back into coherent order and whose contradictions need to be dissolved to enable the stimulation of a technological paradigm by providing innovations—such as products with unprecedent features which are an improvement to existing technologies. Ehrnberg (1995, p. 446) examines the literature with regard to drivers and structural patterns of technological change, which he incorporates into a model, while also developing a metric to evaluate the degree of technological discontinuity, like radical innovation or technological revolution suitable for comparison purposes.

2.3.1 TRIZ

Enhancing the creativity in the problem definition and problem-solving process by putting more systematics into the ideation phase of engineering design (Chechurin, 2016) is in this section at the core of interest.

The Russian scientist and engineer Genrikh Saulovich Altshuller (1926–1998), recognised, based on a systematic patent research, that (a) a large number of inventions are based on a comparatively small number of general solution principles, (b) only the overcoming of contradictions makes innovative development possible, (c) the evolution of technical systems is not incidental but follows specific laws (*technology system evolution theory*), and (d) the revelation of innovations requires insourcing of external knowledge outside the focal operating area. These *patterns of innovation* (Zlotin et al., 2000, p. 3) prompted him together with Rafael Borissowitsch Shapiro, to embed these laws with other concepts into the *Theory of Inventive Problem-Solving* (TRIZ). TRIZ comprises tools that can be related to cutting-edge innovations primarily invented in the technology and engineering sectors (Altshuller and Altov, 1996). Apart from a theory of technological evolution, Fey and Rivin (2005, p. 8) describe contemporary TRIZ as *'[a] methodology for the effective development of new technological systems'* encompassing toolsets for two applications: (1) the development of conceptual designs and (2) the discovery and implementation of next-generation technologies. Livotov (2008) goes even further by specifying TRIZ instruments as the *'[m]ost comprehensive, systematically organized invention knowledge and creative thinking [methodologies] known to man'* (Livotov, 2008, p. 2) that meet the urgent need for systematic tools to foster multi-dimensional thinking in the creative thinking processes as support for managerial decision-making and superseding the unsystematic trial-and-error approaches.

2.3.1.1 General Procedure, Concepts, and Tools

The process starts with a description of the goal: to avoid a premature conclusion of the problem to a solution, TRIZ tools assist in defining a specific technical problem and in finding a solution in the abstract space for its conceptual formulation. In the next step, this solution is then transformed again with creative techniques into specific solutions, from which one solution is finally chosen (Gadd, 2011; Ilevbare et al., 2013). Figure 17 provides a sketch of this general TRIZ process, together with an overview of an extract of TRIZ tools[6].

Altshuller and Altov (1996, p. 15) define solutions of a (technical) system comprising contiguous components as *inventive* if the improvement of one *'[s]ingle part or characteristic of the system [happens] without [the impairment of] other parts or characteristics of the system or adjacent systems.'* The core

[6] For a detailed tool description, kindly refer to Ilevbare et al. (2013, p. 32) and, for a comparison of TRIZ to other design process approaches, to Blanchard et al. (2017).

of each TRIZ instrument is either (a) the concept of *ideality*, which is a function of the sum of benefits in relation to the sum of costs and harms (Ilevbare et al., 2013, p. 32) and a metric for a system's distance to its optimum where a solution is sought in the opposite direction based on specific principles after the identification of an *Ideal Final Result (IFR)* (Livotov, 2008, p. 15; Rantanen and Domb, 2010, p. 14; Savransky, 2000, p. 77), or (b) the resolution of *physical* and *technical contradictions* (Ilevbare et al., 2013, p. 31) between elements in technical systems, necessitating not conventional but *inventive* problem-solving. In this context, *contradiction* is understood as an *'[i]ncompatibility of desired features in a system'* (Ilevbare et al., 2013, p. 31). Furthermore, the concept of *system—supersystem—subsystem* (Ilevbare et al., 2013, pp. 7–8) allows a holistic view of technology systems and their interlinked implications.

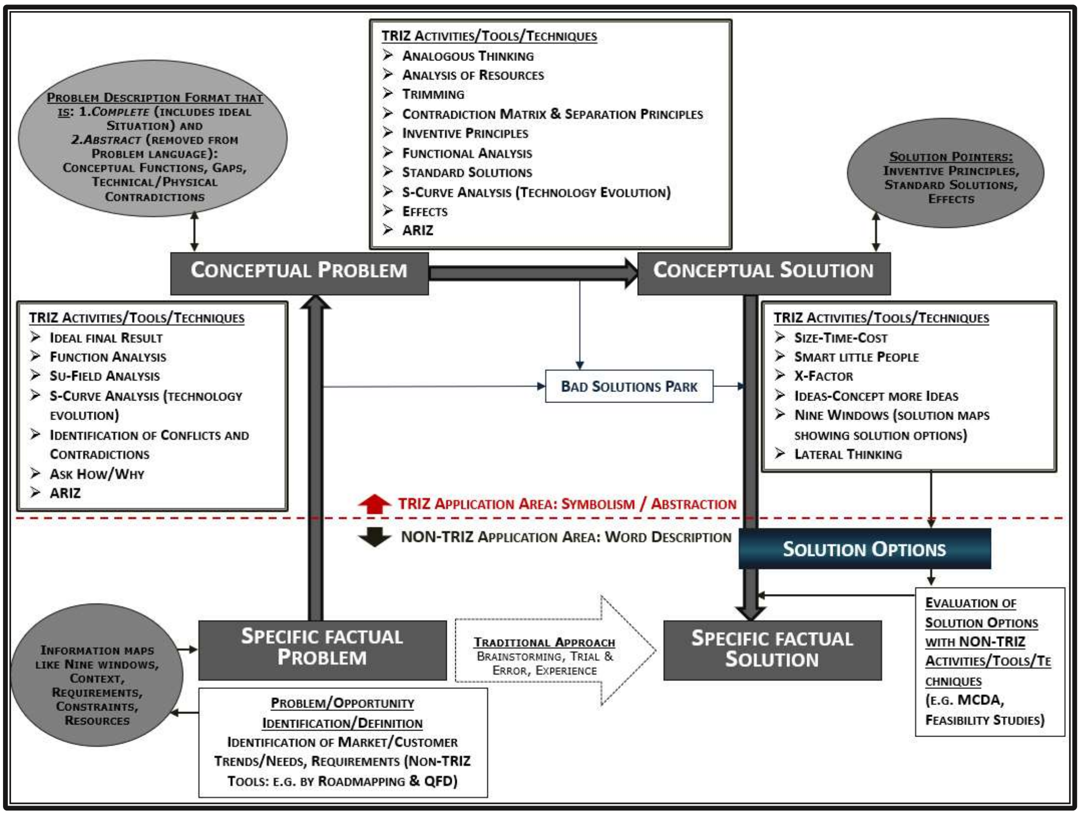


Figure 17: Prism of TRIZ: TRIZ's Systematic Problem-Solving Approach Adapted from Ilevbare et al. (2011, p. 21)

Altshuller's *five levels of inventiveness* categorise the prevailing problems and their respective solutions with regard to their implicit difficulty and give an indication when external knowledge—i.e. knowledge from outside the firm's boundaries—needs to be sourced. Furthermore, TRIZ is optimally applicable at Level 3, where Levels 3–5 require a lot of inventive creativity and a broad knowledge scope, according to Altshuller (cited by Gadd, 2011, pp. 26–29)

(Figure 18) who proposes to use appropriate tools from TRIZ's 13 creativity concepts to structure brainstorming sessions by focusing the group's attention (Appendix Figure 47 and Figure 48).

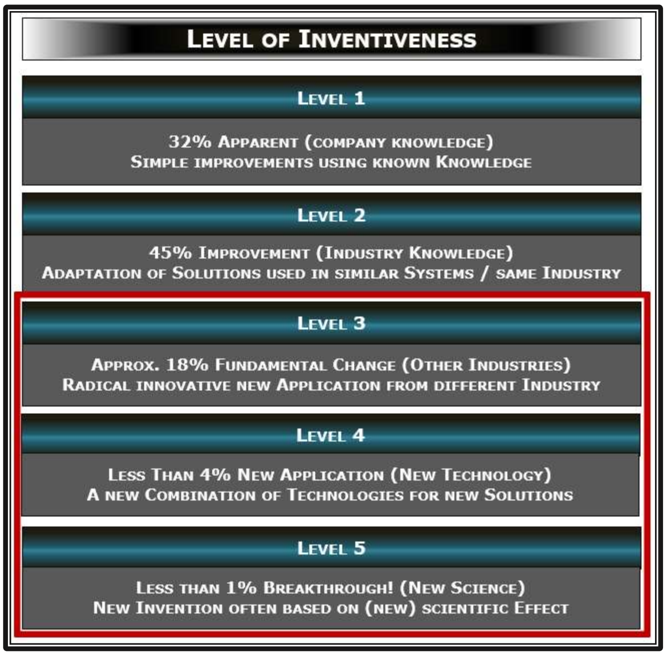


Figure 18: TRIZ Five Levels of Inventiveness (Gadd, 2011, p. 28) and Focus of Thesis

Comparing TRIZ and other design process methodologies, Blanchard et al. (2017, pp. 63–83) conclude that almost all presented approaches have three phases in common, relating to *'[t]riads of subject matters in design'* (Blanchard et al., 2017, pp. 74-75). The first phase (NOW; needs or immersion) describes the current setting ahead of the creative process, where the best framing of the context of the problem is sought. The second phase (WOW; ideation) is where creativity concepts are applied for idea generation. The third phase (HOW; implementation) generates a validated concept[7] illustrated in Figure 49 in the Appendix. The transition from *analysis* to *synthesis* of the horizontal axis in the figure describes a problem-related phase of *exploration* and a solution-related phase of *exploitation. On the other hand,* the progress from *real* to *virtual* on the vertical axis demonstrates the transition from real situations over virtual transformations back to concrete suggestions.

Since TRIZ instruments are in integrated use with other techniques in diverse engineering as well as non-engineering application fields, an initial literature

[7] If the focus is on detecting breakthrough innovations, Blanchard et al. (2017, pp. 72–73) recommend either TRIZ or the KCP design process from the C-K theory (Figure 49) (where 'K' refers to the knowledge space, 'C' to the concept space, and 'P' to propositions).

investigation of peer-reviewed scientific publications of adequate quality and indexed by 'ScienceDirect', one of the principal scientific databases of the thesis, and subsequent content analysis were conducted over a time horizon of the last ten years by screening *Title, Abstract and Keywords (TAK)* for TRIZ-related papers[8] (Table 2). As the terms TRIZ and ARIZ are already significant and descriptive, the search was restricted to these acronyms. Furthermore, the screening interval was chosen due to the increasing interest in open innovation, as substantially characterised by Chesbrough in 2003, and to include the developments in this sector in the most recent years.

TRIZ STUDIES IN INDEXED LITERATURE

Focus of Study: 2008-2018 (Research & review articles, book chapters and reviews, editorials) Muliple assignments possible	**Total Nr. of Occurences of * and TRIZ** (in TAK fields)	**Total Nr. of Occurences of *** (in TAK fields)	**TRIZ Occurence in * [%]**
TRIZ	**359**	**359**	**100,0%**
ARIZ	**122**	**122**	**100,0%**
Creativity	49	3.196	1,5%
Information processing	46	72.237	0,1%
Computer aided innovation (CAI)	24	30	80,0%
Case based reasoning (CBR)	21	617	3,4%
Education	20	72.004	0,0%
Quality function development (QFD)	14	271	5,2%
Decision making	14	41.906	0,0%
Axiomatic design	11	200	5,5%
Eco-design	10	284	3,5%
Technology forecasting	9	107	8,4%
Brainstorming	9	310	2,9%
Biomimetics	8	4.749	0,2%
Morphological analysis	4	2.541	0,2%
Innovation management	3	341	0,9%
Artificial Intelligence (AI)	**3**	**3.185**	**0,1%**
Lead user approach	**1**	**59**	**1,7%**
Virtual Reality (VR)	**1**	**2.323**	**0,0%**
Technology roadmapping (TRM)[!]	**0**	**64**	**0,0%**
Techological Competence Leveraging (TCL)	**0**	**0**	**0,0%**

[!] The term TRM also describes a chemical substance - the search was adapted accordingly.

Table 2: TRIZ Studies in Indexed Literature

[8] Literature research from a single source is not representative, since scientific publications can be found in other databases that show structured material on the integration of TRIZ and roadmapping (Chechurin et al., 2015; Ilevbare et al., 2011) or AI and VR (Bartolo et al., 2007), but a certain tendency can be observed, on which further research can be built.

Chechurin and Borgianni (2016) state that TRIZ's development occurred much earlier than its dissemination in science (compare Chechurin, 2016). In accordance with research of Yoon (2009) and Ilevbare et al. (2013), Table 2 reveals that the proliferation of TRIZ is still unrivalled in techno-centric application areas like computer-aided innovation (80% TRIZ share), which also comprises AI methodologies, compared to non-technical areas, despite gaining momentum there (Ilevbare et al., 2013) and even though it is directly applicable to nontechnical application fields (e.g. innovation management, morphological analysis, brainstorming) according to Zlotin et al. (2000). Highest absolute occurrence of TRIZ was in conjunction with *creativity*, followed by information processing and *Case-Based Reasoning (CBR)*; a technology, which is due to its formal structure and intrinsic logic a predestined application partner of TRIZ.

2.3.1.2 Strengths and Weaknesses

Compared to brainstorming, morphological analysis, lateral thinking, and similar erratic, traditional problem-solving methods that manage to detect a problem and identify the associated root cause while directly seeking a factual solution to a factual problem (Figure 17), TRIZ goes a step further and offers a systematic approach to ensure that the largest possible solution space for the focal problem is investigated and corresponding solutions are found (Gadd, 2011). To underline this effective differentiator, Gadd (2011, p. 52) also emphasises that TRIZ, unlike the former methods that ignore spontaneous and immature solution ideas to half-understood problems, parks these bad solutions in order to attempt to transform them into feasible solutions at another stage in the process, as they may be a viable starting point for further investigations (Figure 17). The results of a cross-sectional study by Ilevbare et al. (2013) concerning preferred and frequently used TRIZ methods are consistent with results from literature, indicating that the most frequently mentioned advantage of these methods is the tremendous decrease in innovation lead time and the possibility of assessing how technologies and technical systems develop. In addition, according to Altshuller and Altov (1996), TRIZ ignites flexibility in the individual psychological thinking pattern, and Savransky (2000) sees the reusability of solutions of one application area in other domains.

Frequently mentioned weak points are TRIZ's high time and resource intensity, high abstraction effort, and complexity due to its strong technical orientation, which explicitly requires the expertise of engineers, particularly if translated for applications in non-technical areas where the likelihood of misinterpretation of

TRIZ techniques is high (Zlotin et al., 2000). These issues induce the scepticism within organisations and thus hinder its adoption. Another revealed drawback is the lack of a TRIZ standard, i.e. instructions about which TRIZ instruments need to be applied to which problem scope and stage of process—a dilemma for which the *Algorithm for Inventive Problem-Solving* (Russian acronym *ARIZ*) Gadd (2011, p. 384 ff.) was invented. ARIZ offers a step-by-step succession of TRIZ tools, but still—so the criticism—does not provide coverage of all TRIZ tools and has a very high level of complexity. Attempts to resolve this conflict and reduce TRIZ-related complexity and confusion were made by Gadd (2011), who offered a guidance framework, and Ross (2006), who visualised the application of the *contradiction matrix* (Gadd, 2011, p. 109 ff.) for the solution of technical contradictions[9].

2.3.1.3 Classification of TRIZ Tools

Regarding the common features of TRIZ instruments, classification of TRIZ instruments regarding addressed purposes can support in generating transparency and ease the choice of the tools. For this purpose, each methodology is attempting to simplify its application. One effort to structure the set of TRIZ tools submits Ungvari (1998) by dividing the set of TRIZ tools into two categories—analytical and analogic—where the latter is comprised of TRIZ versatile basic principles of ideation, contradiction and laws of evolution universally applicable. A more differentiated view offers Zlotin et al. (2000, p. 4) presenting three disjunct TRIZ tool categories according to their focal application purpose: (a) the class of analytical tools perfectly fitted to problem definition, formulation, and modelling; (b) the class of knowledge-based tools suited for problem-solving through instructions for system transformation; and (c) psychological operators for accelerating the processes of creativity and problem-solving. Originally invented for technical-system-solving, the application of TRIZ tools to non-technical fields requires preliminary abstraction and greater adaptation in the case of knowledge-based tools, while analytical TRIZ tools and their psychological operators are immediately employable, requiring fewer adjustments (Zlotin et al., 2000). Moehrle (2005, pp. 4–5) assigns the instruments to five domains (current state, resources, goals, intended state, transformation) in terms of their ability to identify and solve field-related problems.

[9] For an overview of TRIZ tools dependent on main field of application, kindly refer to Appendix Figure 46.

Due to TRIZ's greatest strengths which lie in its application in technical-system-solving and the identification of highly innovative inventions and its less convincing application in business management or technological strategy (Ilevbare et al., 2013) (Table 2), it is a perfect complement to the presented tools of TCL, T-PLUC, and MTP (Table 3), as the tools' integration immediately removes the shortcomings of their stand-alone versions.

Gap Detection of Analyzed Approaches						
0=No, 1=Yes, 2=Depends on Method		**TCL**	**T-PLUC**	**MTP**	**TRM**	**TRIZ**
Product Integration Strategy	Technology-Push	1	1	1	0	0
	(Generates) Market-Pull	0	1	0	1	0
Corporate Foresight / Retropolation	Start with Final Future State	0	0	1	1	2
Abstraction of Technology	To Technology Features (Link to technology remains)	0	0	1	1	1
	To User benefits	1	1	2	2	0
Time- Component	Dynamic Market/User Trends	0	1	1	1	1
	Environmental / Political Developments	0	0	1	1	0
	Strategic, chronological Alignment of Processes	0	0	1	1	1
	Evolution of Technological Systems	0	0	0	0	1
Lead-User Engagement	Early in Process	1	0	0	0	0
	Early, but after objective Trend Analysis	0	1	0	0	0
Strategic Partnerships / Knowledge Search	Pyramiding/Broadcasting	1	1	0	0	0
	Other systematic Approach of Collaboration/Cooperation Partners[1]	0	0	1	0	0
	Ranking of Application Fields dependent on future potenial Partnerships	0	0	1	0	0
	Include Collaboration with external Partners	1	1	1	2	2
Strategic Solution Search	Strategic Problem solving	0	0	0	0	1
	Strategic Technological System Solving	0	0	0	0	1
Technology Classification with respect to Interaction of Technologies	Account for Classifcation, overlapping parts in Supplychain of Technologies	0	0	0	0	1
Visualization of Results	Includes non-virtual possibility to visualize results / data	0	0	0	1	1
Include AI or VR Features	AI-driven Problem Solving	0	0	2	2	2
	VR-supported mobile Collaboration	0	0	0	0	0

Table 3: Overview of Analysed Approaches and Revelation of Methodological Deficits II

Regarding the persistent gaps in Table 3, Delgado-Maciel et al. (2017) detect three drawbacks of TRIZ, whose solution they deem to be of high relevance: (a) the evaluation of effects triggered by the interaction of multiple problems in the prevalent technical system where, according to Delgado-Maciel et al. (2017), the aim should be to ensure that the formulation of the solving strategy is not solely dependent on the experience of the solver, but that the solver is confronted only with the most important interconnected problems; (b) the observation of the system behaviour within a period to deduce therefrom future system states: TRIZ evolution trends give guidance how technical systems evolve based on an exhaustive patent analysis, which did not include protected industrial secrets or not-patented technical achievements, and giving no information about the process in the system apart from the result; and (c) the possibility of simultaneous solutions to conflicts.

Shortcomings, for which AI—presented in the next chapter—provides efficient model approaches. As extension to the world of data and algorithms, Bartolo et al. (2007) examine a concept for the integrated use of tangible virtual reality for product design, allowing the *'[s]imulation of the interaction of humans with virtual objects, the interaction of virtual objects, and the behavior of virtual objects […]'* (Bartolo et al., 2007, p. 35) requiring the input of sensors and multi-physical process computation in real time. The next section is devoted to these two promising technologies and aims to demonstrate their potential for improving the other approaches in this work.

2.4 Tool Enhancements with AI and VR

Global digitisation and digitalisation affect nearly every industrial sector, be it the manufacturing sector (Bogner et al., 2016; Davis et al., 2017), the health sector (Hainc et al., 2017; Krittanawong et al., 2017; Luxton et al., 2016; Steinhubl and Topol, 2015), or innovation management (Kadar et al., 2014), to name but a negligibly small selection, by providing the ability to decrease the complexity in (global) operations by making underlying processes leaner, more efficient, and more customer-oriented. These trends foster the enactment of digital platforms which remove communication obstacles and connect people, cities, and countries worldwide, and whose global flows trigger economic growth.

These techno-centric trends have dramatically changed the way people communicate, collaborate, or even learn (Clarke, 2012), and have prepared the basis for unprecedent applications of computation-intensive technologies like AI and VR.

Before proceeding to the next chapter which provides a global market outlook of AI and explains the relationship of AI, analytics, and big data, the terms *digitisation* and *digitalisation* are stated clearly as they are often used synonymously in the business context or in the literature, although there is an evident difference wherefore the thesis aims to follow 'Gartner's IT Glossary' specification and defines these technologies as follows:

'Digitization is the process of changing from analog to digital form, also known as digital enablement. Said another way, digitization takes an analog process and changes it to a digital form without any different-in-kind changes to the process itself' ('Gartner IT Glossary').

In contrast thereto,

'Digitalization is the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business' ('Gartner IT Glossary').

In a nutshell, while digitisation enhances the efficiency of processes, digitalisation relates to businesses using these technologies to collaborate with people in order to fit their particular needs and requirements.

2.4.1 Concept of AI

As mentioned, digitisation—apart from the coevolution of other disruptive technologies like Internet of Things (IoT) (Atzori et al., 2010; Saarikko et al., 2017), quantum, or cloud computing (Katz, 2017; Menon and Ritwik, 2014) (Table 4)—is the major driver for the sky-rocking demand for AI whose smart technologies generate key solutions that enable companies to create intelligence from existing and new data sources and to provide information for effective decision-making across all corporate domains of an enterprise. The tremendous increase in computational computing power enables the utilisation of AI for highly complex tasks. On the other hand, obstacles for the adoption of digital transformation technologies with cloud computing as one of its ecosystem's key pillars are persistent privacy and security issues and loss of governance (Al-Ruithe et al., 2018). These hurdles drive the interest in using AI, particularly the class of ML algorithms, to fight cyber-security threat, indicating a mutually beneficial relationship between these technologies which is also reflected in Table 4 by the absolute number of occurrences of published scientific papers on this topic.

The *International Data Corporation (IDC)* forecasts that the world-wide data volume will reach 180 zettabytes by 2025, from less than 10 zettabytes in 2015 (Appendix Figure 51) which also fosters the trend often referred to as '*data is the new oil',* which encourages the development of a strong data monetisation revenue stream to achieve USD 58.91 billion with a *Compound Annual Growth Rate (CAGR)* of 29% for global spending on AI (Appendix Figure 50) and USD 203 billion with a CAGR of 11.7% of global revenues for big data and business analytics (Appendix Figure 52) (IDC). These trends indicate that the awareness of the value of data is arriving globally.

"[T]his is why the formal intelligence systems have settled themselves because of their versatility; this in order to identify endogenous capacities and environmental changes through the transformation of data with the knowledge of the strategic value." (Domínguez and Torres, 2010).

2.4.1.1 Classification of AI and its Relationship to Analytics

Definition or classification of AI-related terms like *big data* or *analytics* is not unique in the literature. The definition of *big data analytics* given by Labrinidis and Jagadish (2012; cited by Gandomi and Haider, 2015, p. 140) encompasses two sub-processes: *data management,* which comprises technologies to store structured and unstructured data from different storage silos and to prepare such data for the subsequent process, namely *analytics,* which uses technologies to extract information from such pre-processed big data (Gandomi and Haider, 2015, p. 138). The thesis uses the classification given by Maydon (2017), which subdivides analytics into four key categories, each using a selection of heterogeneous mathematical models to gain insights into data: *Descriptive Analytics, Diagnostic Analytics*[10]*, Predictive Analytics,* and *Prescriptive Analytics* with the interdependent mathematical core technology classes of *Artificial Intelligence (AI), Machine Learning (ML),* and *Deep Learning (DL)* (Figure 20). In recent years, a new class with a high growth potential (Appendix Figure 53), including speech, image, and video recognition, is emerging, called *Cognitive Analytics* (Gudivada et al., 2016), which primarily uses the highly complex class of DL algorithms typically represented by neural networks which differ mainly in network topologies and connection types, such as number of layers, feedforward, or feedback networks (Kriesel, 2005) (Figure 20). The latter category is often directly associated with robotics and AI in a narrow sense. Figure 19 gives an overview of the superimposed analytics blocks in the analytics value chain, their level of business impact, and the required degree of intelligence.

