Strategic Flexibility in Technology Strategy

Managing of Technology Turbulence
by Incumbent Firms in the Manufacturing Industry

Doctoral Thesis

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STATUTORY DECLARATION

I declare that I have authored this thesis independently, that I have not used other than the declared sources and references, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

Graz, February 2010 Björn C. Fellner

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ABSTRACT

In increasingly turbulent business environments of today's globalizing economy, where strategically relevant changes in the context of industrial organizations are no exceptions anymore, the dominant concepts and approaches of firm strategy, like sustainable competitive advantage and strategic fit, have to be explicitly complemented by the notion of strategic flexibility. To date, diverse and heterogeneous research on the notion of strategic flexibility has mainly focused on the overall level of firm strategy. In contrast, this explorative research, which is employing a qualitative research design based on the grounded theory approach, has a specific focus on strategic flexibility in the technology strategy of large-scale and technology-intensive incumbent firms in the manufacturing industry. This research is identifying and analyzing forms of strategic flexibility in a firm's technology strategy when this firm is facing significant changes in their technology context. Objectives of this research are to identify forms of strategic flexibility in technology strategy when firms perceive and manage strategically relevant changes in their technology context and to identify enabling and facilitating efforts for these forms of strategic flexibility. For this reason, a review of existing literature on strategic flexibility, technology strategy of industrial organizations, and technology turbulence in business contexts is conducted, to establish an interview guide for semi-standardized expert interviews with senior technology managers in large-scale and technology-intensive incumbent firms in the manufacturing industry. Based the analysis of 30 interview sessions with 35 experts in 25 companies, this research is identifying distinguishable forms of technology turbulence, which companies are perceiving in their business environment, corresponding forms of strategic flexibility in the technology strategy of these organizations, and transferable recommendations how to enable and facilitate strategic flexibility in the domain of technology strategy. This research shows that the observed forms of strategic flexibility in technology strategies of industrial organizations correspond not only with the specific content of the recognized changes, but also with the initial timing and quality of perception of the relevant changes and their implications for the affected organizations. The findings of this research reveal transferable efforts in the domains of technology strategy content, methodology, organization and leadership, which are proposed to enable and facilitate strategic flexibility of companies.

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PART A: RESEARCH INTENTION

1 INTRODUCTION

"Nothing endures but change. Everything flows, nothing stands still."
Heraclitus, 535-475 B.C.

The first chapter of this thesis will introduce the underlying intent for this research. It will outline the more general problem, which many incumbent firms in the manufacturing industry of western high-wage countries are facing today in the technology context of their organizations. Also, the relevance of this research for management practice and research is highlighted and the addressed gap in existing research is identified. Finally, the structure and content of this thesis is described.

1.1 Problem Outline and Relevance

> *"Technological change demands an even greater measure of adaptability and versatility on the part of the general management of a large organization. Unless management remains alert, it can be stricken with complacency – one of the most insidious dangers we face in business. In most cases it's hard to tell that you have caught the disease until it's almost too late. It is frequently most infectious among companies that have already reached the top. They get to believing in the infallibility of their own judgment." (Watson T. 1963: 63)*

Many incumbent firms[1] in the manufacturing industry of western high-wage countries, which operate on international or global markets, face a dilemma situation in today's business environment. To successfully compete with emerging firms from so-called low-cost countries, these companies have to increase their efforts for technological innovation, either to maintain a competitive cost base by superior process technologies or to differentiate their products with new product functionalities and attributes. Either way is eventually increasing technology intensity[2] of these firms, and therefore competitive advantage of these companies is increasingly based on technology and technological knowledge and innovation. On the other hand, already established positions of technological advantage are becoming less sustainable. The literature identified following driving forces of

[1] Incumbent firms are firms with already established and successful strategic positions in particular markets, businesses and industries (Hamilton W.F. 1990: 143).
[2] In this research firms are described as technology-intensive, if they regard technology as one major source of competitive advantage (Lichtenthaler E. 2002: 1).

this development (Lichtenthaler E. 2002: 2, Ashton W.B., Klavans R.A.1997: 6, Cordero R. 1991: 283ff, Cohen W.M., Levinthal D.A. 1990: 131):

- *Globalization of scientific and technological progress*: In today's globalized economy the process of scientific research and technology development is globally dispersed and interrelated. Today, new technologies or technological innovations may unexpectedly emerge from research facilities all over the globe and scientific findings and results are often publicly shared and communicated within short periods of time.
- *Increasing amount of alternative technologies*: The broad availability of new and mature technologies enables companies to realize similar functionalities by completely different technologies.
- *Increasing technology complexity*: Especially advances in digital information and communication technologies and their increasing diffusion into many products increases the overall complexity of these products and enables convergence of different technologies.
- *Higher frequency of technology substitution and obsolescence*: The shortening of product and technology life-cycles in many industries is a result to an increasing pace of technology adoption and diffusion in industries, which cause a higher frequency of technological substitution and obsolescence.

In a global analysis of interviews with 1000 Chief Executive Officers (CEOs), a recent IBM study identifies a so-called *change gap* (IBM 2008: 14). While 83% of all interviewed CEOs expect substantial change in the business context of their organizations, only 61% could confirm that their companies were able to handle substantial change successfully in the past. The interviewed CEOs expect that over a third of all expected changes are directly related to technological factors (IBM 2008: 16). Although or maybe therefore, technology, technological knowledge and technological innovations are becoming increasingly important and dominant as sources of competitive advantage, established advantages are becoming less sustainable. On the one hand, companies are facing a more dynamic and complex technology environment, which increases uncertainty for technology decisions, but also limits durability of these decisions. At the other hand, the overall criticalness of technology as a strategic variable is increasing. This dilemma situation is challenging conventional views of technology strategy. Many authors argue that technology strategy concepts which are based on the idea of sustainable competitive advantage and strategic positions are not suitable for this kind of environment:

> *"Contemporary thought about technology strategy places decisions about company technology in the context of a company's strategy, but it stops short of treating a company's strategy itself – and the closely associated decision-making practices of general management – as a variable in the process of building, or failing to build, always new advantages on the basis of technology. This implies that business strategy is separate from company technology, and that technology is solely a means to the goals set out in business strategy." (Morone J. 1993: 10)*

Fine argues that in this new environment, a firm needs the ability to continually redesign itself and its technology strategy for chains of temporary technology-based competitive advantages (Fine C.H. 1996: 5). The ability to change quickly and successfully when facing increasingly substantial and also unexpected changes in the business environment is proposed to become more critical than ever (IBM 2008: 18). It is exactly this ability to change and reconfigure an organization and its strategy when confronted with significant changes, which is summarized by the notion of strategic flexibility (Evans J.S. 1991: 69ff). It is therefore concluded that strategic flexibility in technology strategy is highly relevant for incumbent firms in the manufacturing industry, which are confronted with increasing dynamic, complexity and uncertainty in their technology context and an increasing criticalness of technology and related know-how and expertise for competitive advantage.

1.2 Objectives and Addressed Research Gap

The objective of this work is based on the problem outline above. It is argued that strategic flexibility, although not yet clearly defined and conceptualized, is in general a valuable characteristic of a company and its strategy when facing strategically significant changes in its business environment. Intuitively, strategic flexibility may be understood as the ability and willingness of an organization to change its strategy parallel to changes in its business context. Without forestalling later discussions and insights, a preliminary interpretation of strategic flexibility includes the condition of reversibility and changeability of an organization's strategy when facing strategically relevant changes in the business environment. The investigated phenomenon of strategic flexibility is therefore an issue related to strategic management of industrial organizations in turbulent business environment (see Figure 1-1).

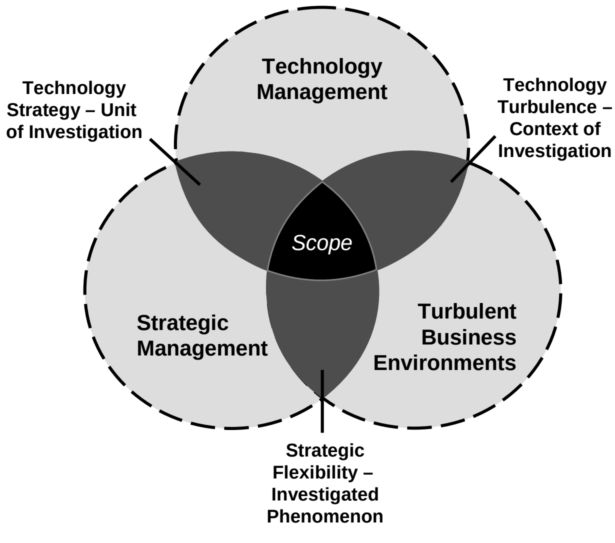


Figure 1-1: Scope of dissertation in the research landscape of general management.

It was also outlined that incumbent firms are increasingly facing massive changes in their technology context. Increasing globalization, interrelation and accessibility of knowledge, markets, industries and economies seem to accelerate processes of adoption, diffusion, imitation, substitution and obsolescence of new technologies and technological innovation. These processes are partly driven by scientific progress in existing and new technologies, but also by new and changing societal and political priorities. It is therefore concluded to focus the context of this research on the technological domain of turbulent business environment. Technology turbulence is understood as condition of strategically relevant change in the technology context of industrial organizations. It is suggested that the strategic management approach of firms to the strategic variables technology and technological innovation is summarized under the notion of technology strategy. Technology strategy, as the linkage between strategic management and technology management of organizations, is identified as the adequate unit of analysis for this investigation.

The scope of this research lies at the very overlap of these three research domains: Studying the investigated phenomenon, *strategic flexibility*, in the identified unit of analysis, *technology strategy of industrial organizations*, under the investigated context of *technology turbulence* in business environments. As none of these three concepts is trivial, one main chapter in this thesis is dedicated to each one of them (see Figure 1-1). Although there is diverse academic research in each of these three domains, there is no designated research on the strategic flexibility in technology strategy. This thesis attempts to close this identified research gap.

1.3 Structure and Content of the Dissertation

Figure 1-2 shows the overall structure of this dissertation, which consists of eight main chapters separated into 4 parts. **Chapter 1** already introduced the initial problem and the overall objective of this research. The chapter positioned the work at the interface of various research domains and highlighted the identified gap in already existing research.

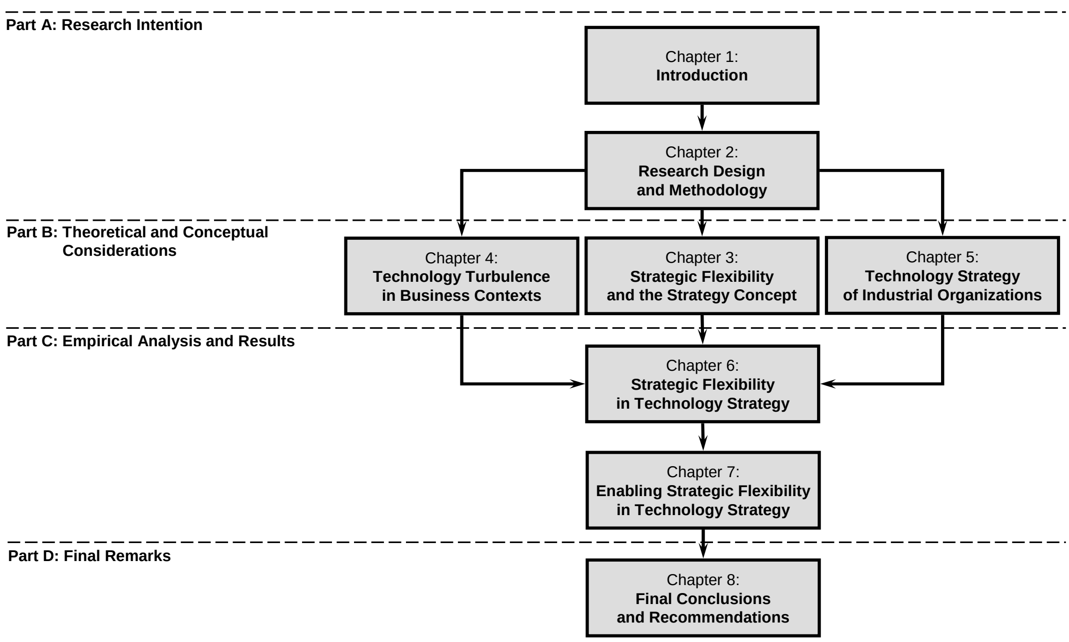


Figure 1-2: ***Structure and content of the dissertation.***

Chapter 2 presents the overall research design and methodology applied in this research, starting with the identification and formulation of adequate research questions based on the problem outline and research objective. Derived from these research questions, a qualitative grounded-theory research approach is outlined. Special issues regarding sampling, data collection and data analysis are addressed.

As there is no specific and designated research on the investigated phenomenon in the context of interest, existing research on strategic flexibility in different but related domains is introduced in **chapter 3**. This chapter identifies and discusses the general notion of strategic flexibility and integrates it into the dominant concept of firm strategy within the business management literature.

Chapter 4 introduces technology turbulence in competitive business environments as an endogenous context variable in this research. Related but distinguishable forms and patterns of strategically relevant changes in the technology context are discussed and summarized in this chapter. Based on desk research of the literature on technology change and technological innovation in business environments, an a-priori construct of technology turbulence is developed.

Chapter 5 discusses technology strategy of industrial organizations as the studied unit of analysis in this research. It reviews and analyzes various approaches and contributions in the academic and practitioner literature. As a result, an a-priori construct of technology strategy is derived, which defines the topics and issues for the collection and analysis of qualitative data on technology strategy in the field.

Based on the analysis of collected empirical data, **chapter 6** is identifying and categorizing forms of technology turbulence, which industrial organizations are facing in their business context. By analyzing the reports on how interviewed senior technology managers of industrial organization perceived and managed historical and recent incidents of technology turbulence, forms of technology turbulence and corresponding forms of strategic flexibility in technology strategies are identified. As a result, the findings of this analysis are summarized in an empirically-grounded conceptual framework of strategic flexibility.

The second part of empirical analyses and results is presented in **chapter 7**. Characteristics and attributes of a technology strategy configuration, which enables and facilitates strategic flexibility, are identified. Based on the reports and appraisal of interviewed senior technology managers, specific efforts and routines are summarized as more general recommendations on how to configure and arrange elements of technology strategy to enable and facilitate strategic flexibility.

As a final discussion of the findings of this research, **chapter 8** summarizes and critically reviews the contribution, limitations and conclusions of this dissertation.