[10] This analytics group is often assigned to *Descriptive Analytics,* e.g. by Sivarajah et al. (2017).

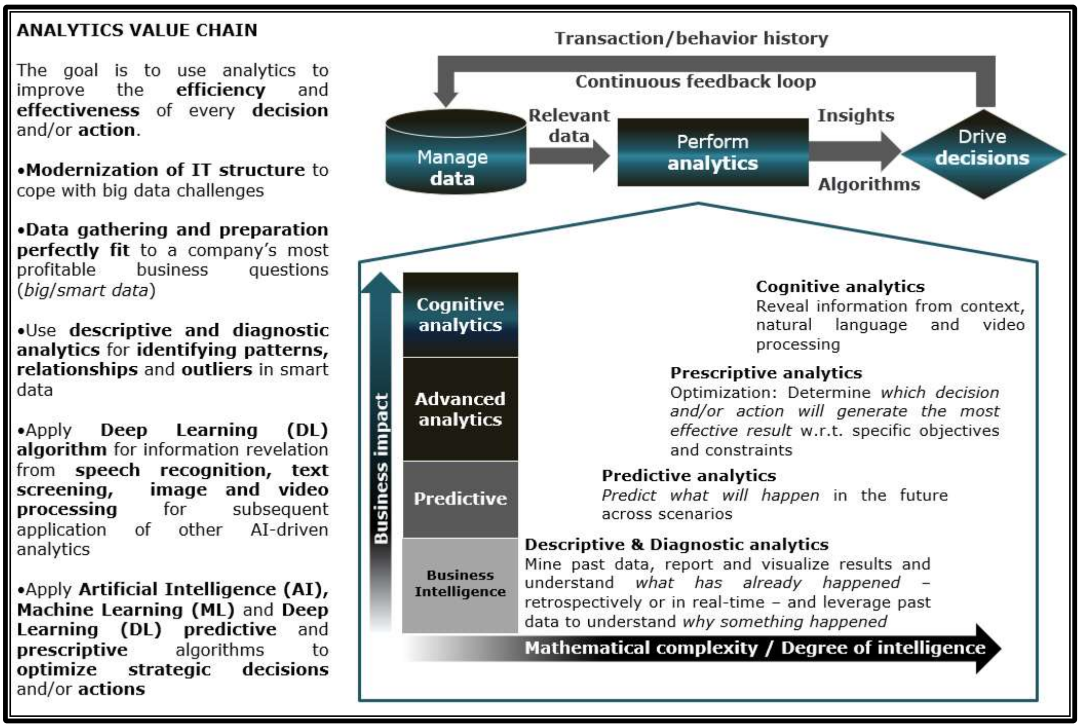


Figure 19: Analytics Value Chain

Elliot (2014) conducted a study in which he screened articles of AI- and robotics-related magazines from 2003 to 2012 to assess the technological status and related trends of AI science and specifically *language, reasoning, vision,* and *movement* processing as being aspects of human capabilities—conventionally understood as AI. Focusing on corresponding analytical methods of big data, like text or video analytics, Gandomi and Haider (2015) highlight the equivalent importance of accounting in analytical methods for big data attributes in terms of volume (magnitude), velocity (data generation, analysis and execution of decision speed), and variety (level of structural heterogeneity) of data and complement these traditional *three V's* by three additional ones: veracity (uncertainty and impreciseness of data), variability (variation in data flow rates and complexity due to multiple diverse data sources), and value (big data exhibits in many cases *low value density*, i.e. a low information value relative to their volume; analysing big volumes of data can increase this value). Beyond, they emphasise the necessity of efficient algorithms for the avoidance of issues related to the enormous amount of data, like high level of heterogeneity, noise accumulation, spurious correlations, and incidental endogeneity, subverting the validity of applied mathematical analysis.

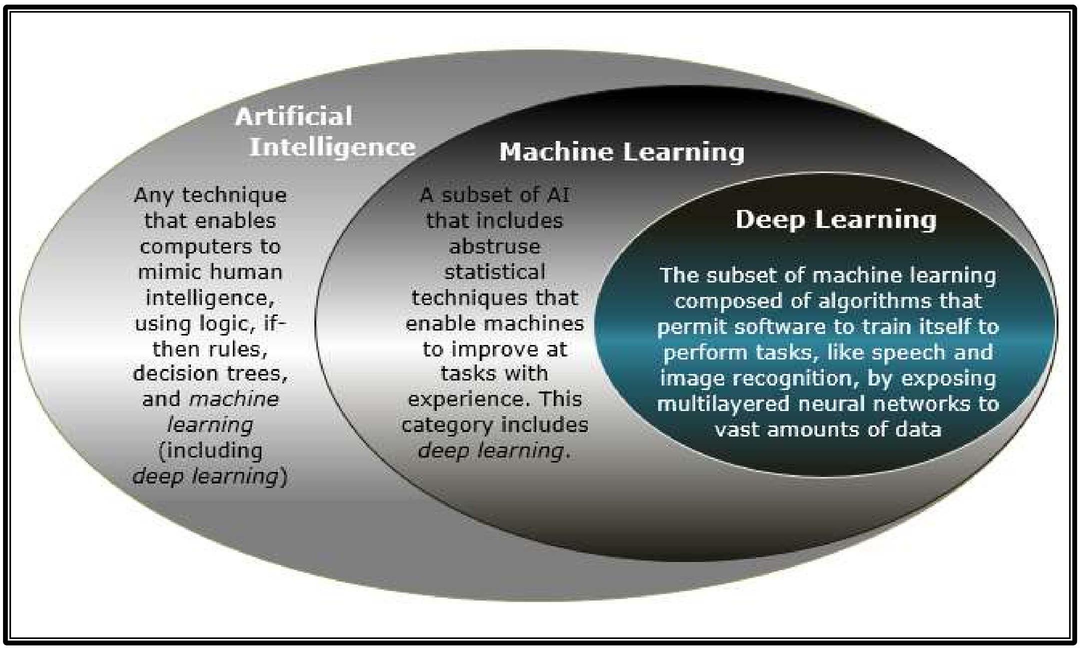


Figure 20: Relationship Between Artificial Intelligence, Machine Learning, and Deep Learning (Meenal, 2017)

2.4.1.2 Strengths and Weaknesses

AI has the inherent potential to lead to true paradigm shifts in multiple industrial sectors, which it penetrates with the enormous power of its heterogeneous set of tools, techniques, and functions (Akhavan-Hejazi and Mohsenian-Rad, 2018; Gudivada et al., 2016). Since AI is a cross-sectional technology suitable for simple tasks like statistical evaluations, market basket analysis for retail, statistical evaluation of marketing strategies to the top league of optimisation of structural systems, dynamic modelling of system behaviour, and convolutional neural network applications for process fault diagnosis (Wu and Zhao, 2018), it positively affects the efficiency and profitability of a broad range of enterprises in numerous applications, which is why it is finding its way into nearly every form of digital technology (Brown, 2018; Chinner, 2018; Marr, 2017). Alternatively, technologies like blockchain, which agglomerates information from distributed databases, will find their way into the AI ecosystem (Kobielus, 2018).

In order to assess high-potential fields where a strong AI trend is observable and assumed to persist, the AI market can be classified according to technology (e.g. DL, ML, natural language processing), solution, end-use, use-case, or geographical region ('Artificial Intelligence Market Size Analysis | Industry Growth Report 2025,' 2018). According to Statista (Armstrong, 2016), the leading AI use-case with expected cumulative revenues of just over USD 8 billion is *'[s]tatic image recognition, classification and tagging'*, ahead of *'[a]lgorithmic trading strategy performance improvement'* with USD 7.5 billion and *'[e]fficient, scalable processing of patient data'* (USD 7.4 billion). Regarding geographical market segmentation, North America is forecasted to reach USD 8.3 trillion gross value-added in 2035 and the Asia Pacific, in particular Japan, are the most promising AI markets exhibiting the highest CAGR (Appendix Figure 54). The results of an accomplished literature research based on TRIZ's literature research settings for consistency purposes are in accordance with Statista's estimation that the health sector to be one of the most appropriate end-use industries of the global AI market (Table 4). For instance, these results are backed by Krittanawong et al. (2017), who underscore the tremendous precision increase in case of application of ML algorithms for the diagnosis and prediction of cardiovascular diseases. Further, Hainc et al. (2017) believe that neuroimage reading for brain pathology detection will be revolutionised by AI.

AI STUDIES IN INDEXED LITERATURE

Focus of Study: 2008-2018 (Research & review articles, book chapters and reviews, editorials) Muliple assignments possible	**Total Nr. of Occurences of * and AI-A-BD**[1] (in TAK fields)	**Total Nr. of Occurences of *** (in TAK fields)	**AI-A-BD Occurence in * [%]**
Artificial Intelligence | Analytics | Big Data (AI-A-BD)	**3.185**	**3.185**	**100,0%**
Technologies			
Cloud computing	476	3.287	14,5%
Internet of Things (IoT)	430	2.563	16,8%
Virtual Reality | Augmented Reality	75	3.119	2,4%
Edge computing	18	102	17,6%
Quantum computing	16	316	5,1%
Blockchain	5	160	3,1%
End-Use Industry or Field			
Health (incl. Medicine)	5.017	217.095	2,3%
Advertising | Media	3.759	73.009	5,1%
Manufacturing	2.892	54.859	5,3%
Law	3.959	53.945	7,3%
Automotive | Transportation	1.328	31.674	4,2%
Agriculture	1.124	44.904	2,5%
Banking, Financial Serices, Insurance (BFSI)	351	21.181	1,7%
Retail	261	5.776	4,5%
Oil and gas	243	5.109	4,8%
Cybersecurity	19	258	7,4%
Ethics	***111***	***5.965***	***1,9%***
Ethics | Moral	198	9.727	2,0%
Ethics | Moral + Health	29	1.696	1,7%

[1] The term Artificial Intelligence was used as it is more descriptiv than AI. In addition, the terms Big Data and Analytics were added.

Table 4: AI Studies in Indexed Literature

Drawbacks of AI algorithms affect their implementation which necessitate high professional expertise as the methods typically require specific software and can become highly complex contingent on the prevalent application area, and to explain model results to respective departments. It also depends on the complexity of the use case and the end-use industry whether close cooperation with experts is indispensable for chosen an appropriate sequence of models or whether—according to Danneels (2007)—'data can be seen in their own right' detached from any industry which can have the advantage of reducing some kind of bias regarding how the data are seen.

According to Hainc et al. (2017), one additional barrier for adopting AI is a general scepticism of humans against new technologies. This is accompanied by another obstacle that is nowadays frequently found and hotly discussed in literature and news: peoples' intrinsic fear of being replaced by AI in the working environment wherefore—in short and underlined by recent research—the next paragraph is dedicated to this topic and its implications for the present work, i.e. to decide where human abilities are highly demanded and for what subprocesses in the presented framework does AI offer unrivalled advantages. A screening of the literature shows a certain inclination: it is not the abilities of AI that are often queried, but their possible unethical use (Luxton et al., 2016) and people's intrinsic fear of being substituted by a new technology (DeCanio, 2016; Frey and Osborne, 2017; Jarrahi, 2018; MacCrory et al., 2014). For this reason, Table 4 includes the terms *ethics* and *moral* in the context of AI. It can be seen that there is increasing scientific interest in this topic and in the forecasting of industry-specific AI-human labour substitution likelihood. One important aspect of the thesis, as revealed by the research of Frey and Osborne (2017), is the distinction between AI and humans in terms of the areas in which AI provides a tremendous increase in efficiency and those where humans still outcompete robots. Summarising the results of the study, it can be said that *'[g]eneralist occupations requiring knowledge of human heuristics, and specialist occupations involving the development of novel ideas and artifacts are at least susceptible to computerisation'* (Frey and Osborne, 2017, p. 266). Occupations like engineering and science, where a high degree of creative intelligence is required, are at low risk of substitution by AI as the relationship between human and artificial intelligence is strongly complementary, without excluding the opposed trend of substitution in the long run. Decanio's (2016) model of the relationship between robots and humans shows the conditions under which it is complementary or substituting and whether wages are affected by a proliferation of computerisation, based on *Houthakker's* (Decanio, 2016. pp. 280–281) aggregate production relationship method. The outcome of the model is that if the estimated elasticity of substitution between human and robotic labour exceeds a threshold of 1.9[11], proliferation of AI will lead to a decrease in human salaries. This is not high relative to the threshold of elasticities of substitution for rather substitutable factors (e.g. 1.6 for college graduate workers vs non-college workers), indicating a relatively high probability of occurrence. A study by Frey and Osborne (2017) about the likelihood of total replacement of the total US workforce (comprising 702 detailed occupations) by AI estimates that 47% of jobs are at high risk of replacement in the coming decades where the authors further differentiate between low-, medium-, and high-risk occupations (Appendix Figure 55). But Decanio (2016) argues that AI has no exclusively negative effect on working conditions. If there is a positive dependency on the wages of the work supplied to the market, the previously mentioned AI-driven decline in wages might be compensated to some extent *'[b]y a voluntary decrease in total employment'* (Decanio, 2016. P.289). Furthermore, people might decide to offer less work for a given salary when work is taken over from AI. Giving this subject a clear positive propensity, Jarrahi (2018) stresses the advantages of a symbiotic relationship between AI and humans in the context of the characteristics of organisational decision-making—namely, uncertainty, complexity, and equivocality—and the need for companies, managers, and employees to adapt in accordance.

In conclusion, discussions about AI, its capabilities, and related potential threats need to separate its technological applicability from its ethically-motivated use, although it is indispensable to discuss the latter in a broader context. As a further implication, the proposed process framework aims to profit from the human-AI symbiosis in the best way, resulting in the embedding of AI techniques in unique human creativity wherever appropriate.

2.4.2 Concept of VR

After an unprecedented hype in the 1990s, VR disappeared from the scene faster than expected. Prices for required equipment were too high and final products were not affordable for the mass market (Osarek, 2016). The ergonomic level was inadequate, the effort for generating content comparatively high (Martin-Gutierrez et al., 2017), and the unrealistically high

[11] The manufacturing industry has an even lower threshold.

expectations of the technology, which were triggered by the media, could not be met, according to VR-pioneer Bezmalinovic (2017), who sees analogies to the contemporary hype. By contrast, Brightman (2017) considers *'[V]R's potential [as] literally infinite'* and warns against assessing its potential in the light of today's market, where its application range is foremost restricted to the gaming and cinematic sector or virtual dress rooms (Osarek, 2016) (Nomura and Sawada, 2001; Raajan et al., 2012). The appearance of promising non-entertainment-related VR use cases like virtual education and learning (Martin-Gutierrez et al., 2017; Pan et al., 2006), stroke rehabilitation (Laver et al., 2011), workplace optimisation for hearing-impaired employees (Szajkowska and Karwasz, 2018), or—relevant to the topic of this thesis—new product development (Bartolo et al., 2007) support Brightman's (2017) perspective and seem to usher in a new virtual era, breaking the boundaries of the former and nurturing the trend of connected work, connected city, and connected home.

Recent technological innovations in the information system and mobile phone sector have already increased the accessibility of the society to virtual technologies as people can get semi-immersed into a real world via a simple smartphone display put in front of their faces. A trend that will be nurtured even more by forthcoming investments by large companies like Apple and Samsung, according to Martin-Gutierrez et al. (2017), and which is supported by IDC figures of global spending on AR and VR of USD 11.4 billion in 2017 to USD 215 billion in 2021 with a CAGR of 113% (Appendix Figure 56). Moreover, as VR is not only an extremely power-intensive computing tool but also a data-intensive technology, it profits exceedingly from the rise of AI, which provides insights into data, in particular text-, speech-, image-, and video-related information recognition, whose subsequent visualisation can be performed by VR.

2.4.2.1 Classification of VR

The thesis borrows the definitions and classification scheme of virtual technologies from Osarek (2016, pp. 12–13), who describes *VR* as computer-generated reality with *'[c]omplete immersion into another world blocking the real world'*, *Augmented Reality (AR)* as using the real world and superimposing virtual information, and *Mixed Reality* (*MR)* as *'[placing] artificial information and objects positionally and rotationally correct into 3D space in real time'*—reminding on *avatars* (Girvan, 2018) —and he summarises all three terms under *xR*[12]*.* Weidig et al. (2014) present a classification scheme in terms of the so-called *interaction techniques based on user-intention,* which were developed for particular input hardware components[13], data types, and application areas to facilitate choice-making in dependence of prevailing research questions for non-VR specialist. Another classification in terms of xR's immersive degree of user involvement provide Li et al. (2013, p. 469), clustering xR's technical features to (a) *desktop virtual reality systems,* where users interact via the personal computer screen but the full virtual experience is missing, (b) *immersive virtual reality systems* providing a true virtual feeling space through devices by *'[closing] participants' vision, hearing, and other feelings'*, (c) *distributed virtual reality systems* linking the former systems distributed over the internet to enable communication at different places, like virtual medical advice, and (d) *enhanced or mixed reality systems* joining the real and the virtual world, which corresponds to Osarek's (2016) definition of MR.

2.4.2.1 Strengths and Weaknesses

The literature review confirms the hypothesised strong interlinkage of xR and new technologies such as IoT, AI, and cloud computing and its currently increased emergence in scientific papers relating to education, gaming, and health (Table 5).

Excluding its obvious benefits in the entertainment sector in general and the gaming and porn (Silver, 2017) industry in particular, or the evolving trends in healthcare (Table 5), and assessing the technologies' potential from a higher perspective, xR's cutting-edge technologies lead to an unprecedent disruption of the way people communicate and collaborate. It can thus trigger cost reductions of various type like travel, accommodation, or training costs, as people can contact one another globally and immediately and can perform offsite training, inspection, and maintenance (Eschen et al., 2018). There seems to be consensus that the xR-enabled real-time data-check (like real-time IoT data), visualisation of scenarios, and simultaneous evaluation of alternatives in the business environment decreases new product lead time by increasing the efficiency and the speed of the decision-making process (Abulrub et al., 2013; Bellos, 2012; Forbes, 2016). As a consequence of this reduced lead time, market rollout can happen sooner, and profits can be incurred earlier.

[12] In the following section, it is indicated whether VR is used on behalf of xR for the matter of improving readability.

[13] To give a rough indication, devices for the xR experience relate to headsets for VR, whereas AR also communicates via tablets, smartphones, or laptops (Seabery, 2018).

Positive side-effects are reported due to increased stakeholder engagement and training scalability due to pre-site training, as xR can be transformed to and linked with e-learning platforms. In addition, xR's exponential decrease in costs in due course will make the technology affordable for innovative SMEs as well (Abulrub et al., 2013), as the purchasing costs need to be set in relation to the lowered project costs due to improved operational efficiency which can hold as well as counterargument to a prior misconception of managers who esteemed the technology being too expensive.

xR Studies in Indexed Literature

Focus of Study: 2008-2018 (Research & review articles, book chapters and reviews, editorials) Muliple assignments possible	**Total Nr. of Occurences of * and xR**[!] (in TAK fields)	**Total Nr. of Occurences of *** (in TAK fields)	**xR Occurence in * [%]**
Virtual Reality (VR) | Augmented Reality (AR) | Mixed Reality (MR) = xR	**3.174**	**3.174**	**100,0%**
Technologies			
Internet of Things (IoT)	27	2.563	1,1%
Cloud computing	25	3.287	0,8%
Artificial Intelligence	20	3.185	0,6%
Edge computing	6	102	5,9%
Quantum computing	1	316	0,3%
Blockchain	1	160	0,6%
End-Use Industry or Field			
Education	400	72.122	0,6%
Gaming | Entertainment[2]	264	15.817	1,7%
Health | Medicine	176	217.095	0,1%
Manufacturing	121	54.859	0,2%
Advertising | Media	116	73.009	0,2%
Automotive | Transportation	43	31.674	0,1%
Law	23	53.945	0,0%
Retail	14	5.776	0,2%
Agriculture	8	44.904	0,0%
Banking, Financial Serices, Insurance (BFSI)	4	21.181	0,0%
Oil and gas	2	5.109	0,0%
Ethics	***5***	***5965***	***0,1%***
Ethics | Moral	9	9.727	0,1%
Ethics | Moral + Health	1	1.231	0,1%

[!] The terms Virtual Reality, Augmented Reality an Mixed Reality were used as they are more descriptiv than VR, AR or MR

Table 5: xR Studies in Indexed Literature

Weak points include technical features like the discrepancies in high-resolution VR tools with lower resolution intermediary devices, required memory size due to data volume (Osarek, 2016), latency of the system, distance perception (Morel et al., 2015), motion sickness due to eye-brain connection issues, and the persistent need for de novo high-end price cuts.

In this thesis—based on the same reasoning as for AI—the technology itself is seen 'in its own right', apart from possible social consequences relating to exhaustive VR-use. However, the related social discussions are indispensable.

VR is used below as a synonym for xR for the sake of readability.

2.4.3 AI and VR: Technological Mutualism

AI and VR technologies exhibit synergies that can be leveraged in combination (Figure 21) but will turn big data into *Gigantic Data (GiganData)* (Osarek, 2016, p. 13). Applying Sandén and Hillman's (2011) classification of technologies as a *bundle of value chains* reveals the mutual nature of the two technologies, which share parts of their value chains. Since they do not compete for markets[14], applications, or resources but rather are alternatives or complement each other, their interaction is assumed to be mutual in accordance with Coccia (2017).

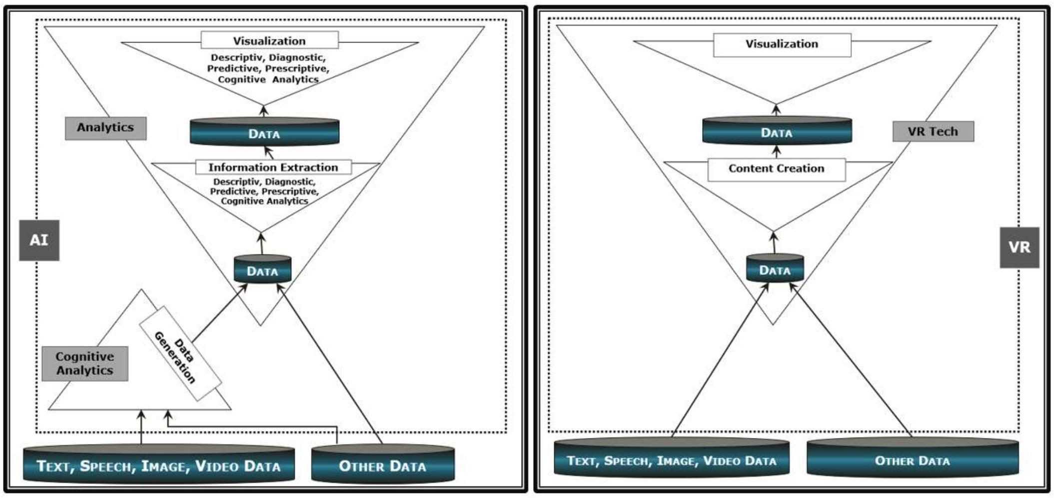


Figure 21: Hierarchies in Value Chains of AI and VR

AI and VR technologies (1) overlap in their value chains in the application *visualising data* using the same input—i.e. data—but executing data processing differently; this proposes the visualisation of analytical data in xR space in 3D (Figure 22); and (2) complementing each other, as AI can deliver insights into

[14] Figure 37 gives an idea of technologies competing for resources or markets following the work of (Sandén and Hillman, 2011).

customer experience in xR space by combining xR data with data from other sources and devices, such as health-tracking data from smart watches, which can then be used to optimise xR technologies and experience (Osarek, 2016).

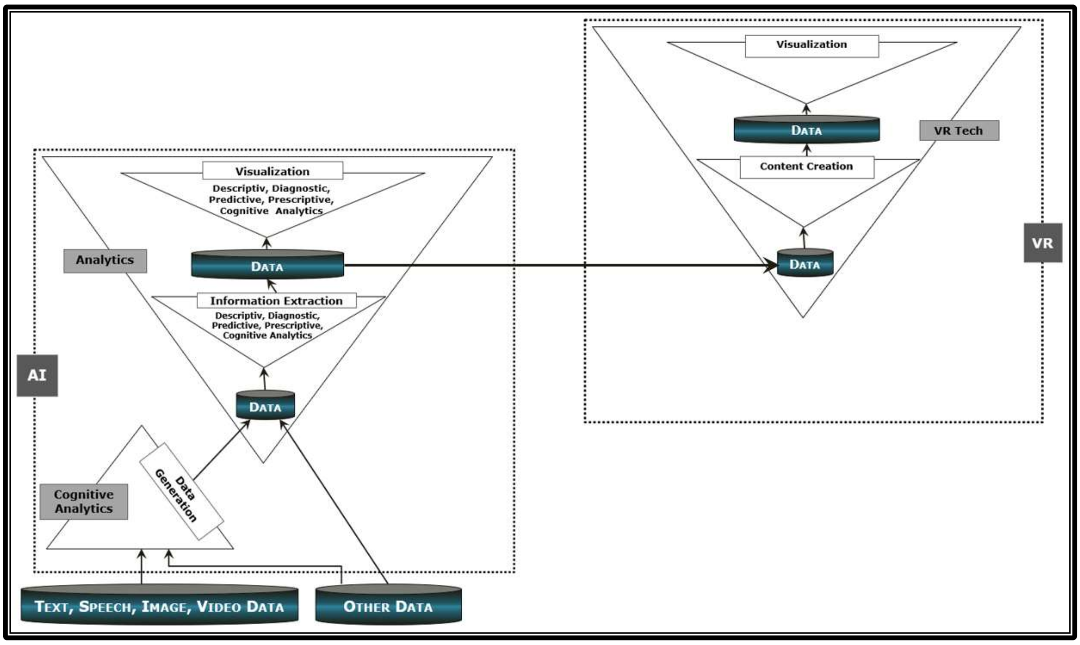


Figure 22: AI and VR Technologies—Synergy 1: Scheme of VR Visualisation for Analytical Data

Respective implications for the model framework comprise the usage of xR to extend the search space for knowledge and global collaboration and to perform *VR and AR analytics* (Osarek, 2016, p. 13) (hereinafter referred to as VR analytics for the sake of readability), which closes the last feature gaps (Table 3) and lifts the capabilities of an integrated framework to a new level of innovation.

In conclusion, Chapter 2 identifies approaches supporting the *New Product Development Process (NPDP),* relating to the identification of use-cases and the indispensable alignment and chronological integration of the technological innovation process across business domains, including resource allocation (TCL, T-PLUC, MTP), strategic technology-related problem-solving (TRIZ), cross-sectional technologies applicable to many techniques underlying these approaches with the ability to enormously optimise the respective methodologies (AI), and finally, a new improvement of the way the people work together (VR). Each approach has its own specifics, but all exhibit features supporting the objective of increasing the likelihood of inventions with high radical character at concurrent cost reductions. MTP, in a supplementary manner, ensures commensurate successful implementation and commercialisation, transforming these inventions into real innovations. These focal concepts, derived from the nucleus of the present study, and their implications for the intended framework are shown in Figure 23.

Focus of Study	Implicit focal Concepts	Implications for Final Model
Combinations of Technologies	Combinations of Technologies	Starting Point
Innovations with high Disruption Potential at Early Phase of Innovation Process	Technology-push Lead-User (T-PLUC)	Wherever in the whole process the use of lead users is indicated, collaboration with this community is prioritized
SOI Search Strategy & Scope	Broadcasting & Pyramiding Community-Based Far distant, Analogous Markets	**@Strategy:** Sequentiell integration of broadcasting & pyramiding to find lead users and other experts to be preferred **@Scope:** Search for solutions in far-distant, analogous markets first
Dependencies of Divisions, Systems, Trends, Ressources Over Time	Technology-Push Road Mapping	Allows to integrate system dynamics over all business domains encompassing elements from technology intelligence, forecasting, planning, and implementation Sequence and content of workshops decisive; Preponed training increases collaboration outcome
Strategic Inventive Problem Solving	TRIZ	Provides systematics to the individual creative think process. Requires TRIZ experts; preponed training increases collaboration outcome
Communication Channels / Visualization	Workshops Open CAI 2.0 /Other Platforms VR/AR	In case of web/VR-based communication: Crucial point: possible knowledge loss ➔ ensure information integrity
OPTIMIZATION of Techniques of TRIZ and MTP	ARTIFICIAL INTELLIGENCE	Requires AI experts ➔ Strategic alliance or inhouse knowledge development required if AI is not core competence in company
Evaluation Strategy Enabling Implementation of detected Market Opportunities	In-House Absorptive Capacity Re-Linking Strategic Partnerships	**@In-House Absorptive Capacity:** No implication for final model, but prerequisite for evaluating the embedding probability of market opportunity options into the company's global business /technology/IT Strategy **@Re-Link step to business** needs to be reflected in the final model

Figure 23: Focal Elements of Model Framework (II)

3 PROCESS FRAMEWORK

Solving problems arising in the NPDP framework is a crucial part of technological innovation. It requires explicit and profound knowledge from relevant domains, which is satisfied through either company-internal sources of knowledge or external SOI. Thus, the declared objective of the present thesis is the enactment of a process framework based on the presented mutually beneficial approaches, with a strong focus on open innovation in the form of building up a network of professional excellence with regard to technology and methodology experts, and lead users as potential market partners. This integrates both types of technology-product integration strategies—technology-push and market-pull. The individual methods presented in this chapter do not exceed a certain level of detail.

As the process framework is intended to lift synergies between TCL, T-PLUC, MTP, TRIZ, AI, and VR, respective integration can be performed either through the integration of one technology into the process of the other or by making a new hybrid and sequential process using each technology separately. To decide how techniques of TCL, T-PLUC, MTP, TRIZ, AI, and VR can be combined in the final framework, this chapter starts by illustrating the bilateral relationships of these technologies used in the subsequent process framework. In the following section, the individual phases of the process framework are presented.

It should be remembered that the interdependence and mutual influence of components in a technical system or living organism are comparable to Sandén and Hillman's (2011) classification of modes of interaction in two-technology systems, where a change in the technologies' features or in overlapping parts of their supply chains can—and, depending on their co-action mode, will—affect the future pathway-evolution of the underlying technologies. Concluding therefrom, the revelation of specific features of technologies with reciprocal supportive and fertilising characteristics is key for shaping jointly beneficial use cases. Therefore, in the first step, the value chains or benefits of the respective technologies are collected and illustrated in Table 6. As can be seen, the combination of the chosen approaches either completely eliminates mutual deficits in framework criteria enacted a priori or enhances other techniques (AI) or the collaboration style of the focus groups (VR). The following holds: Whenever value chains of technologies—i.e. predetermined criteria of the framework—overlap, it is scrutinised whether the technologies are substitutes or alternatives to each other[15]. If a feature is provided by only one technology, the framework absorbs and integrates the respective technology's value chain link into the overall process. At this point, it should be recalled that Sandén and Hillman's (2011) value chain definition also includes other dimensions like personas, resources, and alike which allows a much broader and more complete framing of the value chain. To avoid complicating the topic, these dimensions have not been explicitly named.

GAP DETECTION OF ANALYZED APPROACHES

0=No, 1=Yes, 2=Depends on Method		TCL	T-PLUC	MTP	TRIZ	AI[2]	VR
Product Integration	Technology-Push	1	1	1	0	0	0
	(Generates) Market-Pull	0	1	0	0	0	0
Corporate Foresight / Retropolation	Start with Final Future State	0	0	1	2	0	0
Abstraction of Technology	To Technology Features (Link to technology remains)	0	0	1	1	0	0
	To User benefits	1	1	2	0	0	0
Time- Component	Dynamic Market/User Trends	0	1	1	1	2	0
	Environmental / Political Developments	0	0	1	0	2	0
	Strategic, chronological Alignment of Processes	0	0	1	1	2	0
	Evolution of Technological Systems	0	0	0	1	2	0
Lead-User Engagement	Early in Process	1	0	0	0	0	0
	Early, but after objective Trend Analysis	0	1	0	0	0	0
Strategic Partnerships / Knowledge Search	Pyramiding/Broadcasting	1	1	0	0	0	0
	Other systematic Approach of Collaboration /Cooperation Partners[1]	0	0	1	0	0	0
	Ranking of Application Fields dependent on future potenial Partnerships	0	0	1	0	0	0
	Include Collaboration with external Partners	1	1	1	2	0	0
Strategic Solution Search	Strategic Problem solving	0	0	0	1	2	0
	Strategic Technological System Solving	0	0	0	1	2	0
Technology Classification with respect to Interaction of Technologies	Account for Classification, overlapping parts in Supplychain of Technologies	0	0	0	1	2	0
Visualization of Results	Includes non-virtual possibility to visualize results / data	0	0	0	1	2	0
Include AI or VR Features	AI-driven Problem Solving	0	0	2	2	1	0
	VR-supported mobile Collaboration	0	0	0	0	0	1

[1] Is counted together with Pyramiding / Broadcasting

[2] AI and VR will be treated as enhancements of tools and techniques of other processes. As AI has manifold functions and application options, related features are seen in strong dependence of used function

Table 6: Overview of Analysed Approaches and Revelation of Methodological Deficits III

[15] Sandén and Hillman's (2011) graphical value chain representation facilitates the identification of overlaps, as illustrated in Figure 22.

The final process framework is intended to capture all a priori identified criteria given in Table 6, as these were enacted against the background to invent new products with high disruption potential at early stages of the innovation process.

3.1 Framework Technologies: Analysis of Interaction

From the excerpt of technology features and methodological gaps of the presented technologies used to build the process framework provided in Table 6., insights from the summary of focal elements of the framework, including related implications of the process framework (Figure 23), deductions from the value chain definition given by Sandén and Hillman (2011), and the concise taxonomy of technologies based on Sandén and Hillman (2011) and Coccia (2017) (Figure 4), the following conclusions are drawn:

(I) TCL and T-PLUC: As lead users exhibit unrivalled benefits over other knowledge stakeholders according to literature investigation, they are privileged wherever external knowledge is indicated in the process. The respective search strategy for lead users or experts follows the interlinked and sequential pyramiding-broadcasting approach of Keinz and Prügl (2010).

Furthermore, the chosen technology-product integration strategy will predominantly be that of technology-push. However, since lead users can trigger a market-pull effect as well (as mentioned in Henkel and Jung's (2009) work), it can be said that the framework exhibits and profits from an integrated view of both approaches. In addition, TCL and T-PLUC will be synchronised to one method—dominated by T-PLUC—as they differ in terms of the addressed crowd involved in relinking the product concepts to real applications, products, processes, and services. In contrast to TCL, T-PLUC does not involve the manufacturers, but develops together with lead users business-related solutions for the focal firm. The technology-push roadmapping process of Caetano and Amaral (2011) also illustrates the potential of strategic partnerships—which might be triggered by lead users becoming *market partners* in Caetano and Amaral's (2011) diction—but does not describe an efficient way to approach them best; a gap, which is closed by Keinz and Prügl (2010).

As the technology-push leaduser approach is preferred over other collaboration forms, it is centrally positioned in Figure 24 to signal that TRIZ and AI are used in the framework of the lead-user approach. Direct links from MTP to TRIZ, AI, or VR in the graph presuppose that collaboration or tools are principally used in internal workshops between inhouse project team members.

(II) **MTP:** The technology-push roadmap process of Caetano and Amaral (2011), as embedded in Daim and Oliver's (2008) roadmap procedure, is the focal concept into which the other concepts are integrated.

To conclude which elements can provide an advancement to the existing approaches in the literature, various road mapping processes—technology-push as well as market-pull—were screened with regard to user feedback, features, and the final roadmap. Figure 16 illustrates the representatives of the most distinctive methodologies, the most compelling aspects of which were synthesised into one common model comprising five phases in all, including a distinct number of recommended workshops (sequences). Beyond, as strategic partnerships are deemed to be of central importance for the proposed framework, the classical technology-push roadmap is extended by an additional layer (Figure 32) reflecting strategic alliances—including lead users—separated in terms of collaboration and cooperation partners for the matter of resource allocation and increased completeness of the technological roadmap in general, which is of specific importance for SMEs (Caetano and Amaral, 2011). The final roadmap[16] provides a detailed picture of focal and—if required—related complementary technologies, markets, products, resource allocation, and strategic partnerships, which are indispensable for the invention of feasible innovations.

Depending on the different layers and their underlying purpose, several clusters of tools can be applied in a roadmap (Ilevbare et al., 2011) (Appendix Figure 41). Cho et al. (2014) give an overview of the chronology of technology-forecasting techniques, normative vs explorative and hybrid approaches, where an excerpt of predominantly AI-related methodologies like clustering techniques, timeseries modelling, and system dynamics are quoted to get the first impression about the broad scope of AI application purposes in a roadmapping framework (Appendix Figure 42; Figure 43). To account for the presupposed web-based or VR/AR-based communication in the focal collaboration groups, Lee and Park (2005) provide a web-based system to easily create and customise roadmaps with regard to their application purpose (forecasting, planning, or administration), to facilitate their dissemination and

[16] In fact, there is a bundle of division-related technological roadmaps that are mutually aligned and cross-divisionally verified with different focal points and orientations.

maintenance, and to keep the technology roadmaps up-to-date. In the following sections, it is assumed that web-based technology roadmaps differing in terms of business domains and purpose are used to explain decision-related implications for other layers in the roadmap or other departments of the focal company to internal and external collaboration members, and to visualise project development status quo. Zhang et al. (2010) exemplify the allocation of technologies within the roadmap with regard to their intrinsic technological maturity by supposing the positioning of infantile technologies inside the long-term section of the map and more mature technologies at mid- to near-term. The chosen timeframe indicates whether the company's target should be incremental innovations through optimisation or radical innovations, where substitution is key, as is the case with old technologies. Furthermore, Zhang et al. (2010) underscore the bias in data caused by exceptional internal knowledge and personal judgements, when no corrective opinions are sourced from external experts to increase objectivity and data validity, as being a crucial point of roadmapping.

(III) TRIZ: TRIZ tools are applied in the framework of MTP whenever new technological systems are formed by features, benefits, or—according to the diction of Sandén and Hillman (2011)—overlapping parts of the value chains of technologies that still exhibit contradictions, whose solution requires creative and inventive problem-solving.

TRIZ instruments are invented to give the creative process a systematic component while enhancing the solution space, which extends the probability of increasing the likelihood of a broader range of diverse product concepts, and hence, a higher number of marketable products[17]. Schulz et al. (2000) support a systematic approach in high-pressure product development environments as—according to the authors—traditional trial-and-error leads to innovative products based on superior, robust, mature, and flexible technologies only in the rarest cases (Schulz et al., 2000).

According to the overlaps in their value chains, TRIZ and MTP can be combined in the following variants[18]:

[17] In the following sections, the term *products* refer to products, processes, and services for the sake of readability. The application of MTP for services and processes can necessitate adaptations of the proposed process (Abdul Halim Lim et al., 2015; Martin and Daim, 2012). For an overview of types of road maps, kindly refer to Ilevbare et al. (2011, p. 24).

[18] For a more detailed description of the subsequent variants, kindly refer to Ilevbare et al. (2011).

(a) Version 1: Integration of TRIZ concepts to improve the MTP process

Following Sandén and Hillman (2011), the overlap in the value chains of MTP and TRIZ happens at the horizontal level, where TRIZ tools are applied at the MTP stages: 'Where are we now?' (Current state) ➔ 'How do we get there? (Transformation) ➔ 'Where are we going?' (Intended state/solution)[19]. In this case, the gap detection happens within the TRIZ environment. An enhancement of this variation is the integration of modelling the dynamic behaviour of the roadmap and seeing the roadmap as a system whose approximate structure can be recreated in an AI-driven TRIZ system-dynamics approach.

(b) Version 2: Integration of MTP to improve TRIZ process

In this constellation, MTP extends the features of TRIZ by visualising and linking TRIZ results into the broader business scope, including vertical alignment of horizontal roadmap layers. For this purpose, MTP is executed as the final step to the TRIZ process.

(c) Version 3: Successive linking of both methods—e.g. linking sequential MTP processes through the integration of TRIZ concepts

A variation of Version 2 is the sequential process of applying MTP for problem, opportunity, gap, and defect detection and applying TRIZ to provide solution options for the identified problems, which are again reintegrated into another roadmapping process in the second step (Appendix Figure 58).

(IV) **AI:** For AI as cross-sectional technology, application opportunities are manifold, in which the focus is set specifically on:

- **MTP:** AI tools are applied in the framework of MTP and find application opportunities in bibliometrics, patent research, and forecasting trends through fundamental modelling (Appendix Figure 43).
- **TRIZ:** The integration of elements of both technologies and related effects on the overall process flow need to be evaluated in detail, depending on the prevailing AI approach. Elucidating the synergetic possibilities of AI and TRIZ, the following options are feasible:

(a) Both approaches remain independent

[19] Figure 57 in the Appendix graphically illustrates the application of TRIZ concepts within the MTP framework (Ilevbare et al., 2011).

Sequential deployment of each methodology in senseful order: With respect to the thesis, AI can exclusively be an integrative element into TRIZ (prime example: text-mining or natural language processing for supporting the problem formulation in a TRIZ framework). Using AI as a stand-alone approach for semantic analysis does not affect the complexity of the concerned process but has the added feature of constantly increasing the TRIZ knowledge base if inventive problems and their solutions are tracked and saved in a data base. In case of a new inventive problem, within this knowledge base available solutions can be found with the support of AI-driven semantic similarity search.

(b) *Integration of the two approaches*

- Inventive problem-modelling is performed with TRIZ with subsequent simulation of the problem-solving strategies via AI
- Inventive problem-modelling with AI reveals conflicts and enables subsequent translation into the TRIZ framework
- AI simulation environment incorporates adjusted TRIZ techniques: Elements of TRIZ can be integrated into a sequence of AI functions (as in the case with the system dynamics approach of Delgado-Maciel et al. (2017)) by changing parts of the overall process sequence

(V) VR: VR is predominantly seen as a visualisation tool for pre-processed data from AI and an extension to Open CAI 2.0 (Lopez Flores et al., 2017), a web-based open innovation collaboration platform that uses *Graphical User Interfaces (GUIs)* as a communication channel on the web to collect intelligence from globally dispersed SOI.

The advantage of VR in this context, as a new form of collaboration platform, is revealed in the specific case of including lead users into the collaboration process. Here, the experience of co-working goes beyond sharing content via a virtual environment, as is the case in Open CAI 2.0, but reveals emotions and the unbiased picture of customers in their natural or any other environment if required. In this context, VR does one of the following tasks:

- **AI/MTP:** visualises analytical data from an AI approach or technological roadmaps of different departments via the VR or AR environments

- **Ease of collaboration:** lets members of the collaboration team work over geographical distances with each other[20].

In both cases, product development time and travel-related project costs can be reduced due to increased efficiency in the collaboration process. The following section does not explicitly refer to VR or Open CAI 2.0, but it is presumed that collaboration can leverage the advantages of these new technologies.

Figure 24 visualises the implications of the aforementioned considerations and their consequence for the interlinkage between the methodologies, where the bi-directional arrow between TRIZ and AI indicates that the chosen AI approach determines which technology is to be embedded into the other; the integration can happen in both directions for parts of the TRIZ process. The bold line highlights the preferred collaboration—i.e. lead-user—path while other forms of collaborations are represented by the dashed line, using an according description.

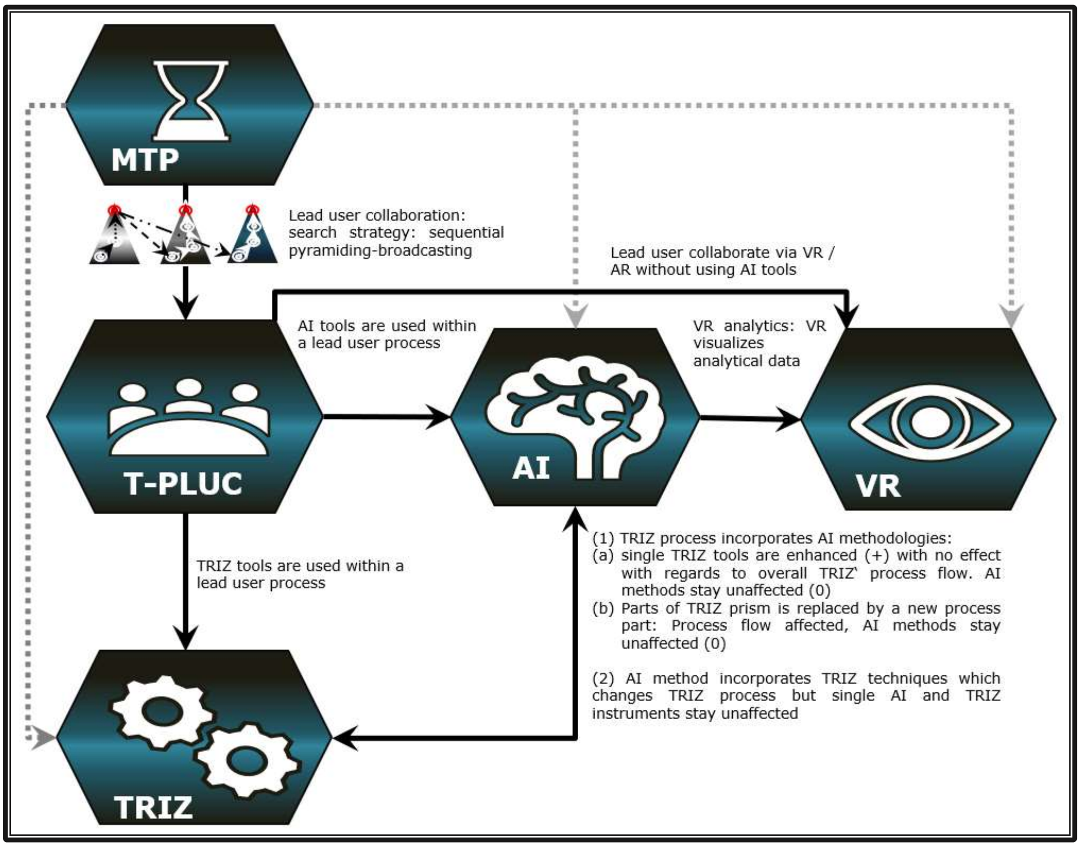


Figure 24: Interrelation of Framework Methodologies

[20] For avatar-based innovation effort enhancement, kindly refer to Kohler et al. (2011).

In the following section, the framework development is explained based on hypothetical two technologies, for which it is assumed that the focal company has a convincing indication that their combination can lead to breakthrough applications and interesting new markets. In general, there is no restriction on the number of technologies involved. Important is the interaction between the chosen technologies—if the relationship is of competitive or mutual nature—and the evolution and its triggers of the common pathway as illustrated in Figure 5, in order to assess what is necessary to generate an integrated feasible value chain out of the value chains of the individual technologies.