In the **appendix** section of this work, important background information on data collection, data analysis and paraphrased interview data with direct reference to the relevant section in the primary data set is added: The interview guide for the semi-structured expert interviews with senior technology managers (Appendix A), anonymous protocol information on the 30 interviews and 35 interview partners, a summarized fact sheet on the 25 studied companies (Appendix B), a list of all 116 reported incidents of technology turbulence with direct reference to the relevant interview section (Appendix C), paraphrased and categorized interview data on the perception and management of these incidents by affected companies (Appendix D), and the underlying analysis and categorization of identified recommendations on how to enable and facilitate strategic flexibility in technology strategy (Appendix E).

During the documentation of this research in this thesis numerous and various **figures and tables** are used, either to present and review conceptual frameworks from existing research or to document, visualize and present the emergence of empirically grounded frameworks and own final results and conclusions (List of Figures, List of Tables). Beginning with chapter 4, **case vignettes** are employed to directly refer to collected primary data. These case vignettes densify the empirical grounding of the complete research and are directly based on paraphrased and coded data from the appendix section and refer to one or multiple cases, incidents, anecdotes and sources (List of Case Vignettes). Additionally, chapter 7 extensively uses **direct quotations** from the interview data to intensify the linkage between original data, analysis and conclusion. All direct quotations are referring to a one ore more specific positions, which mark the record sequence of the relevant interview.

2 RESEARCH DESIGN AND METHODOLOGY

> *"A grounded theory is one that is inductively derived from the study of the phenomenon it represents. That is, it is discovered, developed, and provisionally verified through systematic data collection and analysis of data pertaining to that phenomenon." (Strauss A., Corbin J. 1998: 23)*

The overall research approach of this work follows the knowledge claims of scientific constructivism and pragmatism. These knowledge claims imply that this research is based on some basic assumptions (Creswell J.W. 2003: 9ff):

- The involved research objects and topics are intangible and abstract constructs and concepts.
- These constructs have only meaning in the context of human beings in a specific environmental setting.
- The research's intention is to make sense of and interpret the meanings others have about the world.
- Rather than starting with an existing and closed theory model and specific hypotheses, this research intends to generate and inductively develop a theory, a conceptual framework or a pattern of meaning.
- Choice of research design and methodology is free and pragmatic and is directly derived from the research objectives and questions.

2.1 Research Questions and Research Design

The overall objectives for this research are to identify, observe and describe the phenomenon of strategic flexibility in technology strategies of industrial organizations, which are confronted with various forms of strategically relevant changes in their technology context, and to identify efforts, routines and attributes of technology strategy, which enable and facilitate strategic flexibility. Implicitly, these research objectives are based on several underlying propositions:

- Strategic flexibility in general is an advantageous characteristic of an organization and its strategy when the organization is facing significant turbulences in its business context.
- There are significant turbulences in the technology context of industrial organizations.
- Strategic flexibility in technology strategy can be observed by analyzing technology strategies of industrial organizations over time and during the perception and management of these turbulences by these organizations.

- There are configurations of technology strategy efforts within industrial organizations which enable and facilitate strategic flexibility.

Four research questions, which are derived from the overall objectives of the dissertation and these propositions, are formulated to guide the research efforts throughout this thesis:

RQ 1:	*How is the notion of strategic flexibility related to the general concept of strategy in the context of industrial organizations in competitive businesses environments?*
RQ 2:	*Which forms of technology turbulence do industrial organizations perceive in their business context?*
RQ 3:	*Which forms of strategic flexibility can be identified in technology strategies of industrial organizations when facing technology turbulence?*
RQ 4:	*What enables industrial organizations to create and maintain identified forms of strategic flexibility in their technology strategy?*

These research questions involve three intangible and abstract constructs and their complex causal relationships:

- *Strategic flexibilit*y as the investigated phenomenon of this research.
- *Technology strategy of industrial organizations* as the studied unit of analysis of this research and the entity where the investigated phenomenon is observed.
- *Technology turbulence in business contexts* as an exogenous environmental condition for this research.

Research question 1 guides the review of existing research on the general notion of strategic flexibility. It was already mentioned that there is no specific research on strategic flexibility in technology strategy. Therefore, the overall notion of strategic flexibility, its meaning and its relation to the general concept of firm strategy is in the focus of research question 1. It is not intended to address research question 1 by empirical research, but by reviewing existing research on strategic flexibility in various domains of the business management literature.

Figure 2-1 summarizes research questions 2-4 and the involved constructs in an overall research framework. **Research question 2** is focusing on the perception of technology turbulence by industrial organizations in business contexts and is basically exploring the "why" of strategic flexibility in technology strategy. It is assumed that the technology turbulence in the business contexts of organizations is affecting and is addressed by technology strategies of industrial organizations. Therefore a causal relationship between technology turbulence in the business context of an organization and technology strategy of this organization is proposed and in the focus of this research question. In Figure 2-1 this complex relationship is modeled as a mono-causal relationship between the construct of technology turbulence in a business environment and the technology strategy of an industrial organization.

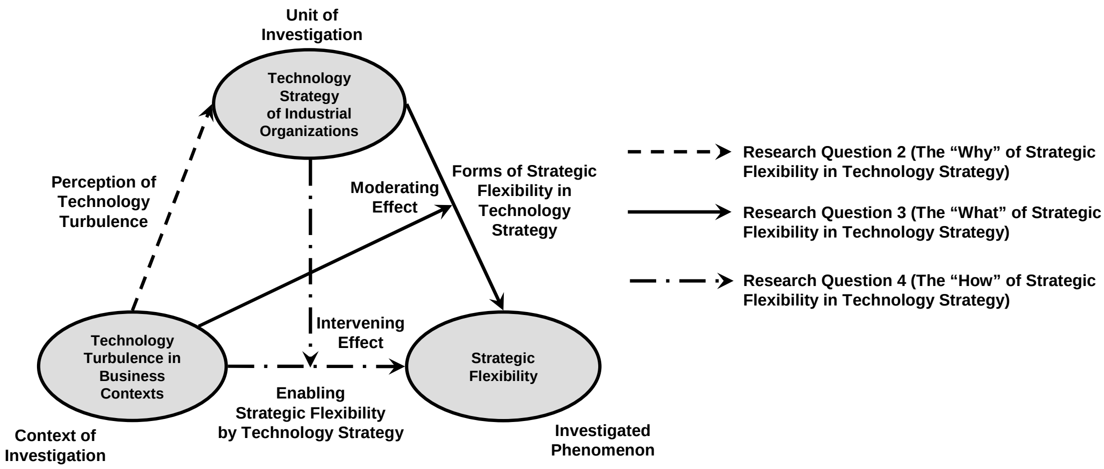


Figure 2-1: Research constructs and research questions as an overall research framework.

Research question 3 is centered on the exploration of the "what" of strategic flexibility in technology strategy. The goal is to identify forms of strategic flexibility in observed technology strategies of industrial organizations when confronted with technology turbulence. It is assumed that strategic flexibility in technology strategy is influenced by specific characteristics of technology turbulence. In Figure 2-1 this relationship is modeled as a mono-causal relationship between the constructs of technology strategy and strategic flexibility, which is affected by a moderating effect of technology turbulence. A moderating construct is one that has a strong contingent effect on two constructs, which are also directly related, and therefore affects this relationship (Baron R. M., Kenny D. A. 1986, Creswell J.W. 2003: 94).

Finally, **research question 4** is interested in attributes, characteristics and configurations of technology strategy in industrial organizations, which enable and facilitate the generation of these identified forms of strategic flexibility (the "how" of strategic flexibility in technology strategy). The intention is to identify routines, principles and practices in technology strategy efforts of organizations, which enable and facilitate the creation and maintenance of strategic flexibility for technology turbulence. In Figure 2-1 this relationship is modeled as a mono-causal relationship between the constructs of technology turbulence and strategic flexibility, which is affected by an intervening or mediating effect of technology strategy. An intervening or mediating construct is one that is affected by a second construct, while affecting a third construct that is also directly influenced by the second construct (Baron R. M., Kenny D. A. 1986, Creswell J.W. 2003: 94). It is exactly the intervening or mediating influence of technology strategy, which is in the very focus of research question 4.

These research questions ask for the nature of proposed complex interrelations between the three core constructs of this research, but no explicit hypotheses on the relationship between research variables are stated and the research questions are quite broad and open. This emphasizes the attribute of general openness and flexibility of qualitative social science research (Maxwell J.A. 2005: 67f). This characteristic is especially important, if the research is not based on an existing and closed theory or model. Explorative what, which and how-questions also strongly indicate the choice of a qualitative research design (Creswell J.W. 2003: 105f). In the fields of strategic management and technology management the most dominant and accepted qualitative research designs are the case study research design (Yin R.K. 2003a, Yin R.K. 2003b, Wrona T. 2005), the grounded theory approach (Glaser B.G., Strauss A.L. 2006, Strauss A., Corbin J. 1998) or pragmatic combinations of both (Eisenhardt K.M. 1989b, Eisenhardt K.M., Graebner M.E. 2007). Additionally, action research, where the researcher takes active influence on the research object as a consultant or change agent, is occasionally employed (Rapoport R.N. 1970, Foster M. 1972, Susman G.I., Evered R.D. 1978).

Because of the explorative nature of the research questions, the intention to develop a new conceptual framework and because of its acceptance in the field of strategic management, it was decided, that a research design which follows the basic propositions of Eisenhardt's research roadmap, will be employed (Eisenhardt K.M. 1989b: 533). This pragmatic approach to apply grounded theory in management research attempts to develop a general, abstract theory on a process, action, interaction or pattern from the collected qualitative data. Eisenhardt's roadmap emphasizes four primary characteristics of grounded theory as a strategy for scientific inquiry:

- As the goal is to develop new theory that is empirically grounded, the research process does not start with rigorous literature-based formulation of a closed model or theory, which consists of specific hypothesis on interrelations between variables of this theory (Strauss A., Corbin J. 1998: 12ff).
- The emerging categories and patterns of the developed theory are constantly compared with the collected data. Sampling, data collection and data analysis are an iterative process and no linear and staged sequence of steps. Feedback loops between sampling, data collection and data analysis are not unintended or explicitly excluded, but a mandatory practice of exploration (Creswell J.W. 2003: 14).
- Sampling is not conducted a-priori to data collection as a statistical process (e.g. random sampling), but is done incrementally and is guided by the cumulated generated insights of already collected data. This procedure is called *theoretical sampling*, because the emerging theory guides the search for new cases (Glaser B.G., Strauss A.L. 2006: 45ff, Strauss A., Corbin J. 1998: 201ff, Eisenhardt K.M., Graebner M.E. 2007: 27).
- Data collection should end when *theoretical saturation* is reached. This is the case when there is enough evidence to support the emerging categories and patterns of the new theory and no new severe contradictions demand the inquiry of additional cases (Strauss A., Corbin J. 1998: 212ff).

Building theory form qualitative data, which can be categorized as incidents, instances, cases, episodes, or anecdotes, involves the creation of theoretical constructs and propositions. Cases are usually descriptions of particular manifestations of a phenomena directly based on the collected data. They can be historical accounts or contemporary description of recent or actual events (Eisenhardt K.M., Graebner M.E. 2007: 25). Although Eisenhardt's pragmatic approach also emphasizes the avoidance of preliminary and specific hypothesis based on existing theory, the most basic adjustment to the original grounded theory approach is that a-priori constructs for relevant and involved research topics are developed. These constructs are developed a-priori to data collection and are based on relevant existing literature (Eisenhardt K.M. 1989b: 536). This adjustment allows focusing the research from the very beginning without sacrificing the general openness for new aspects in the data set and also enables the integration of the conducted research into the existing research landscape. Additionally to these aspects, the idea to enter field research with complete openness and no designated preparation seems to be too naïve and not pragmatic, especially if your research field are profit-oriented industrial organizations and their managers.

Figure 2-2 shows the overall research process of this dissertation. While research question 1 will discuss the general notion of strategic flexibility conceptually, research question 2, 3 and 4 are addressed by an empirical qualitative research design in two stages. The developed a-priori constructs for the three major research constructs of strategic flexibility, technology turbulence and technology strategy are the result of a literature review in the domains of strategic management, technology management and management in turbulent business environments. Based on the synthesized a-priori constructs, empirical research was entered by sampling adequate companies, identifying interviewees and compiling an interview guide for semi-structured expert interviews.

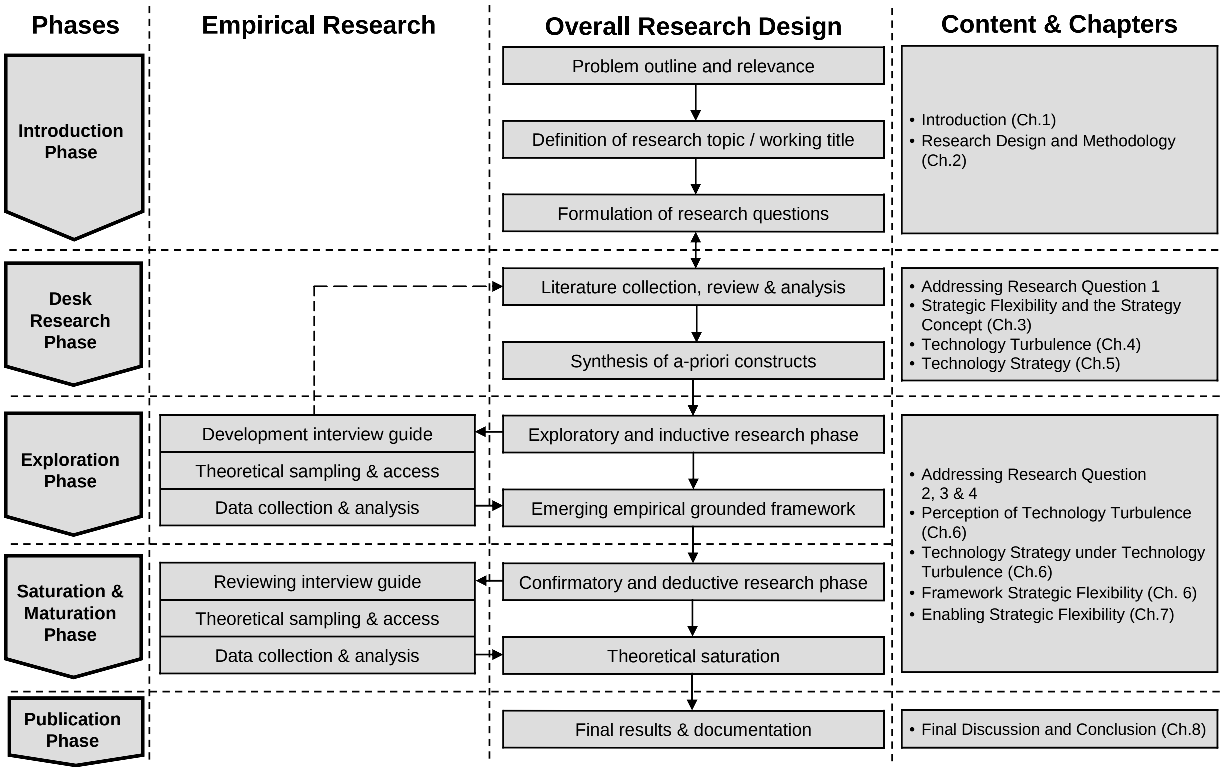


Figure 2-2: ***Research process of dissertation.***

Figure 2-2 shows the distinction of the empirical research into to phases. While in the beginning the empirical research was purely inductive and explorative, the second phase was already guided by a conceptual framework for strategic flexibility in technology strategy, which gradually emerged from the qualitative data. Following the suggestions of the grounded theory approach, the empirical research tried to confirm or contradict theses identified categories and patterns of the emerging framework and increasingly became more confirmatory and deductive. The empirical investigation ended, when identified categories and patterns became *theoretically saturated*. This was the case when enough factual and anecdotal evidence supported the components of the conceptual framework.