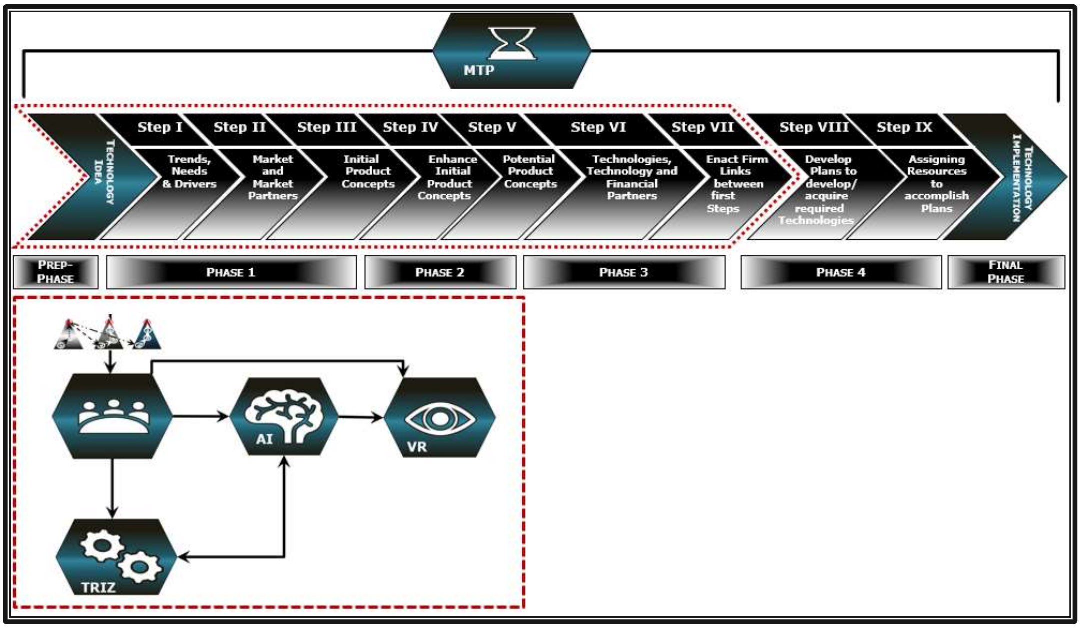


Figure 25: Process Framework, Scope of Thesis, and Application of Subprocess Construct (Modified from Caetano and Amaral (2011) and Daim and Oliver (2008))

Characteristics of the focal company include technology-centricity and predominant adoption of technology-push product-integration strategy. Although all technology-driven enterprises—as well as large corporations—could adopt proposed framework, it predominantly addresses independent research institutes and SMEs that want to close nascent knowledge gaps in co-operations and collaborations with other external companies to extend their network of technological excellence. Large corporations tend not to be dependent on external partnerships to the same scale, as they have the *complementary assets* (Ceccagnoli and Rothaermel, 2008) to develop the required resources inhouse and to acquire start-ups or established companies via pecuniary acquisition (Caetano and Amaral, 2011).

Figure 25 illustrates the whole process framework, from technology idea over the establishment of the third-cut technology roadmap in Step VII. Detailed descriptions of Phase 4 and the final phase are not included in the present work.

In the following section, the division into workshops is done to ensure transparency, where workshop can also refer to a sequence of workshops with the same collaboration group.

3.2 Preparation Phase: Teams, Trends and Trainings

Effectively organising the subsequent workshops and training sessions and building the internal innovation project working team[21] and collaboration groups is key for the open innovation project success. These tasks are incumbent upon the *innovation project steering committee,* which comprises leading managers of the focal company.

- **Workshop 1—Internal: Determine Innovation Project Working Team** (Focus collaboration group: innovation project steering committee)

The process starts with the *formation of an internal innovation project working team* whose skillset—including hard and soft skills—best covers the purpose of the presented intended innovation process. The choice of this group of persons is essential for the project's success probability. External experts who know how such efficient innovation project teams are formed can be consulted upfront (DeCusatis, 2008). For each layer in the roadmap, at least one representative is indicated to be chosen who can recognise implications of decisions for the respective domain and steer the process appropriately from the perspective of the affected division. Although the process is technology-driven, Fan (2011) recommends including non-technical people as decision-makers in the creativity processes as well, going by the assumption that this competence is covered by the innovation project working team. In the following section, technology experts mean specialists in the focal technologies, which can be—but not necessarily need to be—already part of the innovation project working team. This process also reveals gaps in knowledge that need to be closed and also balanced by external SOI, like an independent research institute or university.

[21] The composition of the innovation project working group may vary depending on the focus of the workshop, but due to the high complexity of the used data and approaches and in order to not lose connection to the overall process it is advised to have a strong core of internal employees who participate in every workshop. The more each division is aware of the implications of decisions for other departments, the more efficient are the process and the outcome of the project.

The involvement of the CEO or high-level management depends on the prevalent professional orientation and entrepreneurial mindset. Berg (2016) conducted an empirical field study about the group of people—managers vs creators—that can better predict the success of novel ideas within the prevailing company. He concludes that creators outperform managers due to their ability to think both divergently (important for idea creation) and convergently (relevant for idea generation). Moreover, combining the insights of the works of Bruce et al. (1999)[22] with regard to success-enablers and shortcomings of the applied innovative *'skunks work' approach,* and the study of Baron and Ensley (2006), the involvement of experienced managers or entrepreneurs to inspire the employees and spread seeds of entrepreneurial thinking and acting might be an additional enhancement in the process of organising for innovation. This knowledge transfer can be organised either on the basis of consultancy or via employee delegation to intensive multi-day workshops with entrepreneurs within the framework of company-supported training programmes. This would stimulate the willingness to be experimental and think like an *intrapreneur*. Extending the collaboration with experienced entrepreneurs by university professors and other external entities, it is open to discussion whether those SOI should or at least might support not only the idea generation but also the filtering process of gathered innovative ideas as well. This needs to be assessed with respect to every specific situation in alignment with the company's innovation strategy.

In general, technology roadmapping, lead user analysis, and S-curve analysis are all methods of technology intelligence and technology forecasting[23]. The process framework aims to integrate these approaches to provide an intertwined tool revealing an unprecedent power to get the best of all worlds. The following section discusses the individual underlying methods, with the MTP being the master approach.

- **Workshop 2—Internal: Technology Trend Analysis/Focus of the Technology Roadmap**

[22] For a detailed description of prerequisites for successful innovation, kindly refer to the work of Bruce et al. (1999) which highlights not only the enablers (e.g. skill-related, organisational, or environmental factors) but also the drawbacks of the undertaken 'skunks work' approach for *'[i]dentifyig new markets and new product opportunities [using the prevalent company's] core competencies'* (Bruce et al., 1999, p. 112).

[23] Remark: Technology intelligence and technology forecasting methods are not uniquely differentiated within the literature.

(Focus collaboration group: innovation project working team, internal technology experts, (internal/external)[24] AI, and technology-forecasting expert)

After the project team is built, first a *broad global web-based bibliometric search for technology and related market trends and an in-depth patent analysis* are performed by applying screening tools—which can already be AI-supported by semantic search algorithms (Cho et al., 2014), natural language processing, or text mining—to come up with either a preliminary set of promising technologies related to the focal firm's core technologies, which need to be leveraged across other industries, or promising technologies outside the focal firm's core competencies with strong evidence of business success.

After applying these *technology intelligence* tools to get the first indications about technology trends, the present study aims to estimate the future development of the underlying technologies with *technology forecasting* approaches like the Delphi-method, expert interviews, or S-curve analysis. This is done to detect the maturity level of the focal technologies and deduce therefrom the respective improvement potential (Cho et al., 2014; E. Lichtenthaler, 2008; Moehrle and Isenmann, 2007). For this purpose, focal technologies experts and technology forecasting experts first need to be identified, either within the company or from the external environment, via the pyramiding-broadcasting approach of Keinz and Prügl (2010). This forecasting step triggers a workshop sequence with specialists, depending on the chosen technology forecasting approach.

In addition, existing documents and artefacts are screened to determine the status quo of the currently implemented technological innovation management process and to detect potential defects that the new roadmap needs to obliterate. Roadmap- and workshop-related documents are set up and a draft of a technological roadmap is prepared.

[24] The following section does not distinguish between internal and external expert knowledge resource as it depends on the focal company's internal resources and core competencies whether this expertise is covered.

➤ **Workshop 3—Internal: Training on MTP, TRIZ, AI, and VR**
(Focus collaboration group: innovation project team, (internal/external)[25] technology experts, (internal/external)[26] MTP, TRIZ, AI, VR experts)

Antecedent *training sessions on MTP, TRIZ, AI, and VR* are optional but strongly recommended, as they increase the awareness of the methodological specifics and improve the subsequent process in terms of time and content (Daim and Oliver, 2008).

These preliminary preparational activities result in the determination of focal technologies for the subsequent technology-push roadmapping process. Figure 26 summarises the outlined workshops, activities, and final results of the preparation phase.

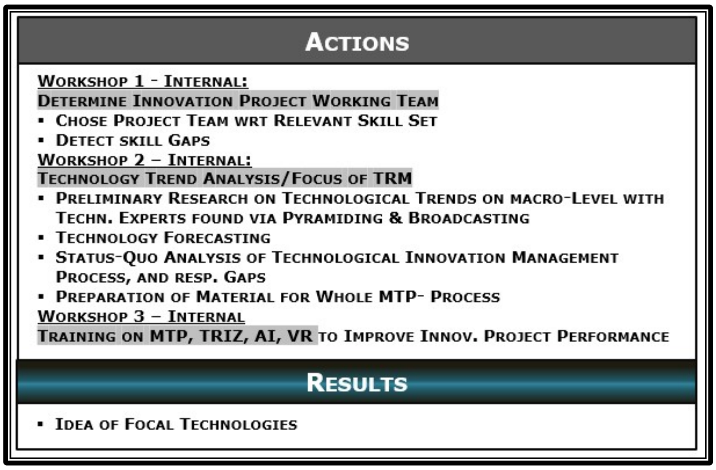


Figure 26: Actions and Results of Pre-Phase

3.3 Phase 1: Integrated Technology Strategy

The commercial success of an invention depends primarily on the *strength of the novel technology and* the *strength of the targeted market*. In case of disruptive technologies, the market might not be yet established, wherefore triggering the first demand through the involvement of lead users exhibiting extraordinary needs, and thus, being receptive to adopt cutting-edge technological developments, is one step to reduce the high uncertainty at the early stages of novel technologies solving problems of this potential customer group. Lead users have established knowledge and intuition about the novel technology's benefits and features. Hence, they exhibit the skills to support the exploration of use cases and the preselection of identified product concepts as

[25] In the following it is not distinguished between an internal and external expert knowledge resource as it depends on the focal company's internal resources and core competencies if this expertise is covered.
[26] See cross reference 25.

well. A priori analysis of the focal technologies' value chains can reveal new combination options with additional user benefits. Therefore, a collaboration with a group of leading experts in these technologies to extract and abstract user benefits is a recommended pre-step in the process, and the use of TRIZ techniques, which increase and enhance every immanent creative-thinking process, is indicated. Assessing technology and market parameters which reflect, among others, the strength, risk, and superiority of the novel technologies and related market indicators, and which will be treated as weak decision criterions, intend to give a first loose fit to the company's business objectives and are supporting the preselection of a set of pre-superior product concepts. In addition, the technologies' underlying technical system is tested and enhanced in the next phase of the innovation process with regard to its factual technical, and physical feasibility and robustness via a computer-aided TRIZ approach.

The outcome of Phase 1 of the proposed framework is a set of preselected and pre-superior novel technologies and product concepts based on technology-push approaches, which integrate aspects of a market-pull product integration strategy.

- **Workshop 4: Visioning and Integration**
  (Focus collaboration group[27]: innovation project steering committee, innovation project working team, technology experts)

After the preliminary technology research is performed, a macro-level analysis of related market, environmental, political, and other trends is conducted to get an indication of interesting business trends relating to the focal technologies and to evaluate a priori certain environmental, political, *Intellectual Property (IP)*-related, or other showstoppers. In this step, the consultancy of technology experts is recommended if the company lacks experience in the selected technologies.

Fed with these impulses, the company internally evaluates what the future pictures of the company should be in keeping with these technologies and what its revised visions are, and—based on a retropolation approach—identifies loose boundaries between actions, technological capabilities, products, and markets to achieve this. To answer the second question of a technology roadmap and relate its outcome directly to what is needed, a

[27] With regard to the involvement of the CEO or high-level management, the same argumentation holds as for Workshop 1.

status-quo assessment of where the company is at present and where its gaps are relating to its defined vision can unveil competency, resource, or other gaps. The declared objective at this stage is, that the solution range is not too restricted but that a vague direction for the company is set. This workshop is concluded with a first-cut fixed vision indicating the direction that the company aims to follow.

- **Result: 'Fix' Vision in the Technological Roadmap**

However, the real revelation of a company's sharp vision when technologies are unfamiliar to the focal company or new application opportunities are still not clear or covered is given only after a deep dive into the technologies' benefits. This triggers an in-depth research to find trends nurtured by these benefits and a subsequent market analysis to detect markets where these either in the company existent or new technologies are of high interest. This is the focus of the subsequent workshop.

- **Workshop 5: Novel Technologies Combinations**
  (Focus collaboration group: innovation project working team, technology experts, TRIZ expert)

To best exploit the characteristics of focal technologies and their interaction, the different value chains of each individual technology need to be identified. If the focal firm lacks internal competencies, external technology experts have to be consulted who have already been found in Workshop 2 via the pyramiding and broadcasting approach of Keinz and Prügl (2010). Although recommended, these people need not necessarily be lead users but are assumed to give good guidance in abstracting the focal technologies' features. Especially at this stage, it is recommended to use TRIZ creativity tools to break up mental barriers of the technology experts as they can easily be stuck in their old mindset and might oversee potential features of the technology, leading to user benefits. Again, we follow the recommendation of Fan (2011) to always involve non-technical people in the problem-solution process—a requirement which is again assumed to be fulfilled by the innovation project working team. In parallel, TRIZ not only enhances creativity but allows a creative process to be steered in a systematic way, which increases the likelihood of a final wider range of identified user benefits.

In the framework of this workshop, the following actions need to be performed and the following technology characteristics assessed for both existing technologies and technologies foreign to the company:

(I) Technologies' features transformed into user benefits

(II) Technologies' supply chains incorporating these features, overlapping parts and mode of interaction to identify the bilateral relationship (in case of two technologies) and therefrom deriving the potential pathway evolution, according to Sandén and Hillman's (2011) research and the example of AI and VR in Chapter 2.4.3.

(III) In case of alternative or complementary features: Recombination of parts of supply chains of both technologies to systematically assess novel technologies and to extend the problem, and subsequently, solution space, via TRIZ creativity tools. Knowledge about the interaction of the technologies' combined value chains facilitates the application of TRIZ's *evolution laws* (Figure 45) of technical systems.

(IV) Technological maturity can be deduced from the technologies' assumed S-curve development or other technology forecasting techniques (Cho et al., 2014) (Appendix Figure 42 and Figure 43), which give an indication about the remaining potential for technology improvement.

- **Abstract features of technologies and the combination of their supply chains (hereinafter called novel technologies) in form of user benefits**

  The subsequent market analysis is performed to evaluate trends that are nurtured by these technology features and user benefits which leads to the identification of industries or market segments with high demand for these trends.

- **(Far-distant, analogous) markets and respective segments**

These steps resemble the first steps of an already ushered T-PLUC[28], which will be followed up by the search for lead users in the identified industrial sectors.

➢ **Workshop 6—External: (Far-distant, analogues) Markets**
(Focus collaboration group: innovation project working team, technology experts, lead users)

Starting point is a systematic search for lead users in alternative application areas through a sequential process of pyramiding and broadcasting. In order to detect user communities that are knowledgeable about applications in

[28] For a detailed description of the underlying approach, kindly refer to Henkel and Jung (2009) and Keinz and Prügl (2010).

which the technologies can have high disruption potential, the lead user search starts systematically with a pyramiding approach in communities that have an idea about other user communities for which the characteristics of the technologies will be of high benefit. A subsequent broadcasting within the recommended new crowd leads to the detection of people of their social network with higher knowledge than other users. This again triggers a pyramiding approach, resulting in the recommendation of other communities where the technologies can be of relevance, and so forth. It needs to be remarked, that the formulation of the questions for the interviewees is exceedingly important here[29]. The next step is to extract solution concepts for the detected markets.

Having identified lead users for the predetermined and new markets for which the prevailing novel technologies' benefits solve crucial problems, all available information about the abstracted features and functions of the focal technologies elaborated in the previous workshop are provided. The formulation of the technologies' user benefits allows a decoupling from the focal technologies, and the lead users detect applications where these benefits lead to strong solutions of prevailing problems in the markets that they know well.

In the next step, a TRIZ process is triggered to foster the detection of new products in the respective market via the abstract space—i.e. to enhance the imagination of the lead users of this market with regard to new application possibilities. In addition, the probability of feasibility of the underlying technical systems of these novel problem-solving technologies needs to be assessed. This is done either by applying the TRIZ process to these novel technologies and getting a rather clear indication, or—in case of limited knowledge about the novel technologies or a low degree of technological maturity—via the use of the *evolution laws* to get at least an indication of the pathways of the technological system (Schulz et al., 2000) and its likelihood of feasibility: Novel technologies will already tend to outcompete existing technologies with regard to their benefits for the customers. But the deployment of the TRIZ process, as described in the following section, is strongly dependent on the technical system's technological maturity and whether a system structure can already be derived which is most likely the

[29] For a detailed description of the underlying process, kindly refer to Keinz and Prügl (2010).

case if the company wants to leverage existing technologies. If company-extraneous technologies exhibit a maturity grade appropriate for a TRIZ process, novel technologies are used in the process described below. If the maturity level of the novel technologies is too low, besides applying evolution laws, a parallel TRIZ process applied to existing technologies could be used and conclusions could be drawn from the required enhancements regarding future abilities and possible gaps[30].

Lead users identify the ideal product, in particular the *Ideal Final Result (IFR)*, for the market in focus from a user's perspective. If comparable products already exist, the new products' relative benefits are made clear. After the IFR is determined for a market, it is not yet modified with regard to the respective context, like focal company's objectives and goals, as it can be performed in a TRIZ-MTP process (Ilevbare et al., 2011), but gaps to functionalities of existing solutions are structured in the first specific-problem formulation, which can be derived via TRIZ's nine-window approach or functional and system analysis. Afterwards, the specific problem is transformed via TRIZ transformation tools like function analysis or SuField Analysis into conceptual problems. These are solved via TRIZ instruments like the contradiction matrix for technical contradiction solving, separation principles for physical contradiction solving, inventive principles, or effects where—in addition to the previous step—*bad solutions* are also collected in the *bad solutions park*. As already mentioned, the above process for existing solutions indicates how novel technologies need to be developed to increase their benefits to reach the intended state of an ideal final result.

Once conceptual initial product (solution) concepts are identified, the subsequent relink is performed using TRIZ creativity tools like *smart little people* or *bad solutions park* to relink to specific solutions—i.e. product concepts where either new markets are created or new application areas within existing markets are revealed.

- **Specific initial product concepts for specific markets (generation of new markets)—unfiltered; no fit to company's organisational objectives, market, or other trends. Probability of feasibility of technology pathways evaluated, but not used for any limitation of the product concepts.**

[30] If this approach is a feasible way to evaluate novel technologies with a very low level of maturity grade, needs to be tested empirically.

As lead users tend to be cutting-edge with regard to analogous technologies and related products for their markets, their involvement in the relinking step to the focal firm's business is likely to further extend the variety and number of the *market opportunities set prior to market entry* (Gruber et al., 2012).

- **Initial Product-Technology[31] Concepts for new Markets**

➢ **Workshop 7—Internal/ External[32]: Preselection of Product Concepts** (Focus collaboration group: innovation project working team, technology experts, lead users)

Up to now, no prioritisation of technologies has been performed, nor has there been any adaptation to the company's organisational objectives and goals or a check to the fit to the company' technological portfolio in order to get a broad range of possible use cases in new application fields. This approach is intended to prevent new technologies from being valued as not feasible too early due to their misfit with the *current* organizational structure.

The process already starts with the limitation to two technologies, then broadens by combining the technology features to novel technologies with new benefits, for which new markets need to be explored. The subsequent portfolio analysis aims to give clear indications and the sequence in which novel technologies are to be invested, implying the technologies' global market size, relative technological position, technological and strategic importance, potential competitive advantage, and economic and industrial synergism. In this workshop, the previously mentioned portfolio management tools relating to the top layers of the Technology Roadmap like scenario analysis, SWOT, STEEP, concept visioning, and experience curve (Appendix Figure 41) come into effect.

With regard to the prioritisation of product concepts, including novel technology combinations, different approaches can be used if they include an in-depth analysis of the novel technologies, their related markets, their fit into

[31] Hereinafter referred to as product concepts but always including the inherent technology.

[32] Lead users and (external) technology experts are consulted for certain technology parameter estimation in the framework of Schulz et al. (2000), where other parameter estimations, especially company-internal ones, might be not revealed to the public.

the portfolio of the company, and associated investment considerations with regard to cost/profit relation[33] to answer the following key question:

- **Which technology paths have a relevant influence on the market and exhibit an appropriate likelihood of technical feasibility while being economically viable at low failure risk?**

- **Which technology paths exhibit a high likelihood of reaching world-class competitiveness within a short time?**

Caetano and Amaral (2011) and Schulz et al. (2000) both present either a statistics-based approach or a prioritisation methodology based on market and technology parameters. In addition, both aim to perform a soft preselection of novel technologies and products—i.e. to kick out those that are totally out of alignment with business requirements—or technological capabilities that will never be assessed by the focal firm. Following Schulz et al.'s (2000) approach and in addition to the already assessed *technological maturity of the* technologies, the novel technologies' *contribution to customer satisfaction* (Schulz et al., 2000, p. 190), the *technological strength* of the novel technologies, whose parameter strength is deeply dependent on technologically comparable competitive products and their inherent *superiority* (Schulz et al., 2000, p. 190), i.e. the competitive advantage potential, are assessed primarily through questionnaire-based ranking by lead users and—where appropriate—the innovation project team and the technology experts. Furthermore, the respective markets' parameters, namely *market growth*, *market strength* or *share*, *competition,* and *contribution to profit* (Schulz et al., 2000, p. 189) are assessed, which can lead in case of breakthrough inventions to deficits in the quality of the respective parameters[34].

According to Schulz et al. (2000), to estimate the business significance of these modelled trends from the market and technology perspective, these eight parameters are put into one graph for an illustrated juxtaposition of the single novel technologies in relation to each other to support portfolio decision-making (Figure 27). The size of the bubbles refers to the novel

[33] Assessments of costs and other parameters can be a hard task in case of not yet established markets for breakthrough inventions.

[34] For a detailed description of parameter assessment, kindly refer to Schulz et al. (2000).

technologies' technological maturity, the colour to the respective degree of superiority, the arrows to the direction of the evolution of the portfolio position, and the length of the arrow to the rate of change.

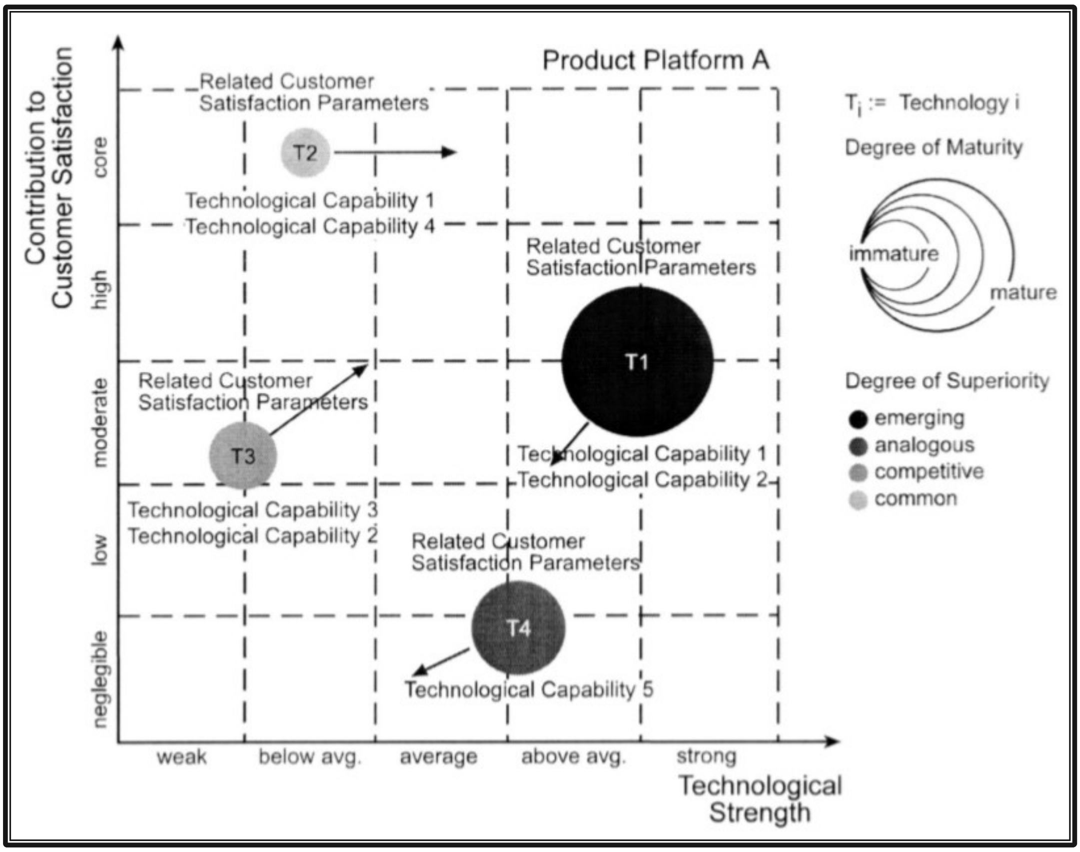


Figure 27: Technology Bubble Portfolio Relating to Technological Parameters (Schulz and Clausing, 1998; Cited by Schulz et al., 2000)

Also taking into account the pre-assessed likelihood of technical feasibility of the novel technologies in Workshop 5, the focal company will internally decide on initial product concepts preselected with a rough fit to the company's organisational objectives, markets, probability of technical feasibility and economic viability, and risk of failure.