The grounded-theory research design applied for this study has to comply with following accepted quality criteria for qualitative and explorative research (Borchardt A., Göthlich S.E. 2009: 44ff, Yin R.K. 2003a: 34ff, Eisenhardt K.M. 1989b: 542ff):

- *Construct validity* can be increased by using and combining multiple sources of data and evidence, by involving additional researchers into data collection and analysis, and by establishing and document a closed chain of evidence between research question, data collection instruments, collected primary and secondary data, data analysis an conclusion. Although this research applied single-informant expert interviews as the dominant mode of data collection, in most cases *construct validity* was increased either by a second or third informant or by complementary secondary data (see chapter 2.3 and Appendix B). Additionally, master students were involved in data collection and analysis in several of the observed companies (see Appendix B). Various case vignettes on primary data during the text and an extensive appendix section on paraphrased and coded primary data also increases *construct validity* by providing high transparency and traceability of data analysis and conclusion (see Appendix C, Appendix D and Appendix E).
- *Internal validity,* which is somewhat related to construct validity, is ensured by employing and providing multiple cases for all identified and emerging concepts and theories in the research. This enables theoretical saturation for each concept and a reliable distinction and differentiation between them. In this research *internal validity* is increased by providing and referring to multiple cases for each identified concept. Additionally, the inductive process of theory building was conducted by applying figures, matrices and tables which are directly referring to primary data from multiple cases and multiple data sources.
- As in most qualitative studies *external validity* or *generalizability* is limited. While quantitative studies normally allow the application of founded conclusions for a sample on the overall population, this is not the case for qualitative studies. For qualitative research external validity is limited to *transferability*. *Transferability* of findings and conclusions based on qualitative research is possible, if the research provides enough information on the studied entities and their environmental context. As this research provides dense information on the studied organization and their specific context during the text and the ap-

pendix section, *transferability* of finding and results to comparable organizations in similar contexts is ensured (e.g. see Appendix B). .

- *Reliability* is, similar to *external validity*, more limited for qualitative research. *Reliability* basically refers to the condition that another researcher will come to the same or similar conclusion when repeating the same or conducting highly similar research. To ensure as much *reliability* for qualitative research as possible, this thesis is emphasizing a precise documentation and traceability of the inductive research and analysis process and the emergence of identified findings and conclusions.

2.2 Company Sampling

As mentioned before, the sampling procedure for qualitative research based on the grounded theory approach is very different to the idea of random sampling in positivistic research. While random sampling from a certain population is a prerequisite for any further statistical analysis, there is no necessity for random sampling, if it is not intended to apply these methods. What guides *theoretical sampling*, which is suggested by grounded theory, is the purpose to go to places, people or events, which will maximize opportunities to discover variations among emerging concepts and to densify and support categories in terms of their properties and dimensions (Strauss A., Corbin J. 1998: 201). Initially, a specific set of criterions was established, which should limit the possible population. These criterions were derived from the objective to identify and study technology strategies of companies in environments of increasing technology turbulence and the chance to find access to adequate interviewees in these companies. It was concluded that strategic flexibility in technology strategy will be more relevant, visible and important in industrial organizations, which fulfill the following criteria:

- *Managerial independent industrial organizations (single enterprises, corporations, independent divisions or business units).* Rationale for theoretical sampling: Only independent industrial organizations are free in strategic decision making and in strategy change.
- *Presence in competitive and international or global markets.* Rationale for theoretical sampling: Avoidance of special cases like local, regional or national monopolies or protective and quasi-monopolistic market structures, where concepts like strategy and competitive advantage are of lower concern.
- *Facilities for and involvement in manufacturing, research, development and engineering of complex product, process, or material technologies.* Rationale for theoretical sampling: Technological changes and technology strategy is more relevant for industrial organizations with technological assets and resources for technological innovation.
- *Large-scale enterprises (initially > 250, eventually >1000 employees).* Rationale for theoretical sampling: More explicit, formal and designated responsibilities, routines and resources for technology strategy.

- *Technology and technological innovation in product, process or material technology is regarded as one major source of competitive advantage in their industries.* Rationale for theoretical sampling: The sensitivity to technology turbulences is higher and the role of technology strategy is more critical, if technology and technological innovation is regarded as source of competitive advantage.
- *Corporate or business headquarters in German speaking countries.* Underlying pragmatic rationale: Access to adequate interview partners and additional information like company presentations, annual reports or websites.

The compliance with these criterions was verified by the subjective appraisal of the researcher before the interview and the expert interviewees at the very beginning of each interview. Following the emerging literature on Chief Technology Officers (CTOs) and on their position at the interface of the domains of manufacturing & operations, research, development & engineering and strategic management in industrial organizations, it is argued that CTOs or very similar positions are adequate representatives for information on the past and current technology strategy of their organizations and can be regarded as experts on technology strategy in their context (Adler P.S., Ferdows K. 1990, Smith R.D. 2003, Medcof J.W. 2008). Appendix B lists details on the final sample of interviewed experts and their organizations. Table 2-1 summarizes the list of the 25 studied companies in alphabetical order.

Table 2-1: Final sample of studied companies (all data from 2007).

Number	Corporate HQ	Company	Number of Employees	Number of Business Units
1	I	Company 1	6,500	4
2	CA/ F/ CH	Company 2	15,000	7
3	A	Company 3	12,300	5
4	A	Company 4	1,100	4
5	A	Company 5	1,070	4
6	A	Company 6	4,100	3
7	A	Company 7	15,453	4
8	A	Company 8	2,605	6
9	CH	Company 9	13,500	3
10	FL	Company 10	18,930	10
11	A	Company 11	2,417	3
12	A	Company 12	1,964	3
13	A	Company 13	6,043	6
14	CA/ A	Company 14	11,000	6
15	CA/ A	Company 15	10,000	6
16	A	Company 16	2,700	4
17	D/ A	Company 17	4,000	3
18	ZA/ A	Company 18	14,000	2
19	A	Company 19	1,100	3
20	CH	Company 20	23,062	4
21	A	Company 21	1,650	6
22	A	Company 22	41,490	5
23	A	Company 23	9,592	11
24	A	Company 24	3,600	6
25	D	Company 25	10,548	7

2.3 Data Collection

The fundament of a grounded theory approach is the collected empirical data. Before entering field research, the existing related literature is reviewed and a-priori constructs for involved topics are developed. The most dominant approach for data collection in this research is semi-structured expert interviewing, also known as semi-standardized or focused elite interviewing (Gläser J., Laudel G. 2004, Richards D. 1996, Bogner A., Littig B., Menz W. (Eds.) 2005, Hertz R., Imber J.B. (Eds.) 1995). In the typology of Bogner and Menz, the expert interviews, which are conducted in this research, have explorative and theory-generating character (Bogner A., Menz W. 2005: 37f). In the context of expert interviewing, the expert is part of the research object of interest to the researcher and not an external observer and analyst of a situation or problem. The state of expertise for a certain research focus is been assigned by the researcher to the expert (Meuser M., Nagel U. 2005: 73, Gläser J., Laudel G. 2004). An expert could be a person,

- who is responsible for the development, implementation or controlling of a solution for a certain problem.

- who has privileged access to information on persons and decision processes in organizations.
- who deals with the unit of analysis on a day-to-day basis.

Sometimes experts are not decision-makers at the highest level of an organizational hierarchy, but on second or third management level or non-executive staff positions. It is usually at these levels, where decisions are analytically prepared and implemented and where the highest knowledge on internal structures, processes, context, and functions can be found (Bähring K. et al. 2008). While in some cases the expert himself is also the unit of analysis and the researcher is interested in his biography, in this research, like in many applications of expert interviewing, the expert is seen as an representative of his organization and also as an representative of his role and function in this organization (Meuser M., Nagel U. 2005: 74). As the technology strategy of industrial organizations is the unit of analysis in this research, the interviews were conducted with senior technology managers with expert knowledge on the technology strategy of their organizations. Due to differences between industries and organizations, interviews were made with chief executive officers, chief technology officers, vice presidents for research and development, vice presidents for product development, vice presidents for corporate development, heads of research and development, heads of engineering, and technology and innovation managers on corporate or business level (see details in Appendix B).

As suggested by most guidelines for expert or elite interviewing, a semi-structured interview guide was used for the interview (Bähring K. et al. 2008, see Appendix A). This means that open-ended questions are formulated and grouped into larger concepts and topics. The topics specific questions for the expert interviews are pre-formulated based on a literature review and the a-priori constructs for technology turbulence and technology strategy (see chapter 4 and 5). Although interview questions are pre-formulated, there was enough room for follow-up questions and rearrangement of question format and sequence during the interview sessions. The necessity of the development of an interview guide helps the interviewer to develop the position of a *quasi- or co-expert* for the relevant research field (Meuser M., Nagel U. 2005: 77ff, Pfadenauer M. 2005, Bogner A., Menz W. 2005: 62). Next to the general advices on how to prepare and conduct expert interviews, there are some special issues for interviewing executives and mangers in corporations which are relevant for this research (Bähring K. et al. 2008, Trinczek R. 2005, Thomas R.J. 1995, Useem M. 1995). These important topics include:

- Access as an interviewer to executives and senior managers as interviewees.
- Long lead times for interview appointments.
- Question format for interviews with corporate executives and managers.
- Time budget and patience of executives and managers.
- Status and age difference between interviewer and corporate executives and managers.
- Issues of confidentiality and anonymity.

Access to corporate executives and higher management was enabled by employing various formal and informal networks available to the researcher and his institution. The lead-time between making the appointment and the interview date was between three days and two months, depending on availability of the interviewee and his location. A formal letter of request, signed by the head of institute and with preliminary information on the research, was sent per e-mail to the interviewees, followed by a phone call to specify the request and to arrange the interview appointment (see Appendix A). All interviews were made face-to-face and personally by the researcher and all but four interviews were made on-site in the offices of the interviewees. As recommended by the literature on expert interviewing, all interviews were digitally recorded to enable a focus on follow-up questions and active listening instead on making precise notes (Bähring K. et al. 2008, Thomas R.J. 1995). Although there was only one formal review of the interview guide, the interview length varied between 40 to 175 minutes, with an average interview length around 100 minutes. While many interviewees initially limited the interview time to a maximum of 60 minutes, all interviews were completed in one session. In seven of 25 organizations more than one person was interviewed, either by additional request of the researcher after the first interview or by an initiative of the initial interviewee. Issues of confidentiality and anonymity were settled before each interview. All interviewees allowed naming the true identity of their organizations. Anonymity was agreed at individual level. No direct and literal quotation from the primary interview data can be backtracked to an interviewee.

Especially in the exploratory phase of data collection and analysis (first 12 interviews), the interview data was complemented by other forms and sources of qualitative data. These additional sources consisted of various company presentations, company websites, annual reports and field research of master students in course of their master thesis projects. In five companies of the sample, nine graduate students, who were supervised by the researcher and a designated employee of the studied organization, spent around four months accompanying, preparing and analyzing technology related strategic decisions within these companies. Although this alternative data source offered additional, rich and valuable insights on the industrial and competitive context and internal processes, routines and procedures of companies, it was not treated and analyzed as primary data but used for plausibility checks and for complementing reports in the interview data.

2.4 Data Analysis

Positivistic data analysis employs statistical methodology to describe and analyze the collected data, which is generated by random sampling procedures and standardized questionnaires and surveys. Analysis of explorative qualitative data is directly based on the iterative and continuous review of the original primary data itself. The process of analyzing qualitative data in text or audio form by identifying categories, patterns and relationships is called *coding* (Bähring K. et al. 2008: 103ff). It implies how the researches as an interpreter of the data differentiates and combines the data and the reflection he makes about this information. *Codes* are tags or labels for assigning units of meaning to an episode, anecdote, answer or text passage in the data and are usually attached during the process of analysis (Miles M.B., Huberman A.M. 1994: 55ff). *Qualitative coding* is the process by which segments of the data are identified as relating to, being an example for, a more general idea of, or instance for a theme, dimension, category or pattern. *Coding* therefore manages and categorizes qualitative data (Lewins A., Silver C. 2007: 81ff). The first 12 interviews, which were conducted in 9 companies, were fully transcribed. These complete transcripts were analyzed and coded by using ATLASti5.2, a software package which was exclusively designed for qualitative data analysis. Although a powerful tool, this research only employed basic functions of text coding, code management and analysis (Lewins A., Silver C. 2007: 91ff). Further tools and functionalities of analysis offered by the software package were not employed. The complete collection, coding and analysis process of the qualitative data in this research eventually consisted of following, overlapping phases:

- Establishing a provisional coding scheme based on research questions and a-priori constructs as an initial starting point for inductive coding of primary data.
- Inductive coding of the first 12 fully transcribed interviews with ATLASti5.2 and emergence of an empirically grounded conceptual framework by an iterative sampling, data collecting and analysis process.
- Review of interview guide and continued data gathering and analysis without transcription of interview records and computer-aided data analysis.
- Further refinement of coding scheme and of the emerging conceptual framework until *theoretical saturation*.
- Re-coding (deductive coding) of all 30 interviews with the final coding scheme.

Following the recommendations of Eisenhardt, Miles and Huberman (Eisenhardt K.M. 1989b, Miles M.B., Huberman A.M. 1994: 58) and not the initial ideas of grounded theory and purely inductive coding (Lewins A., Silver C. 2007: 84), a-priori constructs are used to develop a first initial list of codes as a provisional coding scheme. Apart from that, the overall research approach followed Mintzberg‘s advice and kept this study as purely descriptive and inductive as possible (Mintzberg H. 1979, Eisenhardt K.M., Graebner M.E. 2007: 25). Mintzberg emphasized, that generalizing beyond one’s data, is not an *intellectual immorality*, as often postulated by positivistic knowledge claims, but a mandatory, creative and interpretative step in explorative and inductive research. He states that there would not be any interesting theories, hypothesis or propositions to test, if no one ever generalizes beyond his or her data (Mintzberg H. 1979: 584). As a basic fundament, the iterative process of qualitative data collection and analysis, applied in this research, tired to follow the seven recommendations of Mintzberg for *direct research* as rigorously as possible (Mintzberg H. 1979: 583ff):

1. Keep the research as purely descriptive as possible.
2. The research should rely on simple and elegant methods.
3. The data analysis should be as purely inductive as possible.
4. The research has to be systematic in nature.
5. The data should be collected in real organizational terms and not in detached abstractions.
6. Build a theory, which is supported by anecdotal data and episodes.

7. Synthesize and integrate diverse elements into distinguishable and pure categories and patterns.

PART B: THEORETICAL AND CONCEPTUAL CONSIDERATIONS

3 STRATEGIC FLEXIBILITY AND THE STRATEGY CONCEPT

This chapter reviews existing contributions to the notion of strategic flexibility from the business management literature. The goal is to develop a basic understanding for the notion of strategic flexibility and to identify its relationship to the overall concept of firm strategy. As there are no direct contributions to strategic flexibility in technology strategy, generic themes and elements of the phenomenon of strategic flexibility in general are identified. Based on this analysis and a brief review of the cornerstones of firm strategy, an a-priori construct of strategic flexibility is developed. As outlined in Figure 3-1, the central phenomenon of investigation in this research is the notion strategic flexibility.

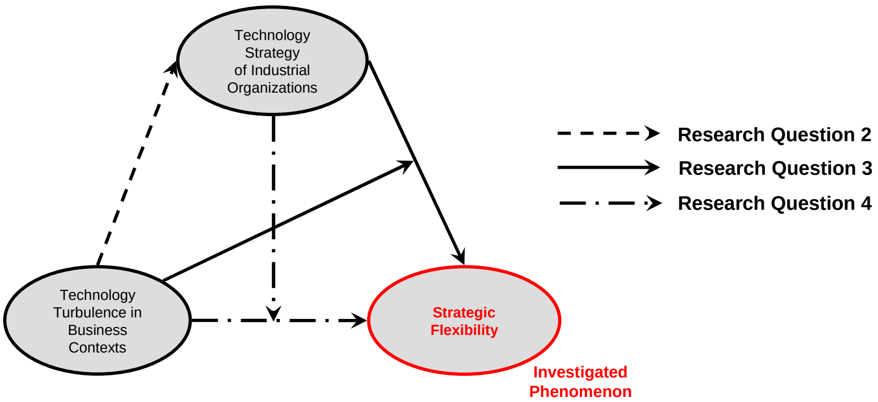


Figure 3-1: ***Strategic flexibility as the investigated phenomenon in the overall research framework.***

3.1 Conventional Strategy Concepts

The most fundamental question in the research field of strategy in competitive business contexts still remains how firms achieve and maintain competitive advantage to generate superior economic firm performance over time (Teece D.J., Pisano G., Shuen A. 1997: 509). Although it appears that this question is answered for strategy in relatively stable business environments, there is an ongoing and diverse academic discourse, if or how these generated insights also apply and suffice in the more turbulent business environments of today. Additionally, there is increasing criticism of traditional and conventional strategy concepts and frameworks by management practitioners, which suggests that this is not the case anymore (Doz Y., Kosonen M 2008, Raynor M.E. 2007, Kim W.C., Mauborgne R. 2005, De Geus A.P. 2002, Fulmer W.E. 2000, De Greene K.B. 1982). This chapter briefly reviews and discusses the cornerstones of conventional concepts of strategy and their limitations in business contexts of increasing turbulence. As this chapter discusses diverse and quite heterogeneous perspectives on the notion of strategy with their own distinct definitions and interpretations, it would be absurd to provide or adopt a highly specific definition of strategy. For this reason, and following a suggestion of Carpenter and Sanders, a direct and simple definition of strategy is adopted at this stage (Carpenter M.A., Sanders W.G. 2009: 34): In general, strategy is the coordinated means by which an organization pursues its goal and objectives (Hambrick D.C., Fredrickson J.W. 2001). Applied to the context of competitive businesses, strategy is seen as *the theory about how to compete successfully* (Barney J.B. 2002: 6). This definition is basically independent from most of the different *strategy schools* in academic research, which were identified by Henry Mintzberg and colleagues (Mintzberg H., Ahlstrand B., Lampel J. 1998: 354ff). This basic definition also allows interpreting strategy differently. Mintzberg offered five basic interpretations of a firm's strategy in the business management context, which he summarizes as the *5Ps of strategy* (Mintzberg H. 1987b: 11ff):

- ***Strategy as Plan:*** Strategy is a consciously intended course of future actions, decisions and guidelines how to reach formulated and specific objectives and goals of the organization.
- ***Strategy as Pattern:*** Strategy is a resulting consistent behavior in a stream of actions and decision, whether intended or not intended.
- ***Strategy as Position:*** Strategy is a relative coordinate via existing competitors in the strategic space of an industry, which is preselected and aspired or already occupied by an organization.
- ***Strategy as Perspective:*** Strategy is the ingrained and shared mental setting of how perceiving the world in the collective mind of an organization.
- ***Strategy as Ploy:*** Strategy is a specific maneuver or behavior, intended to outwit a direct opponent or competitor.

Above all, it is very important to see strategy as an abstract construct and the implication that all strategies, regardless in which specific interpretation and context, are abstractions. They do only exist in the minds of interested parties, which pursue them, which are affected by them or which care for their pursuit and their impact on an organization and its environment (Mintzberg H. 1987b: 16).

One dominating element of the strategy concept in the context of competitive businesses is based on the proposition that the existence of a sound strategy has a positive impact on firm performance and success. Although the basic relationship between firm strategy and superior firm performance is called the *main thesis of strategy research*, there is still an ongoing debate on its theoretical and empirical grounding (Powell T.C. 2003, Arend R.J. 2003, Durand R. 2002, Powell T.C. 2002, Powell T.C. 2001). While there is empirical evidence for the positive influence of strategy on firm performance on corporate, business and various functional level of industrial organizations, the ideas of how to conceptualize and measure a strategy and what should be defined as an adequate indicator for firm performance and success are highly diverse (Thornhill S., White R.E. 2007, Campbell-Hunt C. 2000, Dess G.G., Davis P.S. 1984).

Regardless of these differences, a dominant logic for the strategy concept emerged from most efforts to conceptualize strategy, and this logic can be found in various forms in many strategic management textbooks (e.g. Carpenter M.A., Sanders W.G. 2009, Barney J.B., Hesterly W. 2007). This dominant concept basically reflects the proposed casual linkage of the *main thesis of strategy research* (Arend R.J. 2003). Figure 3-2 shows this conventional logic of the strategy concept in competitive business environments. While there are differences in details, labeling and supporting arguments, this causal linkage is proposed to justify all efforts of strategy formation and implementation within industrial organizations in competitive environments.

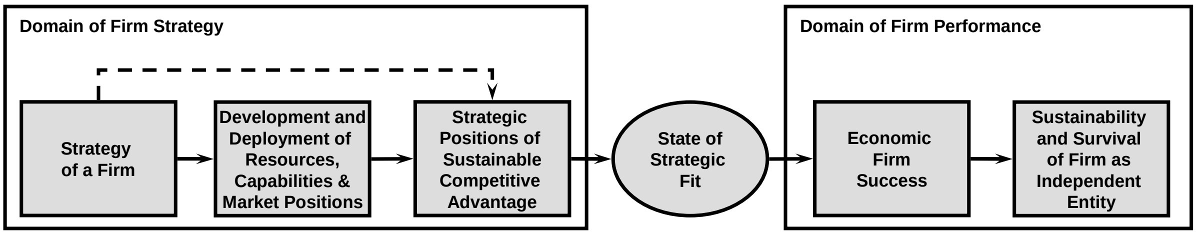


Figure 3-2: The conventional logic of strategy concept.

This dominant concept in the field of strategic management is very much based on the idea of sustainable competitive advantage and has emerged from the *structural-conduct-performance paradigm* of industrial organization economics (Bain J.S. 1959). Although the resource-based view of strategy proposes different or additional sources and mechanisms of competitive advantage, it increased the emphasis on the idea of sustainable competitive advantage (Conner K.R. 1991: 132). It is proposed that a strategy, in any of the explicit or implicit forms identified by Mintzberg, guides the development and deployment of resources, capabilities and market positions of firms in competitive environments (see Figure 3-2). The strategy formation, which may be an active, discrete and conscious act of strategy formulation or a set of interrelated decisions, eventually produces a form of strategic intent. Strategic intent in this context basically refers to the desired positions of competitive advantage, which seems appealing to the organization in its current business environment. A position of competitive advantage is a relative position of advantage via competitors in creating value to the customer allowing a company to earn revenues higher than costs, including costs of capital (Porter M.E. 1985: 33ff).

Competitive advantage is the key concept in most strategic management research (Wiggins R.R., Ruefli T.W. 2005: 888, Wiggins R.R., Ruefli T.W. 2002: 82). It was already introduced into the strategy literature by Ansoff (Ansoff H.I. 1965), but is most associated with the research of Porter (Porter M.E. 1980). More recent research has focused on the sustainability of competitive advantages (Porter M.E. 1985, Ghemawat P. 1986, Barney J.B. 1991, Porter M.E. 1996, Wiggins R.R., Ruefli T.W. 2002, Wiggins R.R., Ruefli T.W. 2005). The concept of sustainable competitive advantage suggests that some distinguished forms of competitive advantage are very difficult to imitate and can therefore maintain superior firm performance in economic terms in the long-run. A competitive advantage is expected to be sustainable, if its source creates value to the customer and if it is rare, not easily imitable, and non-substitutable by a similar sources of competitive advantage (Barney J.B. 1991).

The intention to reach and sustain a position of competitive advantage explicitly or implicitly guides the development and deployment of the organization's existing resources, capabilities and market positions. While these resources and capabilities may be of tangible nature, like industrial assets, production processes, and R&D facilities, they may also be intangible like existing market positions of products and brands or tacit knowledge of employees. If the envisioned strategic positions of competitive advantage can be realized, a state of strategic fit between the firm's resources and capabilities, its business environment, and the pursued form of competitive advantage is reached (Das T.K., Elango B. 1995: 179, Eppink D.J. 1978: 9). A state of strategic fit is constituted by a twofold alignment between the business environment and the intended strategic position and the strategic position and the organization's resources and capabilities. If this state of external and internal strategic fit is realized and maintained, the firm will have economic success, regardless how hostile and competitive its business environment is (Hall W.K. 1980). This *strategic fit-thesis* of strategy, which was first emphasized by Hofer and Schendel (Hofer C.W., Schendel D. 1978) and further developed by Venkatraman and colleague (Venkatraman N., Camillus, J.C. 1984, Venkatraman N. 1989), is a second cornerstone of most today's concepts of strategy (Zajac E.J. Kraatz M.S., Bresser R.F. 2000: 429):

> *"One of the most widely shared and enduring assumptions in the strategy literature is that the appropriateness of a firm's strategy can be defined in terms of fit, match, or congruence with the environmental and organizational contingencies facing the firm. Strategic fit is a core concept of normative models of strategy, and the pursuit of strategic fit has traditionally been viewed as having desirable performance implications."*

The function of many popular strategic management tools and concepts, like SWOT-Analysis, the strategic triangle (Ohmae K. 1982), the 7S-Modell (Peters T.J., Waterman R.H. 1983), the 5-Forces-Model and the value-chain analysis (Porter M.E. 1980, Porter M.E. 1985), is to identify and create either internal or external strategic fit or both. Porter argues that strategy is essentially the creation of strategic fit among a company's activities and its strategic position of competitive advantage. If there is not fit among activities there is no distinct strategy and no sustainability (Porter M.E. 1996: 75). While the choice and creation of external strategic fit is also called strategic positioning, internal strategic fit has various synonyms, such as strategic coherence (Carpenter M.A., Sanders W.G. 2009: 76), strategic consistency, or strategic complementarity of activities (Milgrom P., Roberts J. 1990, Milgrom P., Roberts J. 1995). In many management routines internal strategic fit is ensured by so-called strategic filters, which are applied for a first rough selection of investment and business proposals in decision making procedures. Porter basically argues that it is strategic fit and the complexity to install it, which creates superior profitability and the sustainability of competitive advantage (Porter M.E. 1996: 70ff). Parallel to the concept of competitive advantage, the idea of strategic fit is one of the most dominant ideas in strategy research. One of the most prominent manifestations of internal strategic fit is the *structure-follows-strategy-paradigm* (Chandler A.D. 1962, Sloan A.P. 1972). Figure 3-3 visualizes the concept of internal and external strategic fit, by combining the strategic triangle and the 7S-model.