As an additional step, depending on the outcome of the workshops, the vision of the company is revised—if indicated—and fixed, and first loose links between affected layers in the roadmap, which are at least technologies, products, and markets, are enacted. Up to this point, the close collaboration with technology experts and lead users can lead to future collaboration, and hence, cooperation partners.

Figure 28 again summarises the workshop content and deliverables of this process stage.

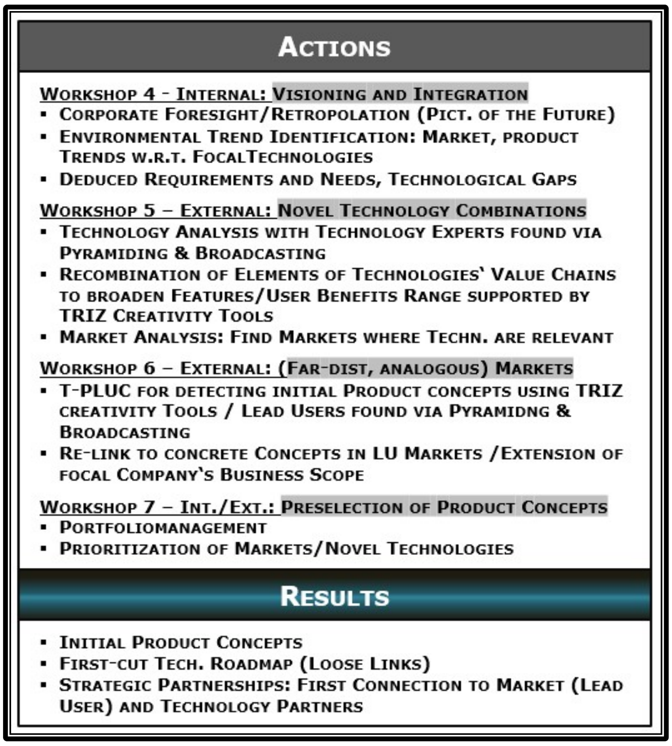


Figure 28: Actions and Results of Process Phase 1

3.4 Phase 2: Potential Product Concepts

Starting point are initial product concepts with underlying, inherent, and likely feasible technological systems: These are evaluated in the following process phase on their factual feasibility followed by an enhancement of the prevalent technical system's most critical parameters through a procedure which targets the increase of the parameters' robustness and the technological maturity of the whole technical system as well. Finally, these superior and robust concepts are passed to the next design phase[35] of a product program.

The present process phase aims to profit from linking invention (TRIZ) and optimisation (AI): TRIZ enhances creative processes with systematics to broaden the conceptual solution space. AI models enhance TRIZ to allow to address even more complex problems and to further extend the solution space and optimise the problem space by redesigning the prevailing technical system with regard to its parameters and construction, based on their impact on the overall system and solution of triggered simulation runs. Optimisation typically leads to incremental innovations, which is why it is applied in the present

[35] Dependent on the level of maturity and grade of parameter robustness the technical system of a novel technology has reached during the presented approach, further, more detailed design can be indicated before the technique is proceeded to the embodiment phase of the product program.

context for optimising the technical system *in the direction of an IFR* and to get technologically feasible and superior innovations with robust parameters.

Borrowing synergetic elements of prescriptive AI models and TRIZ methods from Cavallucci's (2011) *Inventive Design Method (IDM),*[36] which is designed to break up limitations of the TRIZ framework, more complex and broadly diversified problems can be addressed through the use of optimisation models. These affect the stage of solution concept generation. In addition, AI can be used to reframe and revise the inventive problem formulation by semantic search or inventive ontology-based problem-solving (Estrada-Contreras et al., 2014; Yan et al., 2014) when TRIZ knowledge silos need to be surmounted.

(I) AI Optimisation at the Stage of Solution Concept[37] Generation

By exploring the system behaviour under parameter variation through simulation runs based on an optimisation model, which helps to identify relevant parameters of the model and consequently leads to a better choice of contradictions to be solved. The systematic approach of parameter variation and the subsequent procedure to eliminate non-feasible solution concepts triggers a broadening of the solution space and a concretisation of the problem space. This increases the total number of solution concepts found as well as the quality of the resulting solution concepts set, which subsequently enhances the likelihood of an accordingly higher number of specific solutions (Gruber et al., 2008)[38].

(II) AI-driven Natural Language Processing based on Deep Learning Algorithms at the Stage of Problem Formulation

These methodologies are always applicable where knowledge has to be gathered through semantic search. Estrada-Contreras et al. (2014) developed a semantic web application for AI-supported Substance-Field Analysis (referred to as SuField analysis in the figures) (Rantanen and Domb, 2010) which is combining function-oriented SuField analysis-related ontologies and AI-driven natural language processing to find standard solutions for focal

[36] Focusing on *'[i]nnovative product or service design processes in highly constrained environments',* Blanchard et al. (2017) illustrate how smart industrial design activities can be performed in a strategic manner when the problem formulation already incorporates constraints limiting ideation space and fostering additional reality-check loops.

[37] *Solution concepts* are in some studies referred to as *design concepts* (Chinkatham et al., 2017).

[38] Chinkatham and Cavallucci (2015)discuss how to use AI for a rapid feasibility check at the stage of solution concept selection, but it is not in the scope of this thesis.

problems in a TRIZ-related knowledge depository that stores all stated problems and found solutions. Yan et al.'s (2014) work about finding AI-driven semantic similarities in TRIZ knowledge bases goes in a similar direction. In this thesis, semantic search algorithms are applied in bibliometrics and patent research for the inspection of the initial situation and to shape the problem graph.

These two AI building blocks are integrated in the already presented TRIZ-prism in Figure 17. The TRIZ methodologies most important for the presented approach are highlighted with bold font with no limitations regarding the additional usage of other TRIZ instruments if they fit the context. Figure 29 describes this integrated procedure graphically, whose underlying elements are presented in the following section.

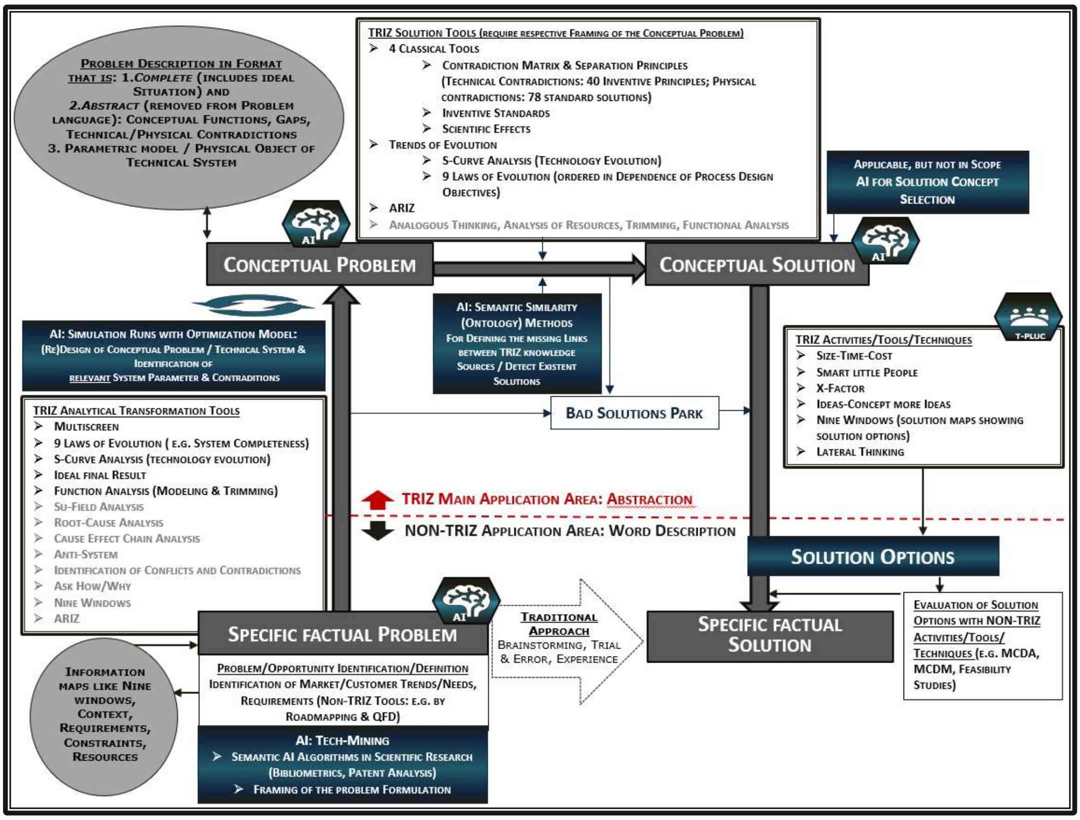


Figure 29: Integrated AI-TRIZ Process (Adapted from Chinkatham et al. (2017) and Ilevbare et al. (2011))

In order to significantly improve the technical system of the conceptual problem in the TRIZ prism, AI-driven simulation-based design tools are combined with creative techniques and other TRIZ concepts as they provide the opportunity to optimise characteristics of the technical design in the virtual space, which blend into the design process and offer traceability. Figure 30 illustrates the linkage between the first four steps of the process, as described in the following section.

Simulation-based design delivers the following advantages:

(1) Increasing the Quality of Resulting Set of Design Concepts
by detecting and preventing unfeasible design concepts from being selected to proceed to the next design phase.

(2) Quantitative Evaluation and Selection of Feasible Design Concepts
Not purely gut-feeling-dependent but also data-driven due to parametric model and the analysis of information of impacts of parameter settings on the whole system.

(3) Changing Roles of Parameters (Action vs Evaluation Parameters[39]) to Create Other Contradiction Sets in order to Extend Solution Space
Through a permutation of parameter constellation and their roles and subsequent measurements of the influence of this change on the system architecture, rather robust technical systems can be identified.

In this context, TRIZ uses AI for the following:

AI-driven Optimisation of Technical and Physical Contradictions
Evaluation and prioritisation of the most effective contradictions and poly-contradiction representation of the technical system, while the primary objective of the design concept flows into the optimisation.

The problem formulation is broader compared to the classic TRIZ method, and the flexible role of parameters increases the design freedom and augments it to another knowledge domain.

Simulation-based design uses *Multidisciplinary Design-Analysis and Optimisation* (MDAO) (Chinkatham et al., 2017, p. 192) which allows to the incorporation of dynamic system behaviour and the consideration of structural components requiring, in particular—apart from an appropriate database—a sufficiently specific framing of the problem and its underlying contradictions. This requirement is not met in many TRIZ application fields, especially in the non-technical ones like management where the framing is too vague for the application of numerical methods. In order to converge to a problem formulation design that is applicable to at least a broad range of application fields and solvable through quantitative models, Dubois et al. (2009) deliver a

[39] For a detailed description of the computer-aided design process and related variable descriptions, kindly refer to Chinkatham et al. (2017).

revision of the definition of technical and physical contradictions, subsumed under *Generalised System of Contradictions (GSC)* (Lin et al., 2017, p. 152).

In general, optimisation algorithms find optimal solutions to a stated problem based on profound mathematical theories without any creative input, but their solution space is restricted to the a priori defined problem space which makes them less applicable to inventive problem-solving, and which requires *'[a] common representation model of a design problem […] to enable shifting from optimization representation models to inventive models.'* offered by Lin et al. (2017, p. 159) who also deliver a proposal for defining and filtering *relevant* contradictions by combining TRIZ methods with optimisation theory and *pareto principles* (Collette and Siarry, 2013)*,* since an appropriate choice and sequence of contradictions imperatively influences the solution space.

Chinkatham et al. (2017) add another guide for using optimisation models for the redesign of a technical system affecting the stage of problem formulation through the approach of simulation-based design revealing design parameters' impact, interrelation based on correlation metrics and action, and hence, increasing the likelihood of revision and improvement of the specification of contradictions.

- **Workshop 8—External: Feasible, Robust, and Superior Novel Technologies** (Focal collaboration group: innovation project working team, technology experts, TRIZ and AI experts)

A preliminary set of initial product concepts and pre-superior novel technologies has already been assessed with regard to the likelihood of technical feasibility and market and business parameters. Hence, the development of factual and feasible technological systems with a superior degree of robustness (relative to each other or other technologies) is now in focus.

For each initial product concept, the methodology described in the following section is applied.

The process of the workshop involves the following steps:

(1) The analysis of the initial situation, resulting in the **problem formulation, which is primarily not customer-centric and includes context, constraints, requirements, and trends of different domains**. If helpful, AI algorithms are used for semantic search, roadmapping approaches, or latest developments in *Quality Function Development (QFD)* methodologies focusing on performance-related efficiency and *ergonomic* *design* (Marsot, 2005, p. 185), i.e. *'[d]o the job harmlessly, effortlessly, and comfortably'* and combine them with traditional creative approaches (e.g. brainstorming, design matrix) to design concepts that have common objectives but (slightly) different characteristics.

The identification of certain trends through bibliometrics, patent research, or any text-driven analysis can be supported by AI-driven semantic search algorithms like *tech-mining* (Porter and Cunningham, 2004)—coining text mining and its technology-driven aspect—which attracts increasing global interest, also perceptible in constantly upwards adjusted global investments in natural language processing (Appendix Figure 53). Tech-mining is based on natural language processing, computational linguistics, and *Knowledge Discovery in Databases (KDD)*" (Porter and Cunningham, 2004, p. 24) and has an exploitative as well as explorative character as it aims to find common patterns in major R&D research activities while detecting atypical juxtapositions in research discoveries and unprecedented tools and approaches to deduce technological and other trends by *'[d]iscovering the context of ideas, innovators, and institutions'* (Porter and Cunningham, 2004, p. 23). Porter and Cunningham (2004) suggest an effective three-step tech-mining problem-solving process comprising three phases: (a) *intelligence,* addressing the systematics to find apt mining source, to establish respective intelligent text queries and to collect, analyse, and clean data; (b) *design*, relating to the systematic enactment of a model framework using algorithms for extracting information, and thus, knowledge from the cleaned data with regard to its problem-solving capabilities and fit to the present problem; and (c) *choice,* referring to the establishment of key criteria and metrics, and the derived subsequent mapping of the most valid knowledge to the focal organisation's business scope.

The quality of the problem formulation is crucially dependent on the expert knowledge of the design teams, which should comprise experts for AI as well, and hence, can trigger the necessity to strategically network or partner with either an external company if AI is beyond the scope of the focal firm's core competences. This affects SMEs significantly more than large organisations, as the latter have *complementary assets*—human, financial, or other resources—to establish the required knowledge inhouse (Ceccagnoli and Rothaermel, 2008). What needs to be accounted for with regard to problem definitions is that linguistic imprecision arises even at the beginning of a design process as all problem-related elements like goals, features, constraints, or customer preferences are formulated by individuals not sharing the same language. Therefore, the development of a unique terminology and its transformation into the abstract formulation in engineering language are indispensable.

The information of preceding analysis flows into the detection of:

- **Problem graph containing all problems and their partial solutions**
- **Parameter set triggering contradictions**
- **Poly-contradiction representation of the technical system** (incorporated in physical object or exhibiting a simulation model)

(2) Definition of the *'[e]volution hypothesis of the future technical system'* (Chinkatham et al., 2017, p. 196) according to identified customer preferences, technical and other requirements or constraints by using TRIZ concepts—in particular *multiscreen* for tracking the effect on design parameters at transition from the current to the future system—the *system completeness law* as one of the objective laws, and the whole *nine laws of evolution* (Gadd, 2011; Zouaoua et al., 2015) (Appendix Figure 45) including the specification of design parameters (control variables, inputs, outputs).

Cavallucci and Rousselot (2011) map the *Laws of Engineering System Evolution (LESE)* (Cavallucci and Rousselot, 2011, p. 484) to the identified relevant system parameters or their contradictions as the evolution hypothesis *'[i]s the logical interpretation of observed facts from the current system to portray the specific characteristics of the future system'* (Chinkatham et al., 2017, p. 190).

- **Evolution hypothesis according to problem specifications**
- **Design parameters**

(3) Exploring the Behaviour of the System with Simulation-Optimisation Trial Runs to gather Information: Approximate definition of an optimisation model under soft constraints and loose boundaries for the design variables, where the main objective of the design approach flows into the optimisation model, and subsequent data collection via trial runs of the optimisation model relating to experiment-based or model-based scenario analysis.

To gather data, trial runs are performed—if available, on the physical object or a parametric model for the technical system. In case of the latter, the underlying optimisation model depends on the fundamental problem of dynamics, structure, and properties and is performed with CAD/CAE tools.

- **Information from trial runs about system behaviour**

(4) Choice of Parameters according to the Impact of their Interaction on the Whole System Architecture based on Correlation Measurement between Design Parameters

Applying statistical methods (e.g. Pearson correlation matrix, t-Student) on the collected information from the simulation runs reveals parameters with stronger influence than others. These most influential parameters are prioritised and first examined but need not necessarily be in the final parameter set, since the parameter selection is performed in dependence with the determined evolution laws, the scenarios, and the design project's objectives, which are directly related to the product concepts. These factors can change the set of parameters to include not only the most influential ones. The fit to the preselected product concepts is important to ensure that the final product-technology concepts resemble a strong market, i.e. customer view, and a strong technology view.

- **Set of important parameters (starting with the most influential ones)**

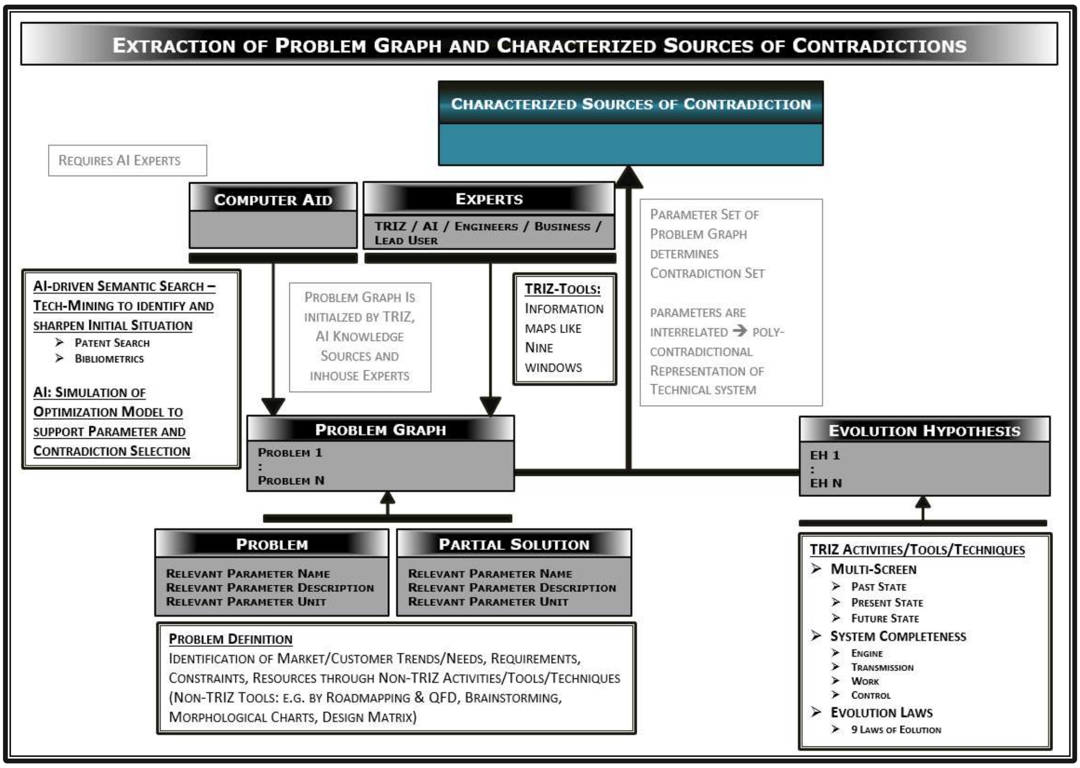


Figure 30: Extraction of Problem Graph and Characterised Sources of Contradictions, Modified from Chinkatham et al. (2017)

(5) Synthesising New Solution Concepts

Model-related contradictions of this parameter subset are evaluated in terms of the evolution laws of the second step of this process, which are then solved with the TRIZ instruments of *S-curve*, *contradiction matrix,* and *inventive principles* (Gadd, 2011) to generate new solutions for the present problem. In this context, Cavallucci et al. (2011) present a poly-contradiction representation of the technical system and an evaluation criterion for filtering the most effective contradictions by choosing contradictions according to laws while ordering laws with respect to the design objectives. Room for improvement in theoretical approaches, according to Cavallucci and Rousselot (2011) in alignment with Altshuller, regarding the determination of the current and future maturity of technologies, i.e. their position on the technology S-curve, exhibiting a huge impact on the concept but respective forecast, is still hard to fill due to a lack in efficient methodologies. Cavallucci and Rousselot's (2011) empirical studies support the aforementioned advantages and drawbacks of the TRIZ approach by highlighting its capability to decrease the development time of innovative products and increasing the respective total number of inventions, while at the same time presupposing a design team with a highly-specialised skillset. A requirement, which the proposed framework aims to address by explicitly bringing TRIZ and AI experts on board of the workshops to increase the success probability of the project.

- **Conceptual Product Concepts Incorporating Viable, Robust, and Most Promising Technology Concepts**

This set of solution concepts is ready to be passed on to the succeeding design stage—*specific design and embodiment* (Chinkatham et al., 2017).

- **Workshop 9—External: Potential Product Concepts**
  (Focal collaboration group: innovation project working team, technology experts, TRIZ experts, lead users)

The solution concepts found in the preceding workshop need to be incorporated into real solution concepts, i.e. potential product concepts. This is done with the help of TRIZ experts, who steer the creative process, and the involvement of lead users who are again invited to participate in the collaboration. At this stage, primarily TRIZ creativity techniques like 'smart little people', 'thinking in time and scale', 'bad solutions park', or 'size-time-cost' come into force (Appendix Figure 47 provides an overview of techniques), where Gadd (2011) recommends organising the tools in a circle rather than a list to give the efficiency of the process an extra boost (Appendix Figure 48). After specific solutions options are identified, they are evaluated via further feasibility studies, *Multiple-Criteria Decision Analysis (MCDA)* (Jahan et al., 2016) *or Multi-Criteria Decision Making (MCDM)* (Kumar et al., 2017), which support the selection of technical substances in product design.

- **Potential Product Concepts Incorporating Viable, Robust, and Most Promising Technology Concepts**

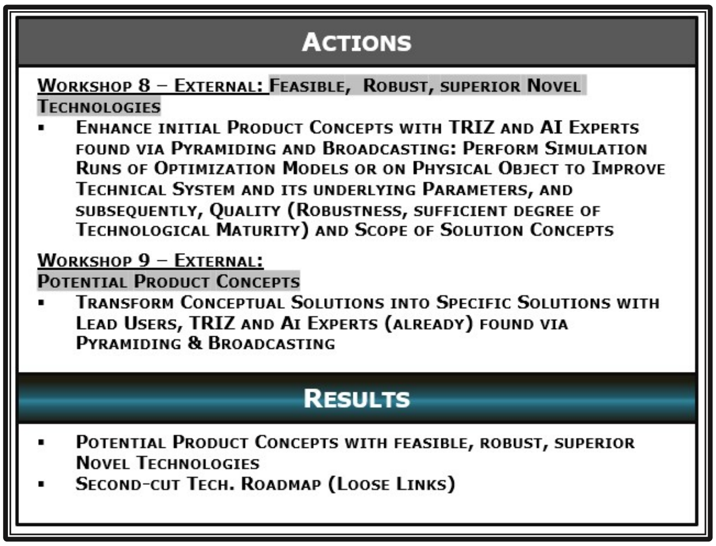


Figure 31: Actions and Results of Process Phase 2

In the next process phase, novel technologies and the related product concepts are prioritised with regard to attractive strategic partnerships with companies collected so far within the process.

3.5 Phase 3: Final Product Concepts and Strategic Partnerships

Results of the previous process phase are product concepts, which have a strong implicit technological system and have already successfully passed a filtering in Phase 1 in terms of most promising markets and technology indicators, and probability of technological feasibility. At that point, the filter process is a weak one, focusing solely on concepts that are absolutely unsuitable for the market, technologically unready, or exhibiting high failure risk.

- **Workshop 10—Internal: Prioritisation of Feasible, Robust, Superior, and Novel Technologies and Strategic Partnerships**
  (Focus collaboration group: innovation project steering committee, innovation project working team, high-level management)

At the present stage, filtering is about determining which of the found technologies can become the (new) core technology, which complementary technologies can be sourced from external companies, and which of these technologies offer the most promising technological, financial, and market-related partnership.

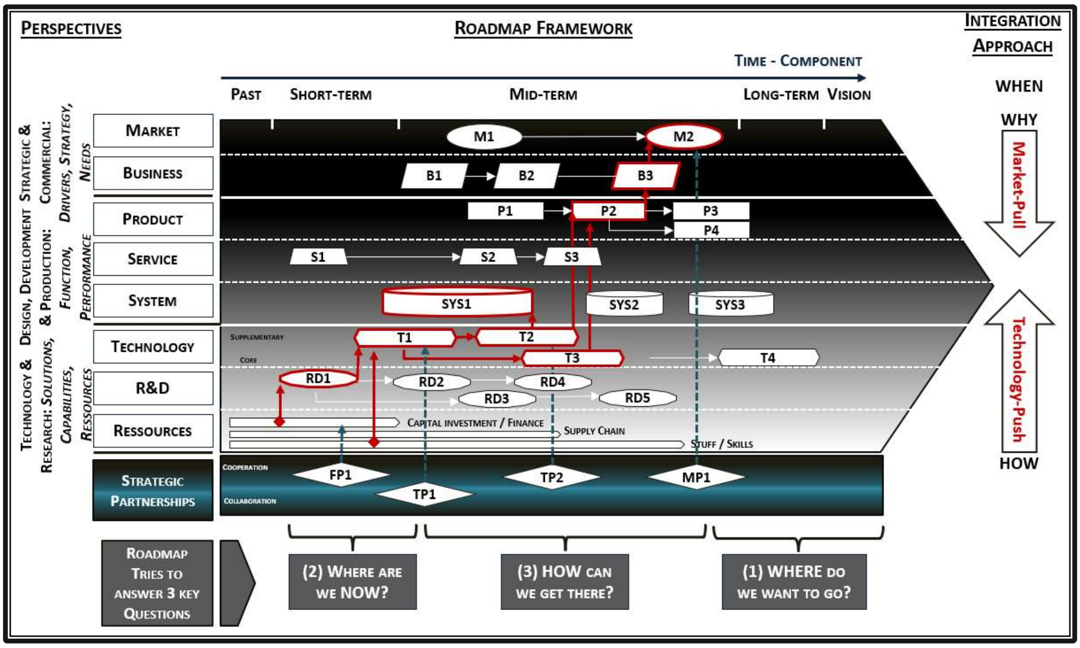


Figure 32: Multi-layer Roadmap Framework Adapted from Phaal and Muller (2009) Supplemented by the Additional Layer of Strategic Partnerships According to Caetano and Amaral (2011)

If the set of use cases for the novel technologies is too broad, the company needs to prioritise all options at its disposal. Caetano and Amaral (2011) propose a ranking of the technologies with regard to their strength of relation to the core competencies of the focal organisation, to detect the core and supplementary technologies, which can then be developed with external companies in the form of *collaboration* or *cooperation* (Caetano and Amaral, 2011, p.322). Borrowing the prioritisation criteria for strategic partnerships from Caetano and Amaral (2011), for every potential partnership of a novel technology criteria are determined, such as *'[c]onfidence, non-competing goals, technological expertise, experience in collaboration, innovation expertise, familiarity in terms of reputation an friendship, honesty, motivation and interest in the partnership, and cultural compatibility'* (Caetano and Amaral, 2011, p. 329). These are ranked using a five-point Likert scale (from 1 least qualified (worst) to 5 most qualified (best)) or—for improvement with regard to exploit of research potential—metric (continuous) rating scales (Treibmaier and Filzmoser, 2009) are recommended. This is done by either the innovation project team or a newly formed decision team involving people from higher hierarchy levels. Subsequently, the average over all criteria are calculated. A similar procedure holds for technology-related financial partners, for which all criteria of technological partners are assessed, except *technological expertise,* which is substituted by *capacity to pay*. By listing all technologies and financial partners, a ranking can be assessed, where the identified core technology is that with the highest grade, i.e. the best fit to the Company's prevailing core competencies or characteristics, which naturally stands out during the sorting[40].

As the last action, the first firm links between respective layers of the first steps are enacted across the roadmaps of all affected divisions and cross-validated through all business domains and their respective purposes. The appropriate final technology roadmap is ready to be presented to the CEO, who has ultimate power of decision before concrete steps of the next two phases are initiated—phase 4: the enactment of strategic and feasible technology development or acquisition plans and the assignment of respective resources, and the final phase: implementation of technologies – both phases are not in the scope of this thesis.

Review and periodic update of the technological roadmap is indispensable for *living t*echnological innovation and to adapt the technological innovation strategy to changing business environments.

3.6 Web- or VR-based Collaboration

As already suggested in Chapter 2.1.4, improvements in information technologies like virtualisation in cloud computing and global enhancements in bandwidth *(*Newman et al., 2016, p. 593) have triggered the so-called social Web 2.0 referring to linking people online to one another or to interest groups. According to Newman et al. (2016), the next generation of the social web—Web 3.0—will integrate the emerged technologies of *'[C]loud computing, Big Data, Internet of Things and security'* (Newman et al., 2016, p. 591) into existing web features and is already on its way to disrupt again the world's future communication. The *Open CAI 2.0 framework* of Hüsig and Kohn (2011) is emerging from Web 2.0, and the*"[s]trategic paradigm shift from closed to open innovation"* (Lopez Flores et al., 2017, p. 211) (discussed in Chapter 2.1.4) and

[40] An alternative would be to build a weighted average, assigning technologies the most, technology partners the second-highest, and financial partners the least weight.

interlinks TRIZ theory and *Case-Based Reasoning* (CBR)[41]. This technology can be adapted accordingly for the collaboration within the examined process framework, triggering the enactment of an *Enterprise 2.0* (Ferron et al., 2011), where web-platform-supported coordination and networking of employees increase the innovation level and work efficiency within a company.

In the roadmap, collaboration and cooperation partner are explicitly stated inn an additional layer, and resources can be applied with regards which communication technology is used.

3.7 Key Innovation Performance Measures

In the final step, the innovation project steering committee needs to find criteria to make the success and knowledge gain from an open innovation project tangible and projects comparable to each other.

Taheri et al. (2017) deliver a contribution to inventive design performance analysis, resulting in the enactment of three key indicators of inventive performance and respective preconditions for application:

(I) ***Inventive Effectiveness*** is *'[t]he capability of realizing design intent according to what has been imagined or intended'* (Taheri et al., 2017, p. 138), i.e. the fit of the innovation outcome in terms of output knowledge (O) with project goals (G), described by

Equation 1:

$$\Pi(\Psi i): O_i == G_i$$

where

Ψi: knowledge processing by design activity i
$\Pi(\Psi i)$: effectiveness value (Π) of design activity i
$O_i == G_i$: output and goal comparison of design activity i

(II) ***Inventive Efficiency*** in this context refers to *'[t]he useful work of activities results in knowledge gain (K^+) by using required resources (R) in performing the activities'* (Taheri et al., 2017, p. 143), described by

Equation 2:

$$\eta(\Psi i) = \frac{K_i^+}{R_i}$$

where

[41] For an exhaustive literature research with regard to academic developments in the field of TRIZ and *Computer-Aided Innovation (CAI)* like data mining or functional analysis, kindly refer to (Lopez Flores et al., 2017, pp. 219–220).

$\eta(\Psi i)$: efficiency value (η) of design activity i
K_i^+: knowledge gain by design activity i
R_i: resources used by design activity i,

and

(III) ***Inventive Pertinence*** is *'[looking] for recognizing the resources [qualified for supporting creativity and/or inventive activities] in consonance with achieving project goals'* (Taheri et al., 2017, p. 146) described by the *'pertinence value of resource used y for design activity i'*

Equation 3:

$$P_{R_y}(\Psi i)$$

Nilsson et al. (2012) provide another approach by contrasting radical and incremental innovations and the respective influence of dichotomy dimensions—namely uncertainty, time, flexibility, and control—on innovation performance measurement.

The provision of concepts for the performance measurement of a technological innovation project completes the development of the process framework.

Figure 33 illustrates the whole proposed four-phase process framework including workshops, respective actions, and results of each phase, and highlights where subprocesses of the presented tools can be applied in the roadmap framework.

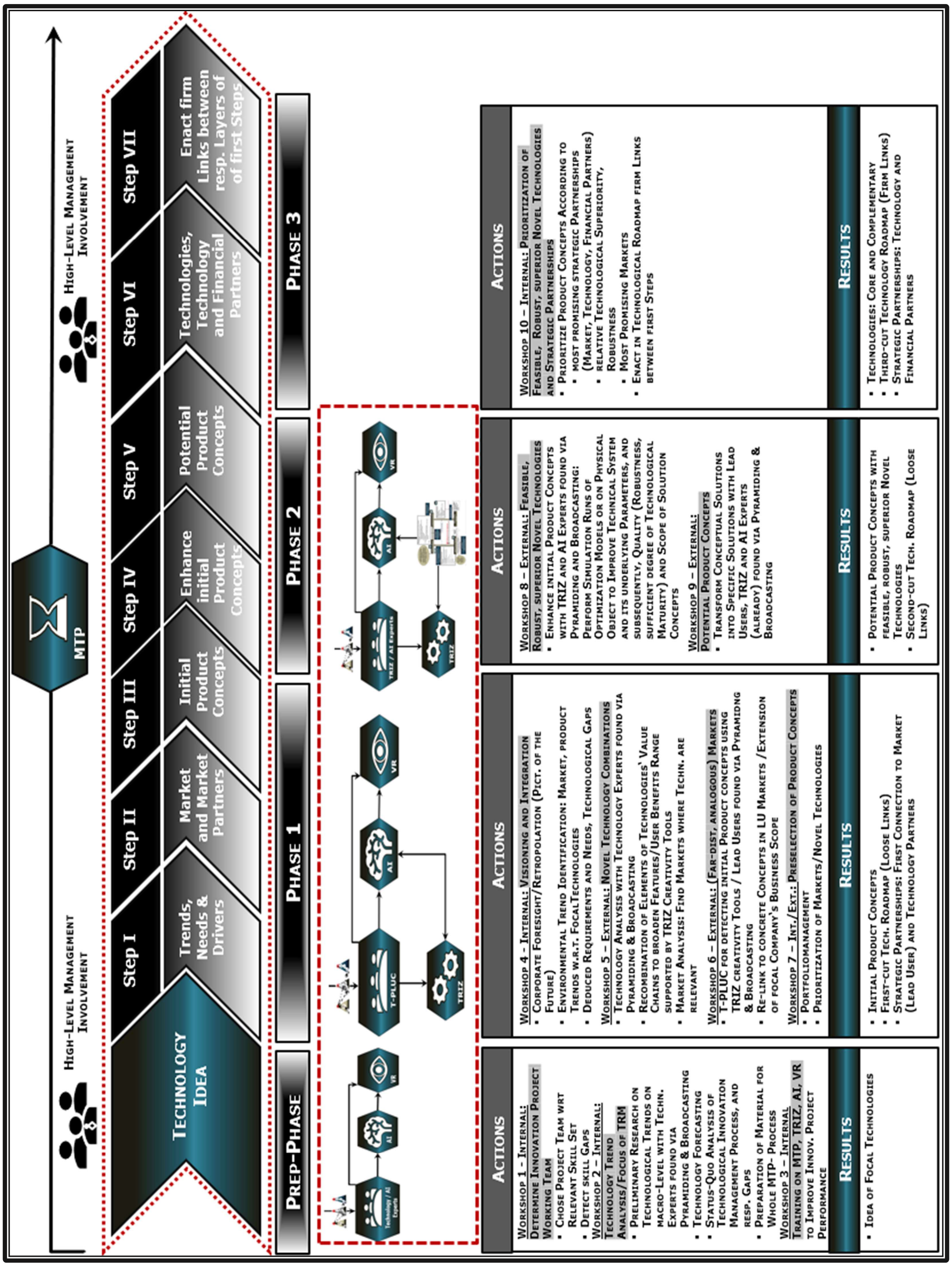


Figure 33: Detailed Process Framework with Actions, Workshops and Results (Modified from Caetano and Amaral (2011) and Daim and Oliver (2008))

4 CONCLUDING REMARKS

This chapter concludes the thesis with Chapter 4.1 which highlights the key components of the presented process framework while Chapter 4.2 presents recommendations for future research deducted from the framework's implicit limitations.

4.1 Synopsis

This thesis contributes to the research on technological innovation management regarding new product development by presenting a process framework that aims to facilitate the identification of inventions with high disruption potential by providing a holistic picture of future customer needs and technological capabilities. It addresses critical innovation-related issues by incorporating the beneficial elements of investigated methods and attempts to remove persistent deficits found within these theoretical concepts through integration into a coherent procedural strategy. The core elements of the process framework are summarised in the following:

- **Strong Focus on Increasing the Systematics in the Individual Approaches and the Holistic Framework:** Empirical studies of comparative research on systematic vs non-systematic approaches—e.g. TRIZ vs brainstorming (Gadd, 2011)—show a clear preference for the former for inclusion in the framework. Even creative thinking processes are supported by TRIZ's creativity tools to overcome psychological inertia. In addition, AI is used for an increased systematic evaluation of contradictions in the scope of a TRIZ environment leading to more robust and mature novel technologies.
- **Synthesis of Technology-Push and Market-Pull Product Integration Strategies:** Technologies are considered to be key resources and innovation drivers of companies, which is why they are given an exceptional leading role in this thesis. Despite focusing exclusively on technology-push concepts for determining market opportunities, the tight and early integration of lead users as exceptional market-knowledge carriers in the process of idea and initial product concept generation and prioritisation aims to balance the strong technology-push orientation of the present methodologies with the voice of market.
- **Concepts for the Classification of Technologies and the Evolution of Pathways of Technological Systems:** The presented definition of technologies as bundles of value chains, related classification based on the

interaction of technologies and the evolution of pathways of these technologies' relationship allow a conceptual and strategic approach for designing the integration of technologies in order to create new technologies with new features customized for future users.

- **Promising Technologies First, Organisational Fit Next:** Brandkamp (2013, p. 15) criticises the evaluation models presented in the literature. Instead of the actual evaluation of technologies based on their characteristics, these models concentrate on their fit into the company's corporate strategy. In order to avoid a too early restriction of the range of identified novel technologies because of their misfit to the current organisational structure, this thesis gives the corporate structure a subordinate role by letting the future customer have a strong voice in the decision-making process, even in the development of product concepts and subsequent selection. The focus is explicitly on the discovery of new fields of application, whose high innovation potential is assumed to justify the transformation or expansion of a company structure.
- **Exceptional Focus on Experts:** The obvious extensive involvement of highly skilled experts from all domains relevant to the methods applied in the course of the process is intended to overcome obstacles for adoption—i.e. the results from user feedback in empirical studies mentioned in previous chapters—and to exploit the capabilities of the individual tools to their maximum extent. The latter is important because there is an empirically examined tendency for technologies to be used only to a limited extent due to unawareness about their application.
- **Preceding Trainings on Methodologies:** Following the experiences of Daim and Oliver (2008), upfront inhouse training sessions on the required methodological approaches—to accelerate the knowledge transfer in the collaboration process and build awareness of the specifics of the applied methods—tend to increase the likelihood of success of the innovation project. Additional TRIZ training workshops with lead users are recommended.
- **Strong Focus on Collaboration and Cooperation Partner Identification: :** In light of Satell's (2016a, 2016b) claim for the necessity of a network of professional excellence, the identification of strong collaboration partners—be it current or future technological, financial, or market partners—and giving promising partnerships an important stake in the final prioritisation of novel technologies and related product concepts comprise a core element of the framework.

- **Constellation of Focus Collaboration Groups:** The importance of this group for the success of the innovation project is undermined and proposals for the structure of the collaboration groups in each workshop are offered, always presupposing that non-technical people are included (Fan, 2011). The creation of this group of motivated, skilled people is an art per se, according to related literature (Gabriel et al., 2017; Lopez Flores et al., 2017).
- **Efficient Search Strategy:** In this thesis used and originally intended for the strategic detection of lead users, is the sequential pyramiding-broadcasting approach of Keinz and Prügl (2010), which is also applied for the identification of any other highly-skilled experts within the framework.
- **Prioritization Steps at Different Stages of the Framework:** In order to provide the user guidance in open questions regarding the prioritization of technologies, markets and investments, respective suggestions relating to applicable approaches have always been provided in the affected steps.
- **Cross-divisional Alignment of Requirements Triggered by Novel Technologies through Roadmap Approach:** The roadmapping approach is used in order to bring a time component into the process and to avoid misfits between the implementation requirements of novel technologies and business strategy, IT landscape or alike to increase their applicability.
- **Collaboration in the Era of Web 2.0 and the Virtual World:** Inspired by the achievements in the mobile and virtual communication and information system sector and to account for people's increased mobility and graphical dispersion, the framework aims to benefit from innovations with web-based platforms that can break up the *opaque, permeable boundaries* (Chapter 1.2) between dispersed knowledge at its core. Although the individual techniques are not discussed in detail because their adoption depends on the prevailing structure of the focal company, trends indicate that these technologies are the backbone of future communication.
- **Metrics for Assessing Project Performance:** For the sake of completeness, a method for creating key indicators to assess and compare innovation project performances is proposed.

These components are esteemed to have an essential stake for the success of a technological innovation project and have been discussed in the course of the development of the process framework.

4.2 Limitations and Recommendations

The paper remains on a conceptual and explanatory level wherefore empirical investigation is strongly indicated to shed light on its de facto usability and feasibility.

Regarding its implicit limitations, the critical points of used methodologies, factors that can have a crucial impact on the implementation of the framework, and the success of the technological innovation project are discussed in the following section and complemented by recommendations, which shall lead the way to further research[42]:

- **Feasibility of Integration of Used Approaches:** Although only those methodologies have been used for which the literature already has empirical evidence or has been indicating a high likelihood of feasible integration, the final proof needs to be acquired by implementing the process framework in different organisational structures and performing real-world field studies. An upfront enactment of organisation-type-specific and organisation-type-transcending indicators will allow the assessment of consistent comparisons within and across company clusters relating to the organisational structure and size of the companies.
- **Enabling Factors for Open Innovation in General and the Implementation of the Framework in particular:** Obstacles that can hinder knowledge transfer within the framework process relate—without claim to completeness—to organisational, cultural, or purely human-related barriers. Referring to the later, Henkel and Jung (2009) hypothesise that the more disruptive and financially promising are the product concepts, the more likely it is that people would not reveal all their knowledge. In the following section, hurdles relating to organisational structure and cultural misfits are addressed.
    - **Designing the Structure of the Organisation for Open Innovation in general and User Innovation in particular:** Dependent on the focal firm, SMEs—which are typically already absorbing technology and market information from external sources—and large corporations can both experience the need to adapt their organisational structure to embrace and foster open innovation and profit from the ignited creativity.

[42] Some topics have already been touched in the course of the development of the framework.

Relating to *open innovation in general*, the transformation of the relevant organisational structure into an *ambidextrous organisation* (Alpkan and Gemici, 2016; Kitapçi and Çelik, 2014) is indicated. This does not affect only large corporations; SMEs in not purely scalable businesses can be affected too, as once a certain customer base is established, these customers need to be served. Therefore, depending on the size of the company, no resources can be spared for further innovation. This organisational form not only gives room for the exploitation of existing businesses but has resources permanently devoted to constantly seeking to source innovation from outside the firm's boundaries, especially to leverage technological competencies to stay competitive and outcompete other market participants in comparable businesses. Structural ambidexterity requires, apart from the existing business unit, an independent unit with its own structure and processes for the emerging business, with full-time project teams embedded in the company's existing hierarchy. This allows a company to react quickly to changing environments, quickly evaluate and grasp or dismiss market opportunities, and get rid of existing businesses that are turning out to be no longer profitable. Depending on the industrial environment and the focal company, the likelihood that the firm would not enjoy the full market potential by allowing smooth solution-search processes is not negligible. Hence, the company might lose its flexibility and innovativeness in the long run. Furthermore, apart from supporting exploitative and explorative excellence, this organisational form allows the sharing of resources like cash, expertise, and customers, to name but few, due to the common managerial level. Further, it exhibits increased efficiency due to the distinct operation of existing and emerging business.

Regarding *user-innovation-triggered organisational restructurings*, Keinz et al. (2012) list the key dimensions of organisational design which are affected by adopting an open innovation approach. They provide organisational design principles for different types of pursuit strategies: searching, harvesting, cooperation, and ecosystem. Lead user involvement requires only the adaptation of human-related elements like *'[w]ork processes, people, coordination and control, and incentive mechanisms […]'* (Keinz et al., 2012, p. 23) in the organisational structure. In contrast thereto, open innovation methodologies like crowdsourcing or toolkits/mass customisation will affect structural dimensions of the required organisation as well, like goals, strategy, and structure. Hienerth et al. (2011) illustrate user-centric business models, among others, with the examples of two large corporations—Lego and IBM— and show how organisational subsystems are affected accordingly. Puranam et al. (2014) consider new forms of organising from a higher and rather problem-solving perspective and contribute to the identification and delimitation of what makes a new organisational form *new,* by referring to novelties in task allocation and reward distribution, information provision, or task division

- **Culture:** As a company's corporate culture, i.e. its pervasive values, beliefs, and attitudes, is the most important enabler or disabler of leveraging technological competence and knowledge. The revision of the focal company's vision and mission statements in the direction of innovation openness alone would be too short-sighted. Therefore, the successive installation of innovation-oriented managers in critical positions to lead by example by supporting an innovation-friendly culture and by enthusing employees—the company's internal market of talents—is an indispensable precondition to foster a perceptible change in the firm's traditional culture, if required. As never before, companies need to focus on offering appealing jobs—both content- and environment-wise—to attract talents with relevant education and professional experience from the external environment. Companies need to bridge or at least mediate the gap in its existing and the upcoming diversity in working styles due to both the employees' generations—with focus on the millennials and generations beyond—and nationalities. This increases the dimension of the construct of the prevailing three cultures—the executive, the engineering, and the operator culture—by another two layers of complexity, with strong impacts on the communication style of knowledge transfer. In this context, Schulz et al. (2000) propose permanently installed integrated teams from both product and technology development, addressing technology development and technology transfer for constant and efficient knowledge exchange.