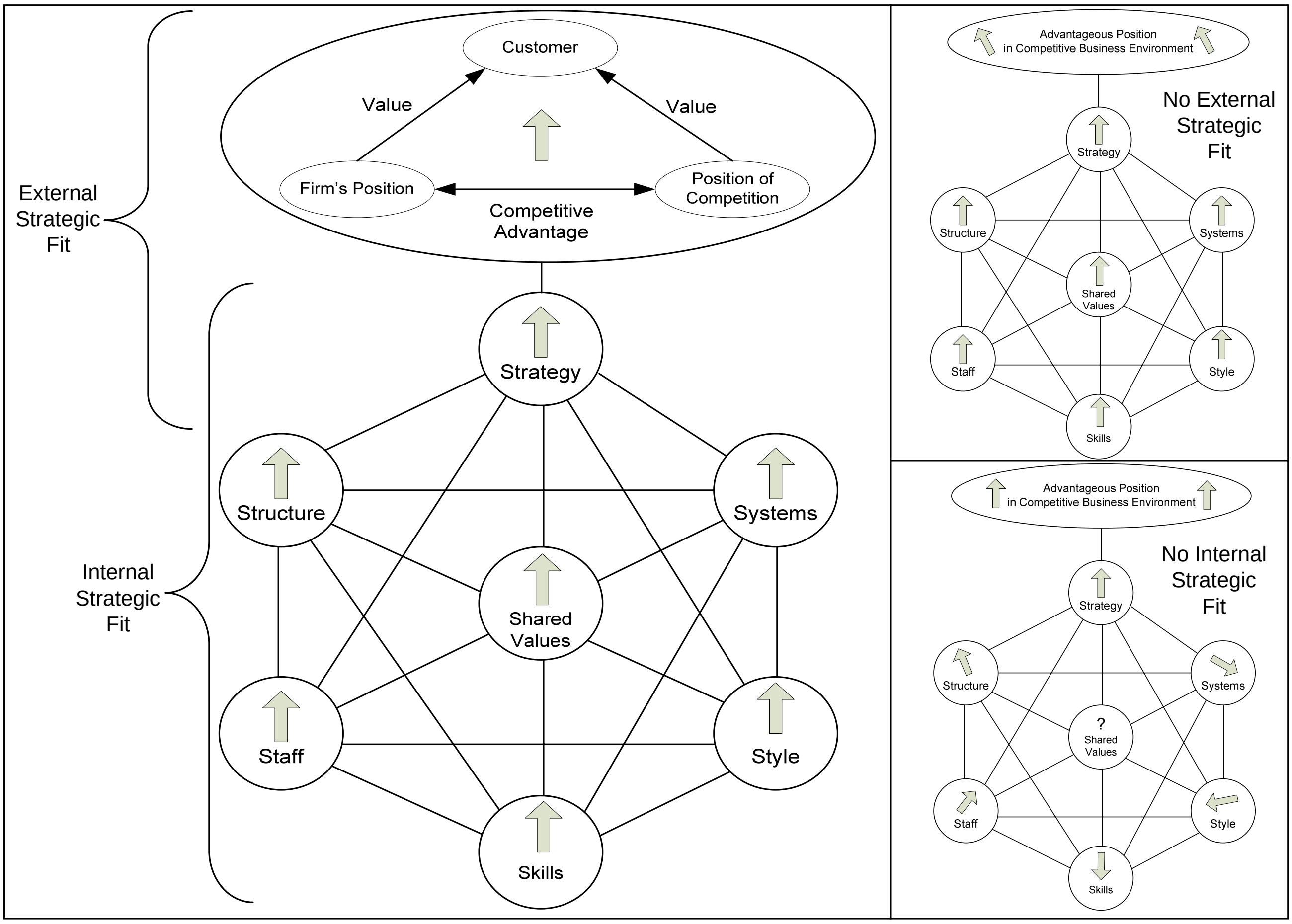


Figure 3-3: ***The concept of internal and external strategic fit in Ohmae's strategic triangle and Peters' and Waterman's 7S-model (adapted from Ohmae K. 1982 and Peters T.J., Waterman R.H. 1983).***

While there is a broad consensus about this basic causal linkage of sound strategies, competitive advantage and firm performance via strategic fit, there are diverse academic discussions about how strategy is developed, formulated or *crafted* and what should be the focus and content of strategic analysis (Mintzberg H. 1987a). It is concluded that the proposed causal linkage in Figure 3-2, which combines the main thesis and strategic-fit-thesis of strategy research, seems to be widely accepted, regardless if strategy is an ex ante intended plan or a pattern of related decisions, which is only identified or analyzed ex post. The notions of competitive advantage and of internal and external strategic fit seem to be the lowest common denominator of most relevant firm strategy concepts for competitive business context (Barney J.B. 2002: 6ff).

3.1.1 Market-based View of Strategy

The market-based view of strategy, strategic positioning school, or competitive-forces approach to strategy was the dominant paradigm in strategy during the in 1980s and 90s and formulates a firm's strategy as a generic strategic position in the competitive landscape or strategic space within an industry and within this industry's value chain. This strategy concept basically claims that competitive advantage could be achieved and sustained by creating defendable market positions within an industry and against relevant competitive forces. Pioneered and dominated by the work of Porter (Porter M.E. 1980, Porter M.E. 1985), this strategy approach recommends generic strategies, which are chosen as a result of an analysis of existing competitive forces in the industrial environment of an organization. The market-based view is derived from the s*tructure-conduct-performance paradigm* of microeconomics' industrial organization approach (Bain J.S. 1959). Organizations within an industry, which pursue the same generic strategy, are called strategic groups (Porter M.E. 1981: 615, Dess G.G., Davis P.S. 1984, Reger R.K., Huff A.S. 1993). The two dominating generic strategies are cost-leadership, also called operational excellence, and differentiation, also called product excellence. As this strategy concept is heavily based on micro-economic analysis of industrial organizations, current industry structure plays a central role in determining and limiting the strategic actions of a company (Porter M.E. 1981). Since the emergence of this strategy concept, a countless amount of prescriptive and analytical tools complemented the initial model of Porter. While typical industrial organizations concepts like economies of scale and scope, learning curve and entry, exit and mobility barriers are predominantly used to analyze industries, their attractiveness, and the choice of a generic strategy, tools of game-theory are used to analyze specific strategic moves and decisions within oligopolistic or duopolistic strategic groups (Dixit A.K., Nalebuff B.J. 1993, Brandenburger A.M., Nalebuff B.J. 1996). As shown in Figure 3-4, the strategy concept of the market-based view primarily emphasizes the question of external strategic fit between the strategy of a firm and its external market environment and the current industry structure (Burmann C. 2002: 94).

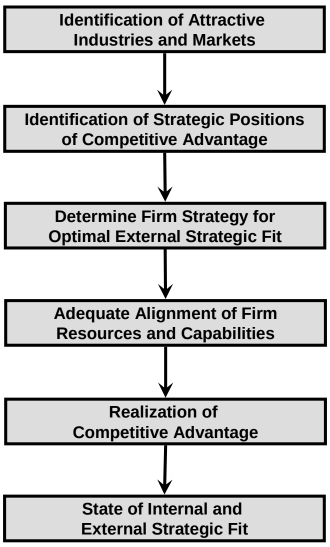


Figure 3-4: ***Simplified perspective of the market-based view of strategy.***

3.1.2 Resource-based View of Strategy

During the early 1990s increasing critique of the market-based view, resulted in the emergence of what is now called the resource-based view of strategy (Wernerfelt B. 1994: 171, Barney J.B. 2001: 643). Basically this resource-based view argues that competitive advantage and firm performance are not based on industry and strategic group membership in form of product and market combinations and generic strategies, but in firm-specific factors, namely resources and capabilities. The basic idea of viewing companies not as bundle of product and market combinations but as a bundle of resources and capabilities was already formulated before (Penrose E.G. 1959, Andrews K.R. 1971), but was first emphasized in form of specific analytical tools by Wernerfelt (Wernerfelt B. 1984). The resource-based view of strategy offers a different perspective on diversification, merger and acquisition activities of multi-product firms. Also first propositions about the positive relationship between the existence of exclusive resource positions and competitive advantage were formulated (Wernerfelt B. 1984: 172ff). The idea of core competencies as sources of sustainable competitive advantage by Prahalad and Hamel, and the suggested negative impact of short-term thinking in strategic business units on the firm-wide exploitation of these core competencies, underscored und supported this views and propositions (Prahalad C.K., Hamel G. 1990). Similar to Prahalad and Hamel, Barney argued that a distinctive set of resources which satisfies certain criteria can be a source of sustained competitive advantage (Barney J.B. 1991: 105ff). The so-called VRINE-criterion states that the resource must be valuable, rare, imperfectly imitable, non-substitutable and exploitable to the firm. Grant named criteria, which determine the degree of sustainability of a current competitive advantage based on resources and capabilities: Durability, transparency, transferability and replicatability (Grant R.M. 1991: 124ff). The strategy concept of the resource-based view emphasizes primarily the internal strategic fit between a strategy and the existing resource-base of a company (see Figure 3-5). In the focus of all strategic efforts is the identification and creation of adequate core competencies, which is followed by a choice of relevant industries, markets, customers, and target groups where these core competencies can be exploited (Burmann C. 2002: 95). Table 3-1 is summarizing the conceptual differences between market and resource-based view of strategy.

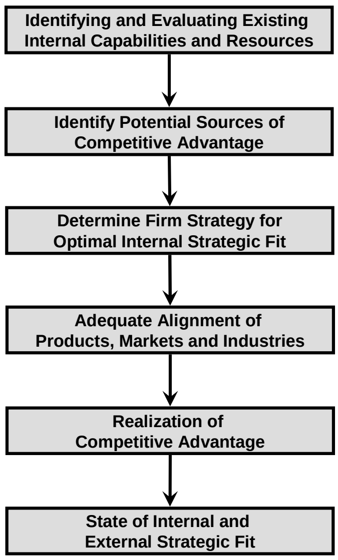


Figure 3-5: ***Simplified perspective of the resource-based view of strategy.***

Table 3-1: Conventional strategy concepts.

Elements	Market-based View	Resource-based View
Unit of Strategic Analysis	Strategic business units, product-market combinations, product groups;	Bundles of resources and competences;
Primary Driver of Strategy	Determine optimal external fit between strategy and business and industry environment;	Determine optimal internal fit between resource and capability base and strategy;
Source of Competitive Advantage	Defendable market positions;	Resources and capabilities;
Sustainability of Competitive Advantage	Possible, by building market entry, exit and mobility barriers and emphasizing industry boundaries;	Possible, by distinctive resources and core capabilities (VRINE criteria);

3.1.3 Criticism and Limitations of Conventional Strategy Concepts

Current management literature suggests that successful firms must be more environment-sensitive because most global industries are becoming progressively more turbulent (Hamel G., Prahalad C.K. 1994, Haeckel S.H. 1999, Raynor M.E. 2007, Doz Y., Kosonen M 2008). To ensure success, the ability of a firm to change must match the complexity and the dynamic of its industrial environment (Ansoff H.I. 1987a: 30). Already in 1984, Maidique and Hayes noted that especially in more technology-intensive industries a certain level of organizational adaptability and agility is necessary to complement stable and orderly planning and budgeting routines. They called this permanent trade-off the *paradox of high technology management* (Maidique M.A., Hayes R.H. 1984: 20f). It was also stated that the ability to proactively switch back and forth between a survival mode when times are more turbulent and a self-development mode when the pace of change is slow, is one success factor of lasting companies with above-average long-term success in all kind of industries (De Geus A.P. 1988: 70). Already in 1979, Krijnen proposed that flexibility itself, next to financial profitability and independence, must be a separate overall goal of firms in competitive business environments. Therefore, efforts to create and maintain flexibility at the highest level of the organization must be reflected in the organizations strategy content, processes and goals (Krijnen H.G. 1979: 63, Ansoff H.I. 1965: 64ff). Similar, Dove and Baumgartner et al. also suggest that in today’s turbulent business environments forms of organizational flexibility must be equal in priority to profitability (Dove R. 2001: 4, Baumgartner R.J. et al. 2006: 17ff). Additionally, current publications argue that in today’s turbulent business environment this is also true for traditional and mature manufacturing businesses and not only in the high-technology arena (Wiggins R.R., Ruefli T.W. 2005). It is often argued that only strategic flexibility will provide potential sources of competitive advantage in the long-run (Lau R.S. 1996: 13, Doz Y., Kosonen M 2008: xvi). Hayes and Pisano strongly argue that in turbulent business environments the goal of strategy itself becomes strategic flexibility, without explicitly framing the concept of strategic flexibility (Hayes R.H., Pisano G.P. 1994: 78). While it is argued that incumbent industrial organizations never reach the kind of flexibility of start-ups and young entrepreneurial firms, because of their high commitments in already existing and specific assets and businesses, Quinn concludes that the demand for flexibility is the same, but the ways to achieve this flexibility must be somewhat different for incumbents (Quinn J.B. 1985a, Quinn J.B. 1985b).

Contrary to neo-classical microeconomic theory (Debreu G. 1959), industrial organization economics (Bain J.S. 1959) and the resource-based view (Conner K.R. 1991), both evolutionary economics (Nelson R.R., Winter S.G. 1982) and the Austrian school of economics (Jacobson R. 1992, Schumpeter J.A. 1934, Schumpeter J.A. 1942) argue that persistent superior performance of firms is the result of continuous entrepreneurial cycles of innovation, imitation and obsoleteness that does not allow a state of stable equilibrium. Neoclassical microeconomic theory basically suggests that a temporary state of disequilibrium will be balanced by supply and demand and does not allow for superior economic performance of one firm in the long-run. Industrial organization economics emphasize that industry structure and architecture influences organizational conduct, and that entry, exit and mobility barriers in industries allow the sustainability of superior economic performance. The resource-based view states that valuable, rare, inimitable and non-substitutable resource configurations enable firms to create and sustain superior economic performance. Although different, these three theories imply a state of stable equilibrium, which emphasizes a static perspective on the concept of firm strategy.