  This enthusiasm-sparking environment, with the aim of extending the *internal market of talents,* is recommended to be complemented by the parallel establishment of *an internal market for ideas* through an in-house ideation platform and guidelines for open innovation processes, together with a strategic but low-bureaucratic approach to assess and screen success-promising ideas based on their financial and non-financial value and their risk-exposures, but in a rather entrepreneurial way, by acting with reason *and* risk affinity at the same time in case of high potential future value of the innovation. From another, higher-level perspective, following innovations with anticipated high profits or at least substantial benefits for the company is not necessarily about taking on more risk, but might involve *taking away risks* from the company, which is assumed to be one characteristic of a good manager. According to Sabharwal (2016), this transformation from *stewardship,* focusing on reducing risk and cost-cutting, to *entrepreneurship,* focusing on wealth creation, is based on emerging disruptive technologies—a development which is also welcomed by shareholders, as entrepreneurial heroes seem to have a keen sense of turning current trends into money, and hence, closing the troika of '*brain-heart-wallet*' (Plasonig, 2018) . Stewards conserve, entrepreneurs create.

- **Detection of Inhouse Absorptive Capacity:** An indispensable prerequisite for the evaluation of product concepts in order to grasp the market opportunity potential is the already mentioned *absorptive capacities*—i.e. experts who can solve the problem or evaluate incoming ideas (Chapter 2.1.3). The implementation of an in-house communication platform where every division can formulate problems and search for knowledge sources in-house can be the first strategic step to decrease the level of *hidden knowledge* (Felin and Zenger, 2014), detect *absorptive capacities* for a problem, or find potential *process promoters* (Rost et al., 2007). This tool has two outstandingly convincing advantages, among others: First, to break up information silos within the company, which is relevant for the solution of the stated problem or the evaluation and filtering of insourced ideas, and second, to involve the employees in ongoing innovation processes by increasing the level of communication within the company, a factor that has not only a strong social component by signalling appreciation for in-house human resources according to the motto '*customers, external knowledge keepers, AND employees first*', but also a non-negligible balancing component by decreasing obstacles related to the 'not-invented-here' syndrome and increasing the likelihood of adoption of knowledge from open innovation due to an awakening of the 'proudly-found-somewhere-else' mentality.
- **Limitations of Technology Roadmapping and Other Technology Forecasting Approaches:** Technology roadmaps largely comprise forecasts of technical developments, which also frequently interact with other technical developments. Forecasts are inherently subject to uncertainty, and the saying that '*planning replaces chance with error*' has serious justification.

Therefore, the question of the application limits of technology roadmaps seems appropriate (Moehrle and Isenmann, 2007, p. 9).

- **Technology impact analysis and technology assessment**: The framework uses exceptional methods of technology intelligence, forecasting, and foresight, due to the focus of the thesis, which primarily considers the claim to innovation. Technology-assessment methods that predominantly examine the social consequences and risks of technologies are although mentioned, not described in detail as they are not in the scope of the thesis. These can give additional insights for the final decision.

A company might create a business model, that can serve as competitive weapon by developing innovation skills and agile processes who are unleashing the power of innovation, but finally, if every endeavour has been made, all internal restructurings and ideation tools have been installed, and soft process guidelines enacted, the smallest unit of essential competitive factors in the equation of innovative ideas and future company success is the individual human resource. People on every hierarchical level, who have the anchored prerequisites like a naturally given, slumbering intrapreneurial mindset which can be sparked by inspiring mentors and leaders. People, who have a broad overview and understanding of various, and outstanding expert knowledge of specific disciplines, and who are intrinsically motivated by their work. More than ever managers of a certain species are essential for the company's future success. Managers with not only professional expertise, but leadership skills, social and emotional intelligence, who live innovation by example, and who have the capabilities to form strong collaboration and cooperation networks with globally dispersed SOI.

Companies need to transform towards open innovation to invite people across scientific and business domains to help them recognize the strategic value of currently emerging technologies and to reveal the unprecedent disruptive potential of respective technological inventions. In this context, the proposed process framework attempts to provide a convenient tool for the identification of highly disruptive technological innovations developed based on a holistic approach, that takes advantage of contemporarily emerging new technologies and integrates open innovation-related key components.

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Appendix

Figures

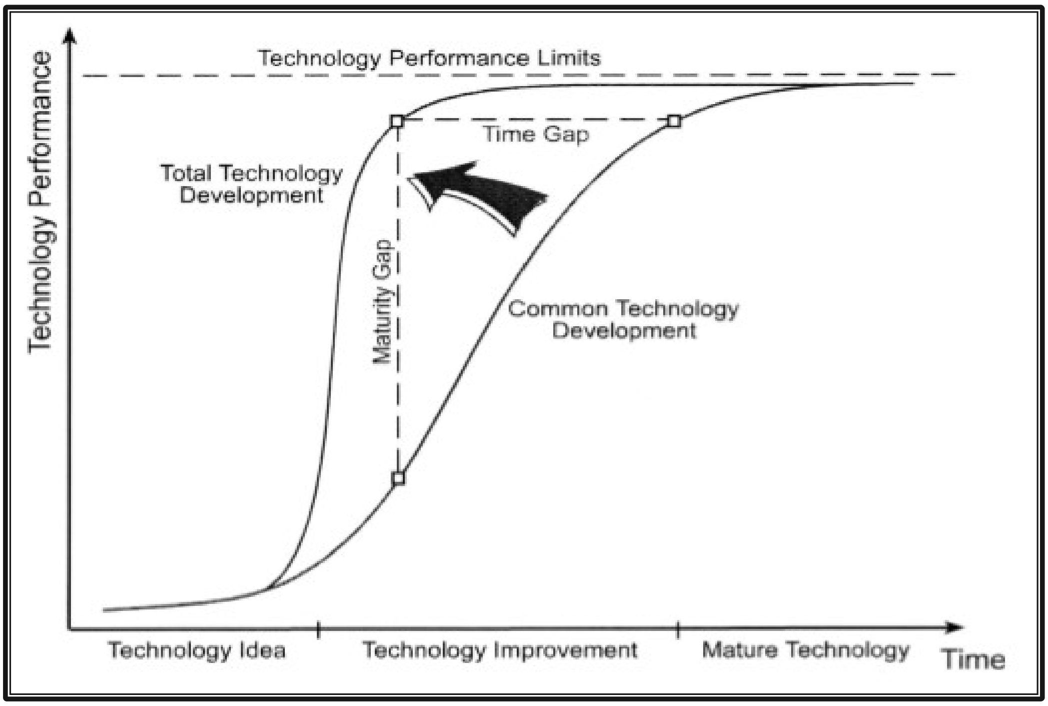


Figure 34: Enhancement of Technology Development (Schulz and Clausing, 1998)

SCIENCE & TECHNOLOGY CONVERGENCE *(S&T)*	
@REALIZATION OF S&T CONVERGENCE: 10 KEY THEORIES	@FACILITATION OF S&T CONVERGENCE: 6 PRINCIPLES FOR CONVERGENCE
1. Unity of Nature Theory 2. Human Interaction Ecosystem Theory 3. Systems adaptive Complexity Theory 4. Economic Growth Theory 5. Specialization Network Theory 6. Reverse Salient Theory 7. Fundamental Integration Principles Theory 8. Progress Asymptote Theory 9. Exogenous Revolution 10. Response to Social Problems Theory	1. Exploiting interdependence among domains in nature and society 2. Improving the convergence-divergence evolutionary cycle 3. System-logic deductive decision making and problem solving 4. Creating and applying high-level cross-domain languages to facilitate transfer of knowledge and novel solutions 5. Confluence of resources for system changes (yielding S-curve of development outcomes vs investments) 6. Using "vision-inspired" basic research to address long-term challenges

Figure 35: Ten Key Theories Supporting the Complex Dynamics of Science and Technology Convergence and Six Principles and Methods Based on the Work of Bainbridge and Roco (2016)

TECHNOLOGY CLASSIFICATION		
ATTRIBUTE	**CHARACTERISTIC**	**DESCRIPTION**
Competition effect	▪ Cost-oriented technologies ▪ Differentiation-oriented technologies ▪ Business renewal-oriented technologies	One and the same technology in different application areas can have a different meaning and result in different competitive effects.
Competitive potential	▪ Pacemaker technologies ▪ Key technologies ▪ Basic technologies ▪ Saturation technology	Depending on its phase in technology development, the potential of the technology regarding its competitive relevance is considered.
Application range	▪ Longitudinal technologies ▪ Cross-sectional technologies ▪ System technologies	This describes the range of possible applications
Complexity	▪ Complex (interdisciplinary) technologies ▪ Simplex / Simple technologies	The degree of difficulty is determined by considering the amount of scientific and technical knowledge for technology development.
Developmental stage	▪ science lines ▪ technology approaches ▪ component technologies ▪ system technologies	The development stage marks the maturity of technologies regarding their application.

Figure 36: Technology Differentiation: Attributes and Characteristics (Spur, 1998, Pfeiffer, 1992; Cited by Kröll, 2007, p. 27)

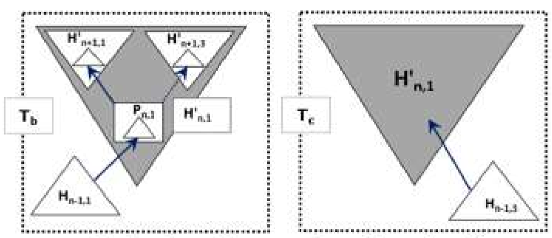
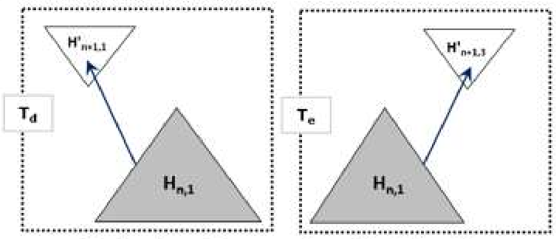
	QUASI-STATIC INTERACTIONS DUE TO OVERLAP		
GRADE	**TYPOLOGY**	**SHORT NOTION**	**VALUE CHAINS**
1	**Technological competition**	**T1: - T2: -**	▪ **For common markets:**  Technology T_b competes with T_c for $H'_{n,1}$ ▪ **For common resources:**  Technology T_d competes with T_e for $H_{n,1}$

Figure 37: Illustration of Technological Competition According to Sandén and Hillman (2011)

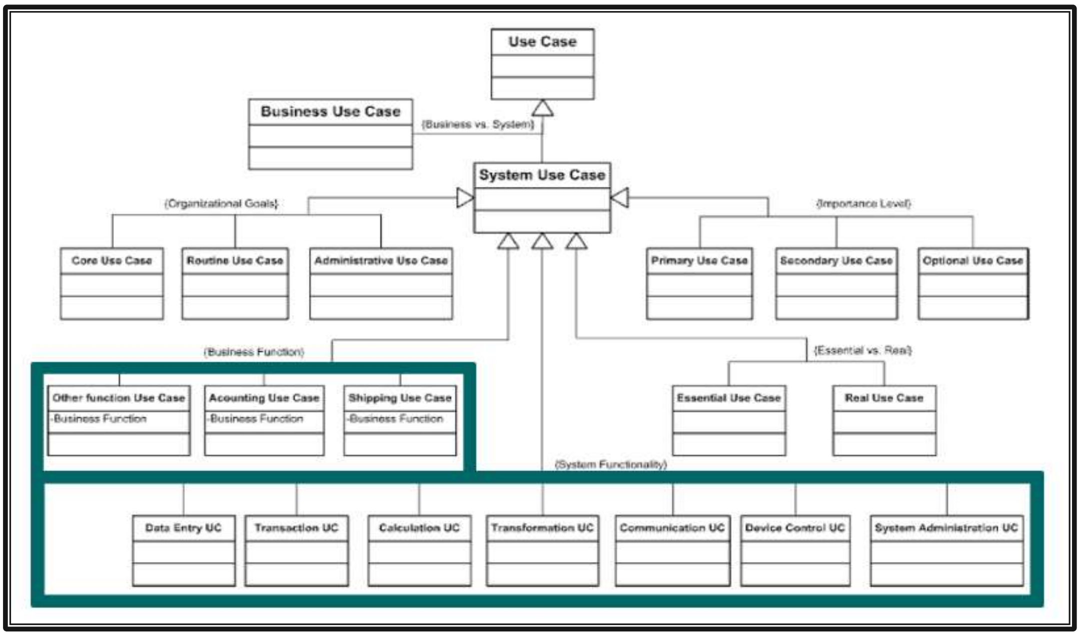


Figure 38: Goldman and Song's (2005) Class Diagram Representation of Taxonomy of Use Case Classification Schemes and Focus of Thesis

MODEL SUMMARY	**DEPENDENT VARIABLES**		
INDEPENDENT VARIABLES	**Market Opportunity Count** (prior to initial entry) ***Negative binomial model***	**Market Opportunity Variety** (prior to initial entry) ***Tobit model***	**Likelihood of Diversification within next 5 Years** (after initial entry) ***Probit model***
CORE VARIABLES			
Team Industry Experience	Significant @ *	Significant @ † and *	Not significant
External Knowledge Sourcing Relationships	**Significant @ *****	Significant @ *	Not significant
Team Technological Experience	Not significant	**Significant @ *****	Not significant
Team Size	Significant @ † and *	Significant @ † and *	Not significant
Entrepreneurial Experience	Significant @ * and **	Not significant	Significant @ *
Marketing Experience	***Negative Impact*** **Significant @ * and ****	Not significant	***Negative Impact*** **Significant @ *****
Aspirations	Significant @ †,* and **	Not significant	
Seed Funding prior to Market Entry	Not significant	Not significant	Significant @ **
Generality of Technology	Significant @ ***	Significant @ † and *	
Inverse Mills Ratio (Selection Correction)	*Negative Impact* Significant @ ** and ***	Not significant	*Negative Impact* Significant @ **
Time since Entry [months]	Not significant	Not significant	Significant @ † and *
	-	-	
Market Opportunity Count (prior to initial entry)	-	-	Significant @ *
Market Opportunity Variety - linear(prior to initial entry)	-	-	Both variables significant @ * only if used together in one model ➔ indication for inverted U-shaped relationship
Market Opportunity Variety-squared (prior to initial entry)	-	-	

†p<0.10, *p<0.05, **p<0.01, ***p<0.001 (two-tailed tests)

Figure 39: Summary of Models for the Three Dependent Variables *Market Opportunity Count*, *Market Opportunity Variety,* and *Likelihood of Diversification within next Five Years*—Focusing Solely on *Significant* Inputs for These Targets[43] Based on the Work of Gruber et al. (2012)

[43] *"[A]s noted in the Methodology section, the properties of nonlinear models do not allow for direct substantive interpretation of interaction effects based on the estimated coefficients"* (Gruber et al., 2012, p. 292).

USE CASE CLASSIFICATION SCHEME DIMENSIONS	BENEFIT	DESCRIPTION	QUESTION / CHECKS
BUSINESS USE CASE	Allocation of best fitting (personnel) resources	▪ Manual AND system processes ▪ Related to business process engineering	
SYSTEM USE CASE		▪ System processes only ▪ Functionality description of deliverables to business use case	
ORGANIZATIONAL GOALS	Allocation of best fitting (personnel) resources	▪ **Core use case:** - Addresses main purpose to system (is not incidental to it) - Describes new/distinctive functionality for the system ▪ **Administrative use case:** - Describes operations necessary for the integrity of the overall's system operation - Maintenance or system operational procedures performed by administrators ▪ **Routine use case:** - Repetitively performed user routines in the normal course of using the system	"Was the system created in order to provide the functionality described in this use case?" *If yes: core use case* "Does this use case describe an operation without which the entire system would not operate properly over time?" *If yes: administrative use case* "Does this use case describe functionality without which user would not be able to properly utilize the system's features and interfaces?" *If yes: routine use case*
ESSENTIAL VS. REAL	Determination of prioritization	▪ **Essential use case:** - High-level description without implementation details - reusable ▪ **Real use case:** - description of design w.r.t. e.g. input/output technologies - tied to technology specific designs Note: No hard distinction between these characteristics	"*What* functionality is implemented?" "*How* is the described functionality implemented?"
IMPORTANCE LEVEL	Determination of prioritization	▪ **Primary use case:** - Provision of essential functionality - Performed frequently ▪ **Secondary use case:** - Provision of less essential functionality - Performed less frequently ▪ **Optional use case:** - Functionality desirable but not essential	"Can system operation begin if this use case has not been implemented?" *If no: primary use case* "Can the system substantially deliver its intended value to the users if this use case has not been implemented?" *If no: Secondary use case* *Otherwise: optional use case*
BUSINESS FUNCTION	Allocation of appropriate *domain expertise* (enables identification of developers and end users)	Use case organization along **business functions** (e.g. accounting, portfolio management, trading)	
SYSTEM FUNCTIONALITY	Allocation of appropriate *system development expertise*	Use case organization along **system functionality** relates use of system resources to relevant business knowledge (Function types: (a) data entry/maintenance, (b) transaction processing, (c) complex calculation, (d) transformation, (e) communication, (f) device control, (g) system administration)	Check use case against primary use case criteria: ▪ It is a goal of the actor of the use case ▪ It includes a complete process from start to finish ▪ It provides a value to the actor

Figure 40: Use Case Classification Descriptions and Respective Questions for the Use Case Evaluation Process (As Stated by Goldman and Song (2005))

Techniques applied in Roadmaps			
LAYER	**TOOL CLUSTER**	**PURPOSE**	**TECHNIQUES**
Top	Market Analysis Tools	Identify future pictures of Company, Scrutiny of Market, Identification of Market Trends, Business Requirements and Needs	Experience Curve
			Porter's Five Forces
			Corporate Foresight /Retropolation
			SWOT
			STEEP
			Scenario Analysis
			Concept visioning
Bottom	Technology Analysis Tools	Identify and attempt to measure technological Trends, allocate respective knowledge	Bibliometrics
			Patent Analysis
			Morphological Analysis
			Soft System Methodology
			Analytic Hierarchy Process
(Not assigned to specific Layer)	Supporting Tools	Analyze Data gathered during Roadmapping Process	QFD
			Innovation matrix
			Matrix Scoring Methods
(Not assigned to specific Layer)	Other Tools		Technology Foresight and Intelligence
			Portfolio Management
			Technology and System Readiness Levels
			Linked Analysis Grids
			Balanced Scorecard
			Porter's Value Chain
			TRIZ

Figure 41: Techniques Applied in Roadmaps (Ilevbare et al., 2011)

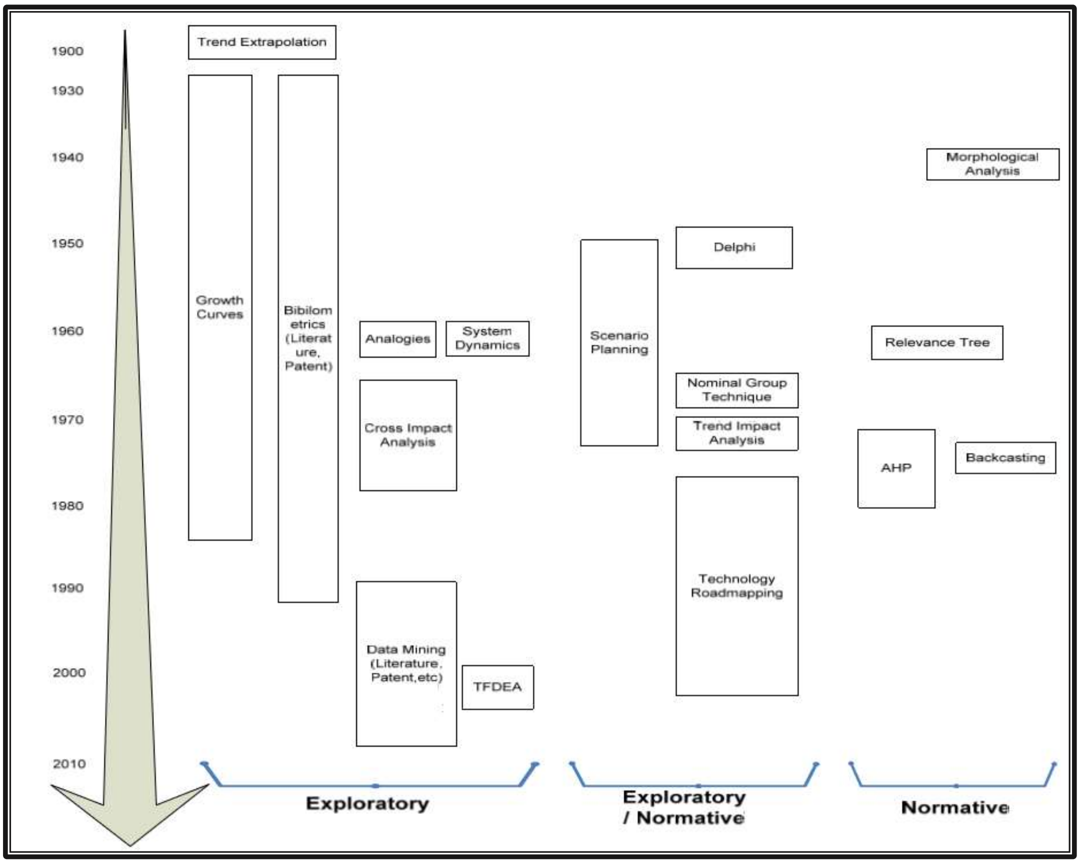


Figure 42: Chronology of Technology Forecasting Techniques (Cho et al., 2014)

Approach	Techniques
Environmental Scanning	- bibliometric analysis - patent landscape analysis, patent alert system, fuzzy-based clustering - data mining, text mining, database tomography, tech mining
Stochastic forecasting	- probabilistic trends and time lags
Trend Extrapolation	- multiple regression, multivariate regression, etc
Measure of Technology	- scoring model, technology frontier
Time Series Analysis	- AR, MA, ARIMA
Growth Curves (S-curves)	- pearl, logistics, gompertz fisher-pry, bass diffusion model, and life cycle analysis
Modeling and Simulation	- system dynamics, agent-based models
Expert Judgmental Forecasting	- Delphi, survey, FGI, role playing, AHP, analogy model, scenario planning, technology roadmapping, etc
Normative Method	- relevance tree, morphological analysis, backcasting, mission flow diagram

Figure 43: Technology Forecasting Techniques (Cho et al., 2014)

TRM applications	Characteristics
TRM incorporate disruptive technology	● identify potential disruptive technologies and products explaining that disruptive technology roadmapping process is different from that of sustaining technology
TRM incorporate supply chain management	● reduce investment uncertainty through shared information within an integrated supply chain
TRM incorporate service strategy	● integrate more sophisticated service functions to the conventional products and systems, bridging Gaps in service operations
TRM incorporate new product development	● propose heuristic approach combining technology roadmapping, information technology (IT) and supply chain management to make more sustainable new product development decisions
TRM integrate with scenario planning	● combine scenario planning with technology roadmapping to mitigate limitations both have, generate multi-scenario roadmapping
TRM incorporate business model	● combine business modelling to create new business value and strategic roadmapping method
TRM incorporate knowledge management	● deal with knowledge management actions upward to business objectives and strategies and downwards to specific knowledge assets

Figure 44: TRM Applications (Cho et al., 2014)[44]

Laws / Axioms of Engineering System Evolution	
Law 1: Law of system's completeness Law 2: Law of energy conductivity Law 3: Law of harmonization Law 4: Law of Ideality Law 5: Law of uneven development of parts Law 6: Law of transition to the super system Law 7: Law of transition to the micro level Law 8: Law of dynamization Law 9: Law of inner Substance-Field deployment	**First axiom:** Technological systems evolve not randomly but according objective laws of evolution. These laws do not depend on human. They should be observed, formulated and used in order to develop efficient methods of problem solving. **Second axiom:** Technological systems evolve not randomly but they have to overcome contradictions. In order to get breakthrough idea, a way is needed to overcome contradictions. **Third axiom:** Each specific problem must be solved in accordance with restrictions of the specific problematic situation, with peculiarities of each specific case and could not be solved in general. A robust solution is a solution that involves as less new resources as possible.