Actual comments argue that exaggerated emphasis on one long-term sustainable competitive advantage has drawn attention away from the fact that strategy must be a dynamic tool for guiding the development of a company over time (Montgomery C.A. 2008: 56). Conventional views of strategy, like strategic planning (Ansoff H.I. 1965) and strategic positioning (Porter M.E. 1980) emphasize a deliberate and sequential process and rigor analysis. According to these perspectives, strategies are actively developed and formulated, based on clear intentions, conscious choice and careful planning prior to any implementation effort. This mode is considered to work well in bureaucratic organizations in stable and predictable industrial environments (Bahrami H., Evans S. 1989: 107, Booth M.E., Philip G 1998: 37). With recognition that an increasing number of organizations operate in different environments, which are disrupted by frequent and sometimes fundamental change, the question is how and what firms plan and organize to achieve not a static but dynamic fit with turbulent settings and what role strategy has to play (Rindova V.P., Kotha S. 2001: 1264). It is argued that traditional behaviors of stability seeking by risk and uncertainty avoidance are increasingly inadequate, but any replacement has not emerged yet (Ilinitch A., D’Aveni R., Lewin A. 1996: 217). Companies which use traditional approaches to strategy development in increasingly turbulent environments will tend to overinvest in building assets and capabilities that are highly specific to a particular strategy and current competitive advantage and will under-invest in creating alternatives for future competitive advantage (Williamson P.J. 1999: 118, Booth M.E., Philip G 1998: 32). Many popular tools for strategy formulation usually begin with an industry analysis, assuming that a product or market paradigm and industry boundaries are stable over time. Many strategy scholars argue that these traditional instruments to formulate a strategy are not able anymore to reap the dynamic aspect of it (Klimecki R.G., Gmür M. 1996: 206, Chiesa V., Manzini R. 1998a: 111-112, Courtney H.G., Kirkland J., Viguerie S.P. 2000: 81, Courtney H.G. 2001: 42, Rindova V.P., Kotha S. 2001: 1263ff, Collins J.C., Porras J.I. 2002: 147, Doz Y., Kosonen M 2008: 17, Carpenter M.A., Sanders W.G. 2009: 204ff).

It is further noticed that strategy in a turbulent industry is really about creating options and opening up new potential possibilities for a later choice (Beinhocker E.D. 1999b: 173). While in stable and static industrial environments companies tend to formalize strategy as making choices and commitments in form of plans, resource allocation procedures and budgets, in turbulent environments the creation and recognition of strategic alternatives should be more in focus of all planning and organizing efforts in the organization (Hamel G. 2009: 94). The choice and the managerial decision itself happens in an entrepreneurial or operational style in *real-time* and not as the last step of a formalized planning and decision process. Accordingly, what becomes most important is a firm's nimbleness to exploit dissipating and changing opportunities (Bhide A. 1986). It is argued that in the face of turbulent industrial environments companies must reengineer their approach to strategy from a pure planning-formulation-implementing mode to the creation of a portfolio of strategic options on the future and integrate planning with opportunism (Williamson P.J. 1999: 117, Montgomery C.A. 2008: 58, Hamel G. 2009: 94). Under these circumstances, the strategy of successful firms must be more adaptive and opportunistic (Kay J.A. 1993: 4). Strategy today has to align itself to the fluid nature of its environment. It must be flexible enough to change constantly and to adapt to outside and internal conditions even as the aspiration to deliver favorable financial outcomes for shareholders in short-term remains constant (Bryan L.L. 2002: 18). These various conclusions suggest that in turbulent environments conventional approaches to strategy are obviously in question and must be complemented with some possibility for *real-time* strategy. This shift in focus of the strategy content and process is one of the major challenges of today's strategic management in industrial organizations.

While generic competitive strategies recommend pure strategies only, an increasing number of scholars emphasize the notion of *ambidexterity or the ambidextrous organization* (Tushman M.L., O'Reilly III C.A. 1996, O'Reilly III C.A., Tushman M.L. 2004, Birkinshaw J., Gibson C.B. 2004, Gibson C.B., Birkinshaw J. 2004). Similar to Mintzberg and McHugh's *adhocracy* (Mintzberg H., McHugh A. 1985), an ambidextrous organization is able to pursue or exploit a currently optimal strategy by an adequate strategic fit with its environment, while exploring new potential strategic fits for the future in parallel (March J.G. 1991). Somewhat comparable, to the notion of ambidextrous organizations in the academic strategic management literature are contributions like the *Living Company* (De Geus A.P. 2002), the *Adaptive Organization* (De Greene K.B. 1982, Fulmer W.E. 2000), the *Adaptive Enterprise* (Haeckel S.H. 1999), the *Adaptive Corporation* (Toffler A. 1985) and the *Agile Enterprise* (Dove R. 2001). While the research stream of the ambidextrous organization argues that exploitation of a current competitive advantage and the exploration of options on new forms and sources of competitive advantage should work in parallel in successful organization, the later focuses more on the ability and willingness of organizations to switch from one competitive advantage to the next in a transition sequence. A company, which is able to successfully switch to new sources and forms of competitive advantage, is regarded as flexible, adaptive or agile. The challenge is to organize, strategize and manage for the current business environment, but also to create alternatives for the long haul (Bahrami H., Evans S. 2005: 4).

As stated in the introduction of this research, it seems to be obvious and evident that business today is conducted in a world of increasing turbulence. Factors a company might not even think of today can determine this company's success or failure tomorrow or threaten its independence and survival, even if today's performance is superior to industry average. Even if a company is able to identify all relevant factors in time, anything that changes one might affect many others factors, too (Brandenburger A.M., Nalebuff B.J. 1996: 7). Somewhat similar to Chakravarthy's notion of turbulent business environments (Chakravarthy B.S. 1997) are the concepts of high-velocity environments (Bourgeois L.J., Eisenhardt K.M. 1988, Eisenhardt K.M. 1989a), hyper-competitive environments (D'Aveni R.A. 1994) and hostile environment (Hall W.K. 1980). These concepts are somewhat generic archetypes of extremely competitive, dynamic, complex, and therefore uncertain industry environments, which are regarded as extreme positions on a continuum of possible industry environments. Although very few industries really operate under these extreme conditions, an increasing number of industries, which were usually considered to be mature and stable, operate in increasingly turbulent business environments today (IBM 2008, Wiggins R.R., Ruefli T.W. 2002, Wiggins R.R., Ruefli T.W. 2005).

In the general academic discussion on increasing turbulence in business environments it is important to distinguish two views: On the one hand there is the absolute level of turbulence in an industry compared to other industries (static, cross-sectional view). In the academic literature, the concept of *industry clockspeed* was developed to measure and describe the level of turbulence in a certain industry and industry segment (Fine C.H. 1996, Fine C.H. 1998). In many cases industry clockspeed was determined by indicators like length of product life-cycle, product development time or average time-to-market (Mendelson H., Pillai R.R. 1999, Carrillo J.E. 2005). On the other hand, there is the acceleration of this industry turbulence experienced by firms over time (dynamic, longitudinal view), which is driven by general and industry specific trends, affecting most competitive industries regardless of their absolute level of industry clockspeed. Mendelson and Pillai developed the notion of *industry clockspeed acceleration* to describe this phenomenon (Mendelson H., Pillai R.R. 1999: 2). While the first is a static and punctual comparison between conditions in different industries and industry segments at a certain point in time, the second notion is about the experienced acceleration of the industry clockspeed over time. Brandenburger and Nalebuff vividly describe this basic idea (Brandenburger A.M., Nalebuff B.J. 1996: 147):

> *"The game isn't about how good your products are; it's about how good you are at improving them. It isn't where you are; it's how fast you're moving. It isn't position; it's speed. You never stand still; you're a moving target. What if others copy your improvement process? […] Now the game isn't about how good your products are, or even how good you are at improving them. It's how good you are at improving your improvement processes. It's not about where you are or even how fast you're moving. It's how fast you can speed up. It's not about position or speed. It's about acceleration."*

There is increasing support for the argument that during the last decades competitive advantage has become significantly harder to sustain and that this is argument is not limited neither to high-technology industries nor to high-velocity service industries, but is valid for a increasingly broader range of industries (Wiggins R.R., Ruefli T.W. 2002, Wiggins R.R., Ruefli T.W. 2005). This doubt on the sustainability of competitive advantage has severe consequences for the strategy concept in competitive businesses, as its fundamentals (main thesis and strategic-fit-thesis of strategy) are based on the notion of sustainable competitive advantage. This phenomenon is called *Red-Queen-Effect* (Kauffman S.A. 1995), after that character's remark in the Lewis Carroll's classic book Through the Looking Glass: *"It takes all the running you can do to keep in the same place."* As shown in Figure 3-6, evidence suggests that the business world resembles a Red Queen race (Kauffman S.A. 1995, Beinhocker E.D. 1997, Beinhocker E.D. 2006).

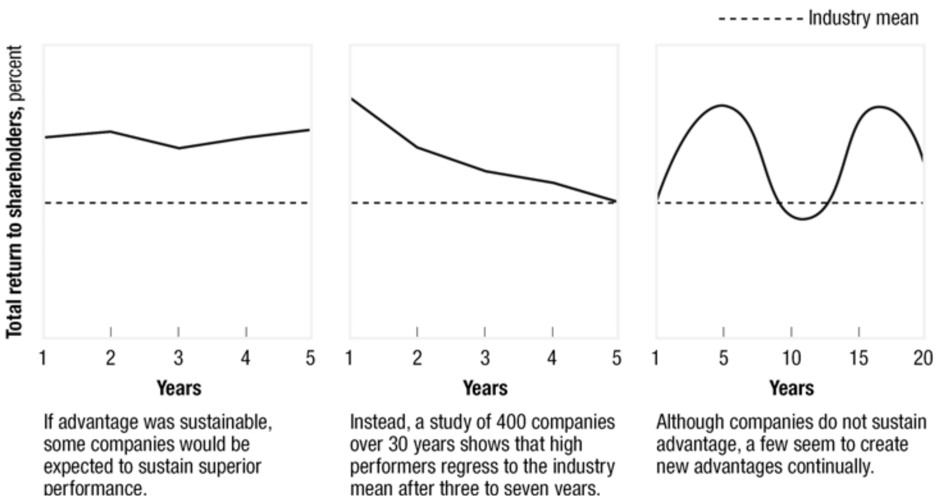


Figure 3-6: ***The Red Queen Effect (Beinhocker E.D. 1997: 116).***

Additionally to the *Red-Queen-Effect,* which shows that competitive advantage cannot be sustained and protected as suggested by the strategic positioning approach, Thornhill and colleagues show that while pure strategic positions in the competitive space in forms of generic strategies are related to short-term profitability in terms of operating profit, they also have a higher risk of failure in terms of survivor or mortality rate of firms in an industry (Thornhill S., White R.E., Raynor, M.E. 2007). In aggregate they demonstrate that higher-return – generic – strategies of firms bear also a higher risk – the risk of failure and mortality (Wernerfelt B., Karnani A. 1987: 190). Raynor extends these results by the observation that the same strategy that maximizes a firm's probability of notable, over average success also maximizes its probability of total failure (Raynor M.E. 2007). He calls this effect the *Strategy Paradox*. Strategic positions emphasize stability and consistency in a firm's pattern of resource commitments. By these resource commitments, firms should develop entry, exit and mobility barriers for themselves and existing or potential competitors and isolating mechanism to protect and sustain existing competitive advantage (Ghemawat P., del Sol P. 1998). In turbulent industrial settings, commitment in form of singular big bets can disable the firms own strategic reorientation and mobility (Wernerfelt B., Karnani A. 1987: 187f, Rindova V.P., Kotha S. 2001: 1263).

As the concept of competitive advantage is related to superior firm performance, this is also the case for their sustainability. If competitive advantage is not sustainable anymore, so are the returns which are based on it. There is a wide variety on techniques, measures and indicators how to measure firm performance (Barney J.B. 2002: 25). Various authors argue that eventually sustainable survival of an industrial organization as an independent entity in the long-run is the ultimate goal of strategy efforts (Collins J.C., Porras J.I. 2002). Therefore, all performance measures should be deducted from this overall goal. Drucker emphasizes that in Schumpeter's economy of change and innovation, economic profits of today are the costs for staying in business tomorrow (Drucker P.F. 1983):

> *"Schumpeter's Economic Development does what neither classical economists nor Marx and Keynes were able to do: It makes profit fulfill an economic function. In the economy of change and innovation, profit, in contrast to Marx and his theory, is not a Mehrwert, a 'surplus value' stolen from the workers. On the contrary, it is the only source of jobs for workers and of labor income. The theory of economic development shows that no one except the innovator makes a genuine 'profit' and the innovator's profit is always quite short-lived. But innovation in Schumpeter's famous phrase is also 'creative destruction'. It makes obsolete yesterday's capital equipment and capital investment. The more an economy progresses, the more capital formation will it therefore need. Thus what the classical economists – or the accountants and stock exchange – considers 'profit' is a genuine cost, the cost of staying in business, the cost of a future in which nothing is predictable except that today's profitable business will become tomorrow's white elephant."*

Following Drucker's argument, it is concluded that in more turbulent business environments current economic success of a firm is not sufficient for its own sustainability and survival in the long-run. Recent research doubt, if any competitive advantage can be sustained in today's business environment as suggested by both, market-based and resourced-based perspectives of firm strategy (Bhide A. 1986, D'Aveni R.A. 1994, Brown S.L., Eisenhardt K.M. 1998, Foster R., Kaplan S. 2001). If superior firm performance can not be maintained by a sustained position of competitive advantage, than firms should not try to identify the competitive advantage, which is sustainable but should focus on generating temporary competitive advantages continuously (D'Aveni R.A. 1994: 7, Wiggins R.R., Ruefli T.W. 2005 :887, Jacobson R. 1992: 799). Accordingly, Fine states that all competitive advantage is only temporary (Fine C.H. 1996:1, Fine C.H. 1998: 30). Hamel and Välikangas argue that the world is becoming turbulent faster than organizations are becoming resilient and that success and competitive advantage has never been so fragile and short living (Hamel G., Välikangas L. 2003: 2).

While it may be important to know how long a current competitive advantage and the underlying resources and capabilities can be exclusively sustained and exploited, it may hinder the more important perspective that in today's business environment the only way to enable sustained superior performance is to focus efforts on capabilities, which are able to generate temporary competitive advantages on a regular basis. It seems evident that the classic resource-based perspective focuses on strategies for exploiting existing firm-specific assets and competencies (Teece D.J., Pisano G., Shuen A. 1997: 514). But as argued, core competencies in one technology generation can turn into *core rigidities* for the next technology generation (Leonard-Barton D. 1995: 29). At the same time that they enable and stimulate innovation and learning, they hinder it (Leonard-Barton D. 1992: 123). Collins and Porras describe that successful visionary companies, which were *build to last*, must also have the ability to leave and change their core capabilities, because eventually they will become obsolete. They recommend not to tie a company's fate to a specific idea, but to be prepared to kill, revise or evolve an idea (Collins J.C., Porras J.I. 2002: 29ff). It is also recognized that companies often get into trouble by confusing core and non-core items of a company. In their point of view both strategy and current operations are only temporary manifestations of a core ideology and therefore must be open for change and evolution (Collins J.C., Porras J.I. 2002: 81ff). Changing external stabilization via markets and product, as suggested by the market-based view of strategy, against internal stabilization via core competencies or similar concepts, as suggested by the resource-based view, seems not to be a real paradigm change (Klimecki R.G., Gmür M. 1996: 208). So it can be argued that the classic resource-based approach is inherently static and not able to absorb the dynamic of today's turbulent business environment (Teece D.J. 2007: 1344).

Table 3-2 is summarizing the identified limitations of the core elements of the conventional strategy concept when facing strategically relevant changes in the business context. Empirical research showed for various industries, many of them considered to be mature manufacturing industries, that competitive advantage is not sustainable.

Table 3-2: ***Summarizing important limitations of the conventional strategy concept in turbulent business environments.***

	Limitations of Conventional Strategy Concept regarding		
Core Elements	**Market-based View**	**Resource-based View**	**Evidence**
Firm Performance	Current economic profitability is a necessary but not sufficient criterion for sustainability, survival and independence of an organization in the long-run.		Foster R., Kaplan S. 2001, Wiggins R.R., Ruefli T.W. 2002, Wiggins R.R., Ruefli T.W. 2005, Fine C.H. 1998, D'Aveni R.A. 1994, Brown S.L., Eisenhardt K.M. 1998, Thornhill S., White R.E. 2007, Thornhill S., White R.E., Raynor, M.E. 2007.
Strategic Fit	Focus and commitment to internal and external strategic fit with the current business context may allow for superior economic performance in the short-run but also increases risk of mortality in the long-run.		
Competitive Advantage	Attained or pursued strategic positions of competitive advantage are only temporary and their period of sustainability in an industry is limited and not predictable.		
Sources of Competitive Advantage	Permeability of entry, exit and mobility barriers within and across industry boundaries.	Core competence and capability become core rigidities over time.	Teece D.J. 2007, Leonard-Barton D. 1992, Leonard-Barton D. 1995, Harrigan K.R. 1985.

3.2 The Notion of Strategic Flexibility

"It is a great piece of skill to know how to guide your luck even while waiting for it."
Baltasar Gracián y Morales, 1601-1658

As there is hardly any contribution to strategic flexibility, which is directly related to technology strategy, this subchapter reviews contributions to the notion strategic flexibility from various management disciplines like marketing management (Grewal R., Tansuhaj P. 2001, Hagen A., Hassan M., Wilkie M. 2005, Johnson J.L. et al. 2003), general management and strategic management (Aaker D.A., Mascarenhas B. 1984, Buckley A. 1997, Das T.K., Elango B. 1995), management science (Carlsson B. 1989, Golden W., Powell P. 2000, De Toni A., Tonchia S. 2005), and product management (Sanchez R. 1993, Sanchez R. 1995, Sanchez R. 1997).

After various suggested definitions are reviewed, the implied interpretations of strategic flexibility are discussed. Although strategic flexibility as explicit phenomenon is increasingly discussed in the academic and practitioner literature, compared to more operational forms of flexibility, like manufacturing flexibility, it is still an unexplored concept (De Toni A., Tonchia S. 2005: 525). Strategic flexibility of organizations is usually distinguished from operational and tactical or competitive flexibility. While operational flexibility is the internal capacity of an organization for handling variation in its daily operational routines, tactical or competitive flexibility can be described as the ability of a company for tactical moves within a specific competitive arena regarding the behavior of direct or potential competitors (Carlsson B. 1989: 186ff). It is important to emphasize that both operational and tactical flexibility can be a potential source of competitive advantage for a company in a certain business context, while strategic flexibility is related to the ability of a company to change sources and forms of competitive advantage.

3.2.1 Definitions of Strategic Flexibility

The term strategic flexibility has been widely but inconsistently used by management scholars and others to broadly summarize an industrial organization’s ability to successfully face the various demands of fundamentally changing industrial environments (Hamel G. et al. (Eds.) 1998). Very often the term strategic flexibility is used without offering a definition, interpretation or conceptualization. The main reason it is still unclear what exactly is meant by the term strategic flexibility, is that there are very few recommendations how to operationalize, implement and eventually measure the concept in real-world industrial organizations (De Toni A., Tonchia S. 2005: 525ff, Golden W., Powell P. 2000: 373). It is a quite challenging task to determine appropriate measures for strategic flexibility, especially if someone leaves the ground of conceptual discussion and intends to give practical advice how to enhance it in reality (Bierly P.E., Chakrabarti A.K. 1996: 378). While it is important to know what strategic flexibility is, it is also necessary to integrate the phenomenon into the overall concept of firm strategy and to identify its relationship with core concepts of strategy like competitive advantage, strategic fit and firm performance and success.

Already in 1978, Eppink discussed the concept of strategic flexibility, but without offering a clear definition (Eppink D.J. 1978: 10ff). He named strategic flexibility the highest state of organizational flexibility and described it as a characteristic of an organization, which makes it less vulnerable for or puts it in a better position to respond successfully to unforeseen environmental change. This first description already implicitly recognizes two sides of strategic flexibility: A reactive or ex post side of strategic flexibility and a proactive or ex ante side of strategic flexibility, depending when measures to increase strategic flexibility are implemented relative to an important strategic event or change in the environment of the organization. This basic distinction in how and when strategic flexibility is realized, proves to be elemental for any further discussion, because it already states implicitly that a company can plan or at least prepare for some level of strategic flexibility.

One of the first definitions of strategic flexibility was provided by Aaker and Mascarenhas (Aaker D.A., Mascarenhas B. 1984: 74) who define strategic flexibility as the ability of an organization to adapt to substantial, uncertain and fast occurring – relative to the required action time – environmental changes, which have a meaningful impact on that organization's performance. These environmental changes must be substantial enough to impose severe long-term constraints when ignored and create some need for strategic adaption. This description already offers some important attributes of strategic flexibility: First, it can be seen as an organizational ability and second, this ability enables to adapt after or during an unanticipated event, which has significant impact on the organization's performance. In this context strategic flexibility is mainly seen as a capability to handle unanticipated events ex post. Compared to Eppink's approach (Eppink D.J. 1978) this definition obviously emphasizes strategic flexibility as the organizational ability for adaption after or during a strategically relevant event takes place and not the ability to prepare an organization for strategic changes. One might therefore be tempted to regard strategic flexibility as the easy or fallback strategic alternative, but it is argued that even just the ability for reactive adaption implicitly requires proactive strategic efforts before strategic changes occur (Courtney H.G. 2001: 47).

Sanchez describes strategic flexibility as condition of having strategic options that are created through the combined effects of an organization's coordination flexibility in acquiring and using flexible resources. A firm's strategic flexibility – that is its set of strategic options – depends jointly on the inherent flexibilities of the resources available for use by the organization and the organization's flexibility in applying those resources to various uses in pursuing alternative courses of action (Sanchez R. 1997: 71-72; Sanchez R. 1995: 138). Sanchez describes strategic flexibility as a preferable organizational state of having choice in form of strategic options, which have already been created, and not so much as an organizational ability to react to strategically relevant changes. Here, already some clues how strategic flexibility can be generated, before events require it, are given: Basically, strategic flexibility is a set of alternative options, which are created by acquisition and use of flexible resources, which are flexibly coordinated. Compared to Aaker D.A., Mascarenhas B. 1984, here the organizational ability of creating strategic flexibility, before it is needed, is the main theme. This view of strategic flexibility, which clearly focuses on the creation of options, regardless if these options are eventually exercised, goes along with Eppink's notion of planning or preparing for strategic flexibility (Eppink D.J. 1978).

Genus (Genus A. 1995: 287) names the *strategic management version of flexibility* – strategic flexibility – the least developed one and defined strategic flexibility, following Harrigan's work (Harrigan K.R. 1985), as the ability of firms to reposition themselves in a market, change their game plans or dismantle their current strategies when the customers they serve are no longer as attractive as they once were. This notion of strategic flexibility describes strategic flexibility as the potential to realize strategic mobility, like leaving or entering different market segments or industries and is primarily explained by structural factors and limitations of these industries and markets (entry-, exit- and mobility-barriers). This notion clearly focuses on the changeability of business strategies of companies in certain industries. Here the capability to utilize a potential strategic flexibility is discussed. Obviously, there is a difference between the potential strategic flexibility and the ability of really using this potential when it proves to be necessary. Again, this distinction refers to planning and preparing for strategic flexibility to reach an organizational state of strategic flexibility and the actual execution of strategic flexibility and the organizational ability to do so. In this context strategic mobility can be seen as the real amount of how an organization utilizes its strategic flexibility when confronted with strategic change.

Das and Elango (Das T.K., Elango B. 1995: 181) define strategic flexibility as the ability of an organization to respond to changes in the environment in a timely and appropriate manner with due regard to the competitive forces in the market place. They emphasize that strategic flexibility should allow an organization to be nimble and swift in exploring opportunities, while reducing the negative impact on its survival. Again, the reactive character of strategic flexibility in responding to external environmental forces is emphasized. Also, next to the ability to give a response, the quality of this response – timely and adequate – and an observation of actual environmental factors are mentioned. Following this view, increasing strategic flexibility can be seen as a strategic form of corporate strategic risk-management. Obviously next to the ability to react at all, the ability to react timely and appropriate is also a key attribute of strategic flexibility.

Evans (Evans J.S. 1991) provided one of the most complete conceptual discussions, taking into account many other related concepts of flexibility. He proposes strategic flexibility as an expedient capability for managing capricious settings, such as those confronted in technology-intensive arenas (Evans J.S. 1991: 69). Strategic flexibility thus provides an organization with the capability to modify strategies. Evans argues that the capability to modify a currently followed strategy makes it necessary include both ex ante and ex post elements of strategic flexibility. He argues that strategic flexibility is at premium *when the rules by which a game gets played are redefined or when the nature of the game itself changes* (Evans J.S. 1991: 85). Evan's notion of the capability to modify a strategy also implies that, at an extreme, strategic flexibility must also allow formulating completely new strategies to substitute obsolete ones in the case of massive strategic change.

Hitt and his colleagues directly connect strategic flexibility to competitive advantage: Strategic flexibility is the capability of the firm to pro-act or respond quickly to changing competitive conditions and thereby develop and/or maintain new forms of competitive advantage (Hitt M.A., Keats B.W., DeMarie S.M. 1998: 26). Here, a clear distinction is mentioned between reactive and proactive strategic flexibility and the notion of quickness clearly confirms the time and speed dimension of strategic flexibility, which has already been proposed by Das and Elango (Das T.K., Elango B. 1995). The authors also suggest that real strategic flexibility allows an organization exploiting already existing competitive advantages and exploring new ones. This notion of strategic flexibility clearly underlines that strategic flexibility is not just a defensive instrument to maintain current competitive advantages, but also emphasizes the generation of new ones.

Similar to this position is Grewal and Tansuhaj's statement that strategic flexibility represents the organizational ability to manage economic and political risks by promptly responding in a proactive or reactive manner to market threats and opportunities (Grewal R., Tansuhaj P. 2001: 72). Again proactive and reactive measures are mentioned to confront future threats and opportunities and strategic flexibility is described as an ability to manage risk. Also the view that strategic flexibility is a potential, which must be exercised when necessary, is confirmed. While Eppink emphasized the requirement for strategic flexibility to handle real uncertainty and unexpected events (Eppink D.J. 1978), Grewals and Tansuhaj's highlight its function to manage anticipated risks proactively.

A somewhat different description of strategic flexibility is provided by Fisscher and Weerd-Nederhof (Fisscher O., de Weerd-Nederhof P. 2001: 223), which states that a condition of readiness of an organization to act and react is the core of strategic flexibility. They say that strategic flexibility can be seen as a performance dimension of a firm referring to the readiness of an organization to adapt to, anticipate or even create future performance requirements. This readiness to anticipate, the readiness to adapt and the readiness to innovate, clearly refers to some organizational state of ex ante strategic flexibility.

Johnson et al. (Johnson J.L. et al. 2003) explicitly distinguish strategic flexibility from general flexibility by arguing that the degree of flexibility in general seems to be a function of available choices, but strategic flexibility is the generation and creation of these alternatives for choice in the long-run. This comment strongly suggests that strategic flexibility is mainly a function of the ability of creating strategic options for the long-run and that strategic flexibility cannot be created spontaneously at the very moment it is needed. The state of having choices when necessary must be prepared. This confirms Sanchez's view of strategic flexibility as a set of existing and executable strategic options (Sanchez R. 1993, Sanchez R. 1995, Sanchez R. 1997).

More specifically, Shimizu and Hitt (Shimizu K., Hitt M.A. 2004) describe strategic flexibility as an organization's capability to identify major changes in the external environment to quickly commit resources to the new courses of action in response to change, and to recognize and act promptly when it is time to halt or reverse such resource commitments. They say that maintaining strategic flexibility is one of the most important yet most difficult tasks of managers and organizations in a dynamic environment. This definition also mentions different dimensions of strategic flexibility, but all of them ex post to strategic change in the organization's environment: First, the identification of occurring changes in the environment, second, the ability of promptly responding to it, and third, the ability for adapting and correcting the strategy based on this prompt response.

Nadkarni and Narayanan also provide a more specific description of strategic flexibility of organizations. They define strategic flexibility as the ability to precipitate intentional changes and adapt to environmental changes through continuous changes in current strategic actions, asset deployment and investment strategies. In their view organizations realize strategic flexibility through their strategic actions and flexible firms exhibit both diversity in strategic responses and rapid shifts from one strategy to another (Nadkarni S., Narayanan V.K. 2007: 245). Many of the elements of strategic flexibility described here were already mentioned: A clear reference to ex ante and ex post strategic flexibility is made and the existence of diverse strategic responses and the ability to shift rapidly from one strategy to another are core elements.

Haasis and Juechter (Haasis H., Juechter H. 2007: 60) ad to the definition of strategic flexibility the willingness of an organization for proactive and reactive handling of changing internal and external condition by a goal oriented and efficient creation and utilization of flexibility potential at strategic decision level. Finally, Hamel and Välikangas describe strategic flexibility as a strategy that is forever morphing, forever conforming itself to emerging opportunities and incipient trends (Hamel G., Välikangas L. 2003: 3). Table 3-3 gives an overview of the heterogeneity of identified references and interpretations of strategic flexibility in various fields of business management. Additionally the most central elements are classified.