Figure 45: Laws of Engineering System Evolution (Cavallucci and Rousselot, 2011, p. 489)

[44] For respective literature references it is kindly referred to Cho et al. (2014).

tools in the field of TRIZ					
main field of application	tool	remarkable issues	procedure SP	procedure CK	referring to
current state	function analysis (system analysis)	modeling of positive and negative functions of a system	×		• substance-field-analysis • resource analysis
	object analysis (system analysis)	modeling of objects (represent components or products) of a system	×		• substance-field-analysis • resource analysis
	contradiction	confronting desired functions with harmful factors	×		• system analysis • ideality
	substance-field-analysis	modeling of substances and fields of a problem	×		• system analysis • resource analysis
	evolution analysis	analyzing of the previous evolution of a system	×		• evolution prediction
resource analysis	resource analysis	making aware of all available resources in and around a system	×		• system analysis • substance-field-analysis
transformation	inventive principles (IP) in independent form	direct applying of abstract inventive principles		×	• contradiction
	IP with contradiction matrix	transferring the desired function and the harmful factor of a problem to the contradiction matrix and applying of recommended abstract inventive principles		×	• contradiction
	separation principles	separating of conflicting system requirements	×		• contradiction
	substance-field-modulation	applying of standard operations		×	• substance-field-analysis
	evolution prediction	anticipating of the further development of a system		×	• evolution analysis
	resource variation	applying of the available resources	×		• resource analysis
	scientific effects and phenomena	making use of scientific effects and phenomena of different disciplines		×	• system analysis
goals	idealty	radical asking for the best possible solution	×		• contradiction • evolution prediction
	fitting	considering of restricting basic conditions	×		• contradiction
intended state	strong solution	balancing between ideality and fitting	×		• ideality • fitting

Figure 46: TRIZ Tools and Main Fields of Application (Pannenbaecker, 2001; Adapted by Moehrle, 2005, p. 6)

1. Define and seek an *Ideal Outcome* which solves the problem itself.
2. *X-Factor* – Imagine something which solves the problem.
3. *Thinking in Time and Scale* – Nine Boxes Maps (*Time* steps Before, During, After. *Scale* – zoom in and out – look at the details and the whole context to understand the problem situation and see all possible solutions).
4. *BAD Solution Park* – Capture all IDEAS – everyone's BAD solutions (even if unusual or unattainable etc.).
5. *Subversion* – Try the solution the other way round – Invert it – try the opposite.
6. *Prism of TRIZ* (understand essential problem and see if someone else has already solved this problem).
7. Model the problem and solutions with *Smart Little People*.
8. Apply *Size-Time-Cost* (exaggeration thinking tool).
9. *Simple language* (no technical jargon or acronyms to obscure simple truths).
10. Look for *Life and Death analogies* (Has someone got solutions which are to them critical and therefore very good?).
11. Distil solution *IDEAS* to the *CONCEPTS* behind them, multiply solutions with more Ideas for each concept.
12. *Ask Why?* To identify benefits instead of features or functions.
13. *Combine* all the *good* from various *solutions* (e.g. create a carrot–cabbage with edible roots *and* leaves).

Figure 47:TRIZ Creativity Triggers (Gadd, 2011, p. 14)

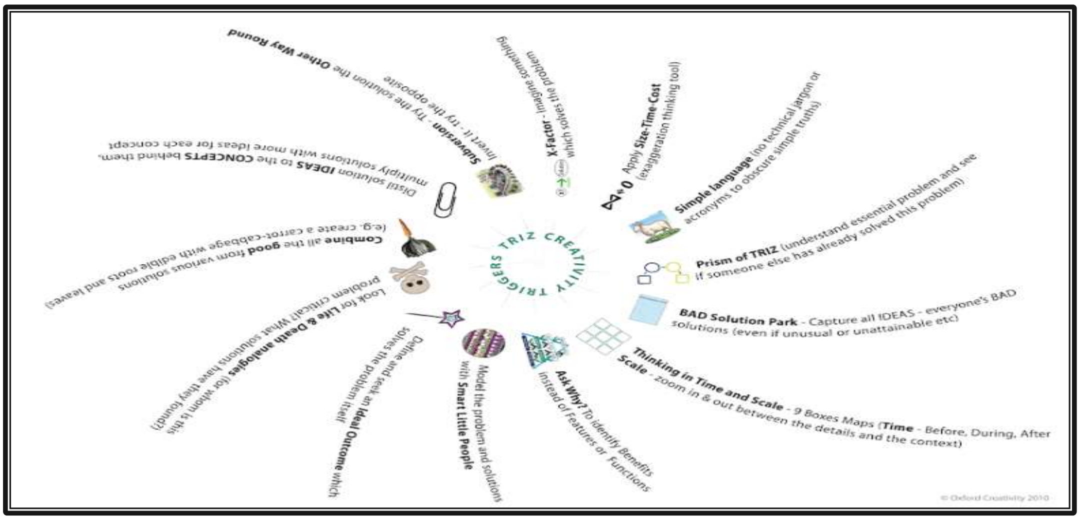


Figure 48:TRIZ Creativity Triggers Proposed to be Organized in a Circle or Mind Map but not in a Priority List (Gadd, 2011, p. 19)

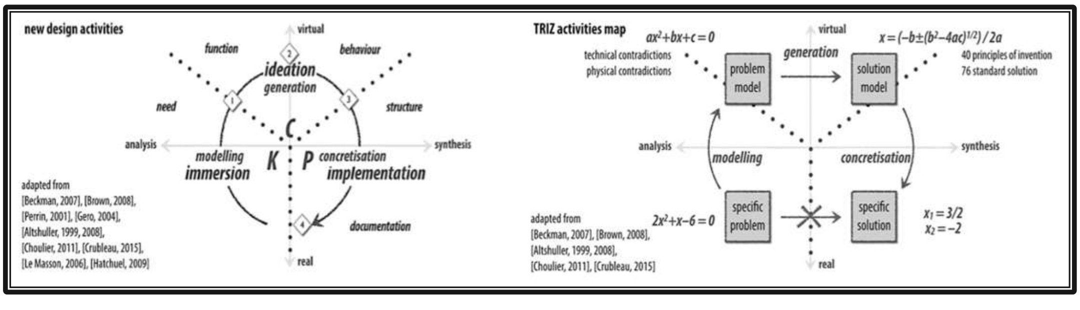


Figure 49: Design Process Map (Blanchard et al., 2017, p. 72)

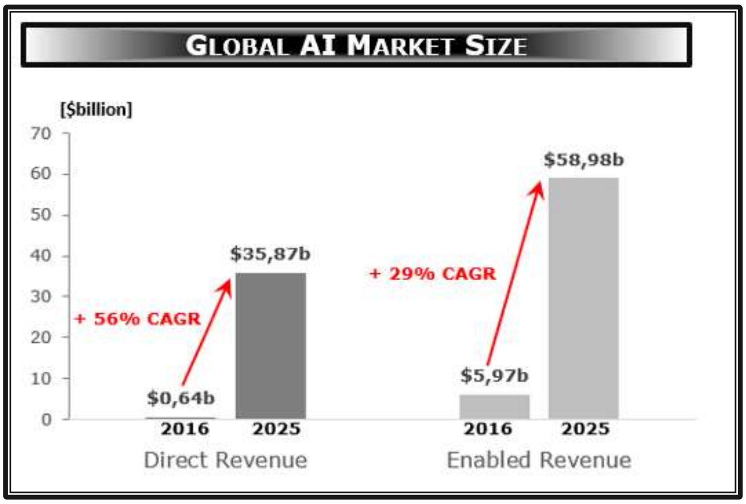


Figure 50: Global AI Market Size ('Artificial Intelligence Market Size Analysis | Industry Growth Report 2025,' 2018)

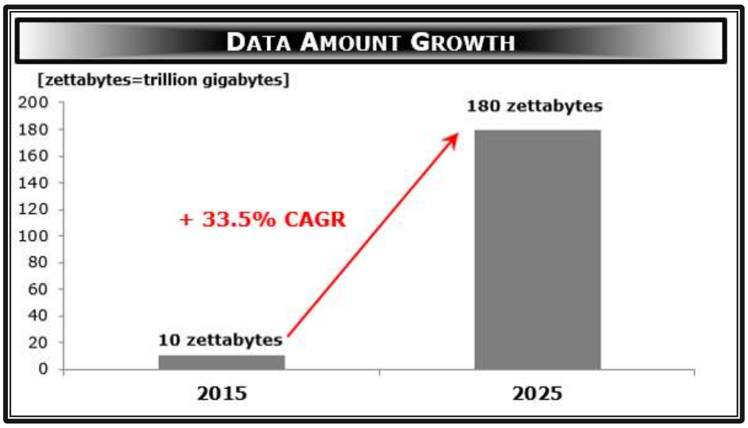


Figure 51: Data Amount Growth ('IDC,' 2018)

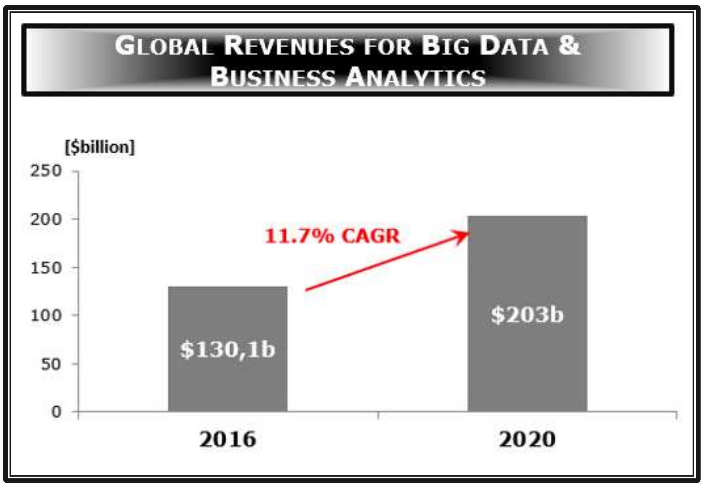


Figure 52: Global Revenues for Big Data and Business Analytics ('IDC,' 2018)

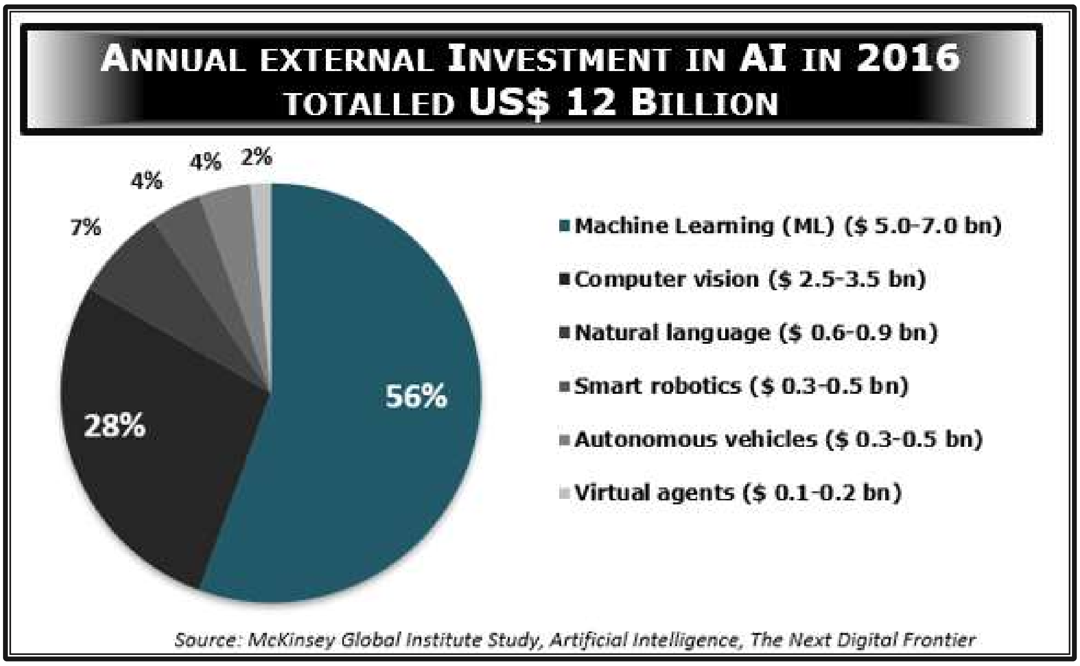


Figure 53: Annual External Investment in AI in 2016 (Columbus, 2017)

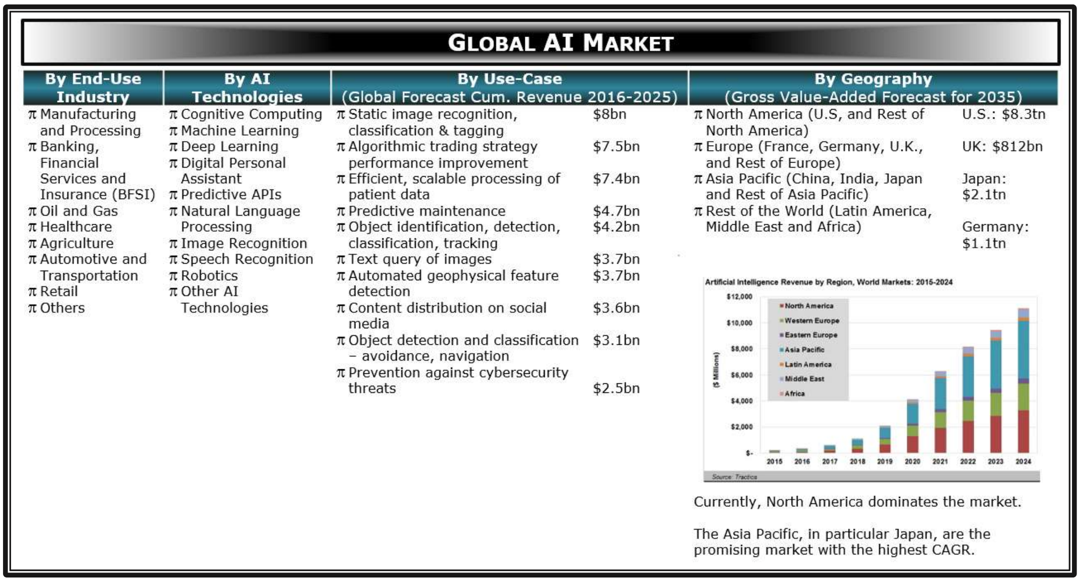


Figure 54: Global AI Market (Armstrong, 2016)[45]

45 Segmentation by solution (hardware, software, services) was neglected in figure. Software and service solutions are predicted to lead the market with regard to progressive direct revenue.

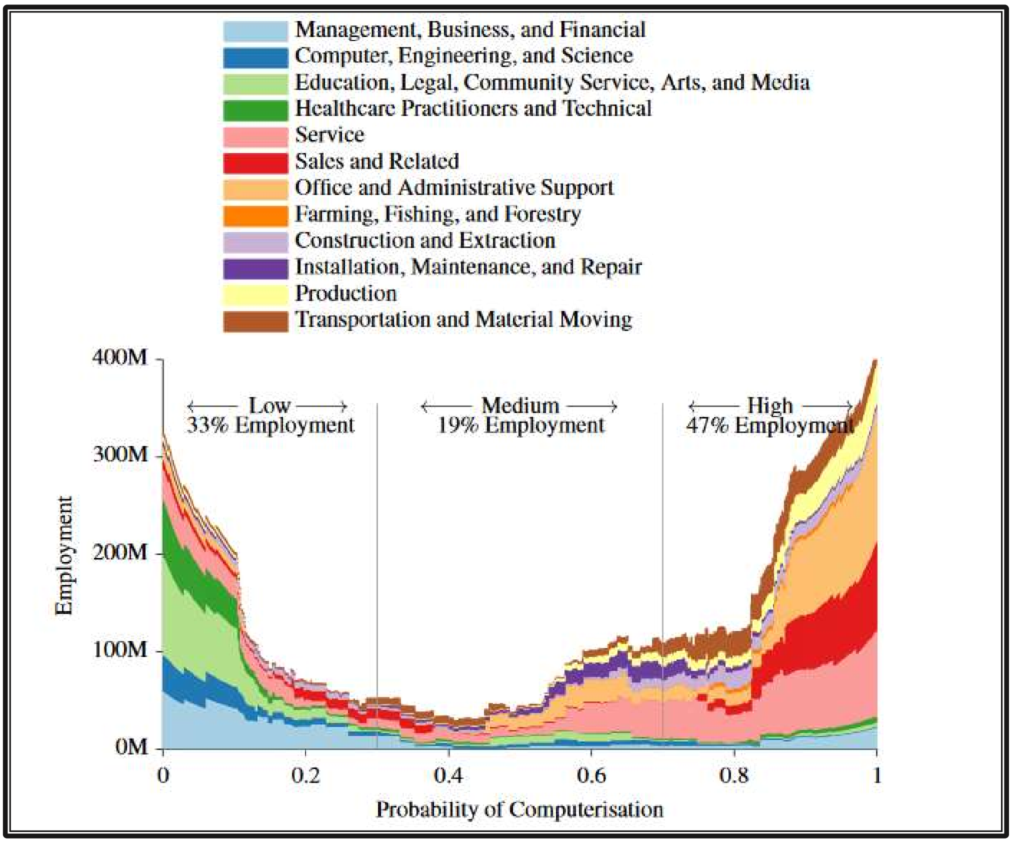


Figure 55: Employment Affected by Computerization (Frey and Osborne, 2017)[46]

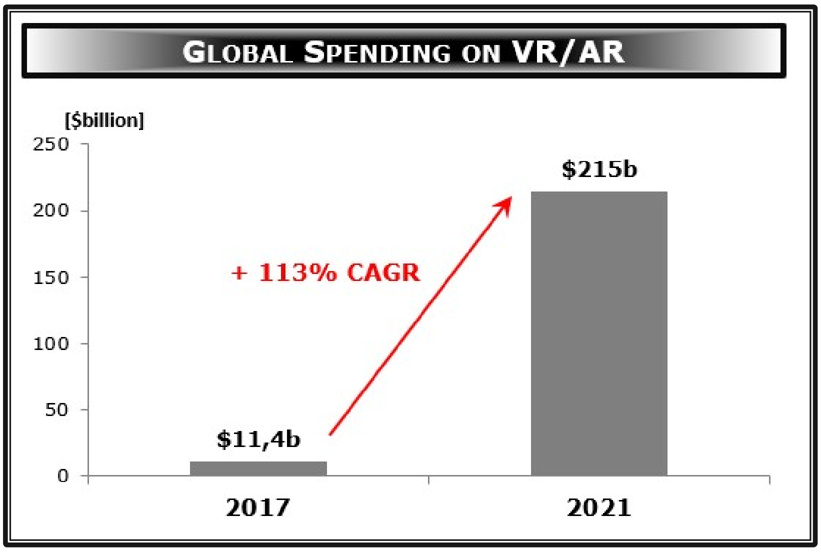


Figure 56: Global Spendings on VR and AR ('IDC,' 2017)

[46] *"[N]ote: The distribution of Bureau of Labor Statistics 2010 occupational employment over the probability of computerisation, along with the share in low, medium and high probability categories. Note that the total area under all curves is equal to total US employment. For ease of visualisation, the plot was produced by smoothing employment over a sliding window of width 0.1 (in probability)."* (Frey and Osborne, 2017, p.267)

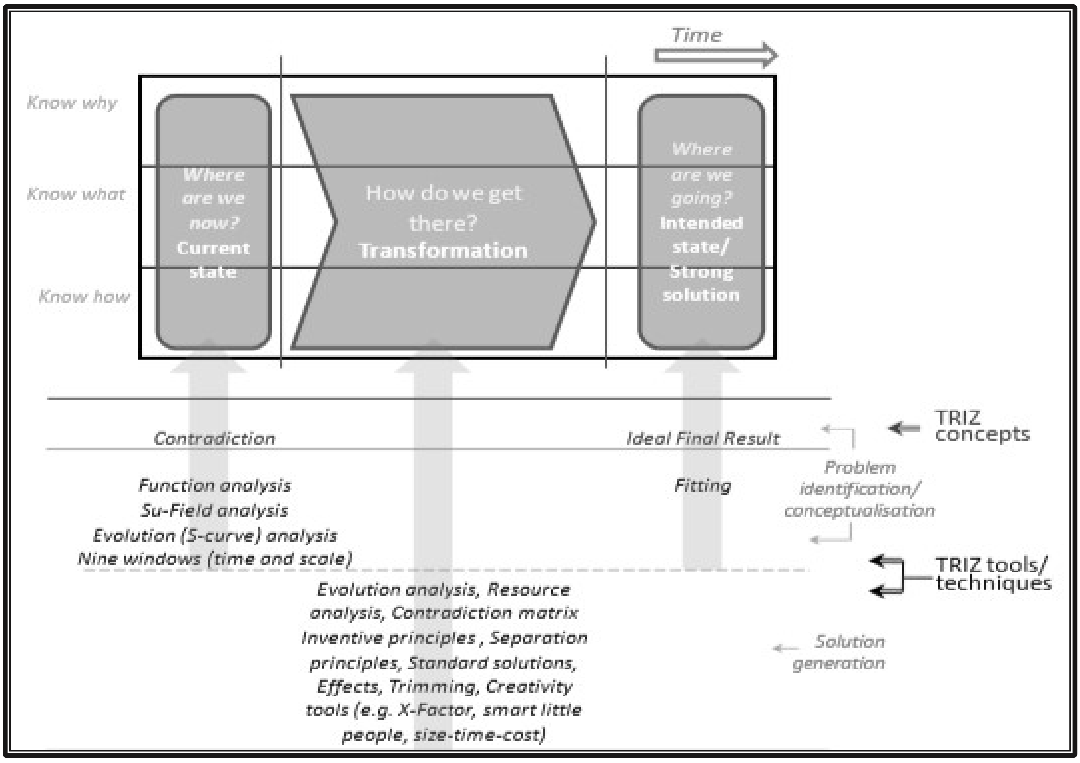


Figure 57: Version 1: Draft of Integration of TRIZ Concepts to Improve the MTP Process (Ilevbare et al., 2011)

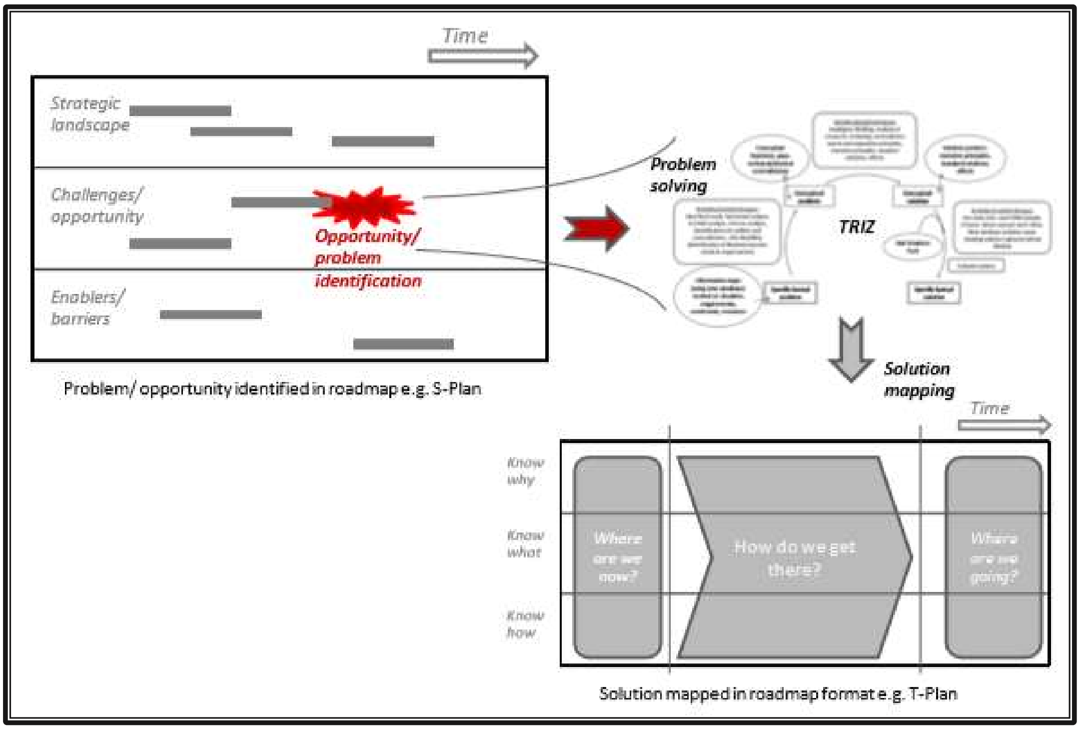


Figure 58: Version 3: Draft of Successive Linking of TRIZ and MTP Processes (Ilevbare et al., 2011)