Table 3-3: ***Summary of definitions and interpretations of strategic flexibility in alphabetic order.***

Authors	Definition of Strategic Flexibility	Dominant Perspective	Time Domain
Aaker D.A., Mascarenhas B. 1984: 74.	The ability of an organization to adapt to substantial, uncertain and fast occurring (relative to the required action time) environmental changes, which have a meaningful impact on that organization's performance.	Organizational capability	Reactive
Abbott A., Benerji K. 2003: 6.	To achieve strategic flexibility, a corporation must enhance flexible capabilities and should not only exclusively focus on developing routines that work well in one competitive situation, but are not appropriate in a changed competitive context.	State; Organizational capability	Reactive
Bahrami H. 1992: 35f.	A blend of capabilities and attributes … to precipitate intentional changes, to continuously respond to unanticipated changes, and to adjust to the unexpected consequences of predictable changes.	State; Organizational capability	Proactive and reactive
Bierly P.E., Chakrabarti A.K. 1996: 370.	Strategic flexibility can be defined as the firm's ability to change strategic decisions in response to either internal or external changes in the environment.	Organizational capability	Reactive
Buckley A. 1997: 75.	Emphasis on the idea of creating options and their valuation.	Strategic options	Proactive
Buckley P.J., Casson M.C. 1998: 23.	Ability to reallocate resources quickly and smoothly in response to change.	Organizational capability	Reactive
Burmann C. 2002: 48ff.	Strategic flexibility is the action potential (in terms of alternatives and speed) of corporations for active and offensive exploitation of growth opportunities by changing its production and offered product and service portfolio.	Strategic options	Proactive
Carlsson B. 1989: 197ff.	Positioning of a company regarding future market changes and the management of internal change.	State	Proactive
Das T.K., Elango B. 1995: 60f.	Complementary notion to strategic fit which prepares the organization to respond to changes in the environment in a timely and appropriate manner with due regard to the competitive forces in the market place.	State	Reactive
De Toni A., Tonchia S. 2005: 532.	Strategic flexibility is the scope and variety of strategic options within existing and on new businesses and the speed and rapidity in exercising these options when necessary or advantageous.	Strategic options; Organizational capability	Proactive and reactive
Eppink D.J. 1978: 10ff.	A characteristic of an organization that makes it less vulnerable for or puts it in a better position to respond successfully to unforeseen environmental change.	State	Proactive and reactive
Evans J.S. 1991: 73f.	Strategic flexibility is a polymorphous ability of a company to create and react to change and to change its strategy.	Organizational capability	Proactive and reactive
Fisscher O., de Weerd-Nederhof P. 2001: 223.	Strategic flexibility can be seen as a performance dimension referring to the readiness of an organization to adapt to, anticipate or even create future performance requirements.	State	Proactive and reactive
Grewal R., Tansuhaj P. 2001: 72.	Strategic flexibility represents the organizational ability to manage economic and political risks by promptly responding in a proactive or reactive manner market threats and opportunities.	Organizational capability	Proactive and reactive

Authors	Definition of Strategic Flexibility	Dominant Perspective	Time Domain
Haasis H., Juechter H. 2007: 60.	The ability and also the willingness of an organization for proactive and reactive handling of changing internal and external condition by a goal oriented and efficient creation and utilization of flexibility potential on strategic decision level.	Organizational capability	Proactive and reactive
Hagen A., Hassan M., Wilkie M. 2005: 8, Hagen A., Tootoonchi A., Siddiqi S. 2006: 195.	The organization's capability to identify major changes in the external environment, quickly commit resources to new courses of action in response to these changes, and recognize and act promptly when its time to stop or reverse existing resource commitments.	Organizational capability	Reactive
Hamel G., Välikangas L. 2003: 3.	Strategic flexibility is a strategy that is forever morphing, forever conforming itself to emerging opportunities and incipient trends.	State	Reactive
Harrigan K.R. 1985: 1f.	Ability of firms to reposition themselves in a market, change their game plans or dismantle their current strategies when the customers they serve are no longer as attractive as they once were.	Organizational capability	Reactive
Hayes R.H., Pisano G.P. 1994: 78.	In turbulent environments the goal of strategy becomes strategic flexibility. The capability to switch positions – from, for example rapid product development to low costs – relatively quickly and with minimal resources.	Sate; Organizational capability	Proactive and reactive;
Hilmer H.-J. 1987: 27.	Three components as part of a holistic and systemic flexibility: Action alternatives, action speed, action willingness.	Strategic options; Organizational capability	Proactive and reactive
Hitt M.A., Keats B.W., DeMarie S.M. 1998: 26f.	Strategic flexibility is the capability of the firm to proact or to respond quickly to changing competitive conditions and thereby develop and/or maintain competitive advantage.	Organizational capability	Proactive and reactive
Johnson J.L. et al. 2003: 77.	Strategic flexibility is the generation and creation of alternatives for choice over the long run.	Strategic options	Proactive
Jones R.A., Ostroy J.M. 1984: 16.	Flexibility is a property of an initial position and the possibility to switch to a different position.	State	Proactive and reactive
Kaluza B. 1994: 71.	Flexibility is not an end in itself, but always a mean for achieving objectives.	State	-
Kogut B. 1985: 27.	Flexibility is gained by the firm's independence on assets which are already in place.	State	-
Krijnen H.G. 1979: 63.	Flexibility is considered to be a separate basic goal next to rentability and independence in turbulent environments.	State	Proactive
Lau R.S. 1996: 13.	Strategic flexibility, as a prerequisite, allows accompany to shift from one strategy to another, from one competitive priority to another, but also implies long-term commitments.	State	Reactive
Lei D., Hitt M.A., Goldhar J.D. 1996: 512.	Strategic flexibility is the need to become more adept at responding to competitor moves and the parallel engagement in opportunistic searches for under-served or unlocated market segments and niches.	State	Proactive and reactive
Mandelbaum M., Buzacott J. 1990: 18.	Amount of options which can be exercised later.	Strategic options	Proactive and reactive
Matusik S.F., Hill C.W. 1998: 682.	A firm's ability to response quickly to changing market conditions.	Organizational capability	Reactive
Meffert H. 1985: 122ff.	Strategic flexibility is no strategy but an attribute dimension of a strategy.	State	-

Authors	Definition of Strategic Flexibility	Dominant Perspective	Time Domain
Nadkarni S., Narayanan V.K. 2007: 245.	Strategic flexibility is the ability to precipitate intentional changes and adapt to environmental changes through continuous changes in current strategic actions, asset deployment and investment strategies. Organizations realize strategic flexibility through their strategic actions and flexible firms exhibit both diversity in strategic responses and rapid shifts from one strategy to another.	Organizational capability	Proactive and reactive
Reichwald R., Behrbohm P. 1983: 837.	Characteristic of the flexibility of a system is the existence of degrees of freedom. Threatening changes are compensated for by flexibility, while advantageous changes can be exploited by this flexibility.	State	Proactive and reactive
Sanchez R. 1993: 254ff.	Existence of a well structured set of strategic options. There is a difference between maximum strategic flexibility and optimal strategic flexibility.	Strategic options	Proactive
Sanchez R. 1995: 71ff, Sanchez R. 1997: 138.	The condition of an organization of having strategic options that are created through the combined effects of an organization's coordination flexibility in acquiring and using flexible resources.	State; Strategic options	Proactive
Schneeweiß C., Kühn M. 1990: 379f.	Range of possible actions and speed of reaction define a goal oriented flexibility of a system in a changing environment.	Strategic options	Proactive and reactive
Shimizu K., Hitt M.A. 2004: 44.	Strategic flexibility is an organization's capability to identify major changes in the external environment to quickly commit resources to the new courses of action in response to change, and to recognize and act promptly when it is time to halt or reverse such resource commitments.	Organizational capability	Proactive and reactive
Volberda H.W. 1996: 360ff, Volberda H.W. 1997: 172.	Strategic flexibility is the combined result of the responsiveness of an organization and the controlling capacity of its management.	State	Reactive
Weick K.E. 1982: 386.	Ability to modify current practices to adapt to environmental change by observation of the environment and preparation of responses.	Organizational capability	Proactive and reactive
Wolff C. 2005: 12.	Strategic flexibility is a meta-resource of a dynamic and open system which allows for a situational, fast proactive and reactive action.	Organizational capability	Proactive and reactive

While the definitions and interpretations of strategic flexibility differ widely in the existing literature, the notion of a strategic event or change consistently appears in direct connection with the increasing demand for strategic flexibility. Eppink (Eppink D.J. 1978: 10) already specified criteria, which constitute strategic change: First, it contains high degree unfamiliarity. While the strategic event may be forecasted or anticipated, the organization has no specific experience and therefore no routine answer ready to tackle this situation of a strategic change. Second, there is some urgency in reaction necessary to be able to response in a satisfactory way. And third, if strategic change is ignored or poorly handled, the negative impact on an organization's overall strategic goals and firm performance will be substantial. This could have the form of decreasing performance of the organization or foregone profits of a missed opportunity. Similar to this notion of strategic change is Evans' concept of a *triggering episode* (Evans J.S. 1991) or Hitt's et al. *strategic discontinuities* (Hitt M.A., Keats B.W., DeMarie S.M. 1998). Unpredictability and degree of anticipation of strategic changes are limiting factors for a firm's capability to prepare effectively and efficiently in a preplanned manner (Das

T.K., Elango B. 1995: 180). This unpredictability combined with a dynamic pace of change clearly constrains the possibility to prepare proactively and specifically. The time domain in Table 3-3 outlines, if the corresponding approach to strategic flexibility has a proactive, reactive or proactive and reactive component regarding this triggering episode.

3.2.2 Dominant Perspectives on Strategic Flexibility

It seems that the notion of strategic flexibility has no unique and accepted definition and interpretation. Nevertheless, there is a general understanding that strategic flexibility is a valuable characteristic, condition or ability of a company in a changing environment. In some cases, a state of flexibility is implicitly or explicitly connected with the existence of choice in form of alternatives to the current condition. In the meta-analysis of interpretations of strategic flexibility from various management disciplines, three dominant categories were identified (see Table 3-3). Most reviewed approaches to strategic flexibility can be assigned to one of these three categories:

- Strategy flexibility as an organizational state, condition or characteristic.
- Strategic flexibility as strategic options.
- Strategic flexibility as an organizational capability.

3.2.2.1 Strategic Flexibility as an Organizational State

Some authors emphasize strategic flexibility as a targeted state or condition of the overall organization and its pursued strategy. Das and Elango describe strategic flexibility as a complementary concept to the state of strategic fit. They emphasize that in increasingly dynamic and uncertain environments a pure emphasis of strategic fit may threaten the survival of the overall enterprise (Das T.K., Elango B. 1995: 60, 72). Carlsson applies similar arguments, using the notion static and dynamic efficiency instead of strategic fit and flexibility (Carlsson B. 1989: 183f). Eppink emphasized strategic flexibility as state of an organization, which allows it to successfully handle strategic change in its environment. He also argues that for survival of an organization, a good strategic fit is necessary, but because of strategic changes in the business environment, which can make a partly or complete strategic fit obsolete, strategic fit alone is not sufficient for survival (Eppink D.J. 1978: 9f). Concluding from Eppink's interpretation, it is proposed that under conditions of strategic change strategic flexibility is a complementary state to strategic fit, which is emphasized as a core element by all conventional strategy concepts. Very similar Fisscher and Weerd-Nederhof describe strategic flexibility as the organizational readiness of a company to anticipate and adapt. They also emphasize a dynamic tension between short and long-term goals of organizations in changing environments, which has to be addressed by strategically well-chosen and balanced mix of focus on current operational effectiveness and business success and strategic flexibility for future innovations (Fisscher O., de Weerd-Nederhof P. 2001: 223). This interpretation also emphasizes a trade-off between a state of strategic fit for current environmental conditions and a state of strategic flexibility for possible future contexts. Table 3-4 summarizes similar dichotomic couples in the academic and practitioner management literature.

Table 3-4: ***Similar notions to the state of strategic fit and the state of strategic flexibility in the literature.***

	Strategy as the Creation of a Balance between	
Authors	**Equivalent to the State of Strategic Fit**	**Equivalent to State of Strategic Flexibility**
Bahrami H., Evans S. 1989, Bahrami H. 1992.	Stability	Flexibility
Hamel G., Välikangas L. 2003.	Operational efficiency	Strategic efficiency
Peters T.J., Waterman R.H. 1983.	Tight execution	Loose adapting
Collins J.C., Porras J.I. 2002.	Control	Creativity
March J.G. 1991.	Exploitation	Exploration
Foster R., Kaplan S. 2001.	Operating mode	Innovating mode
Ghemawat P. 1986, Ghemawat P., del Sol P. 1998.	Commitment	Flexibility
Chakravarthy B.S. 1982.	Managing strategic fit	Managing (intended) strategic misfit
Bessant J. et al. 2002.	Leanness and fitness	Agility
Burgelman R.A., Grove A.S. 1996.	Strategic intent	Strategic dissonance
Burmann C. 2002.	Static strategic fit	Dynamic strategic fit
Hamel G., Prahalad C.K. 1994.	Strategic fit	Strategic stretch
Wernerfelt B., Karnani A. 1987.	Focus	Flexibility
Mintzberg H. 1987a.	Stability	Change
Brown S.L., Eisenhardt K.M. 1998.	Bureaucracy	Chaos
Boynton A.C., Victor B. 1991.	Static stability	Dynamic stability

Although applying their own vocabulary, all these authors basically suggest that strategy must create a balanced state between similar notions to strategic fit and strategic flexibility. In real-world environments, which imply strategically relevant changes, this balance becomes necessary by the uncertainty on the adequateness of today's commitments in tomorrow's business context. It is therefore proposed that in turbulent business environments in which the non-sustainability of any existing or pursued competitive advantage is limiting the adequateness of a specific strategic fit, the strategy of an organization should balance the state of strategic fit with strategic flexibility.

3.2.2.2 Strategic Flexibility as Strategic Options

Several of the reviewed notions of strategic flexibility describe it as a set of open strategic options, which are available to company. These interpretations include the identifications and creation of strategic options before they are needed and their execution when necessary or advantageous. Sanchez, for example, emphasizes that strategic flexibility of a firm is actually defined by its set of strategic options (Sanchez R. 1993: 254). Similar to strategic flexibility there is no generally valid definition of a strategic option, but there is a shared understanding of its basic meaning. In general terms, an option is the right but not the obligation to do something under some pre-specified condition (Barney J.B. 2002: 314). Sharp defined options in the business context as the ability, but not the obligation, to take advantage of opportunities available at a later date, that would not have been possible without an earlier investment in this option (Sharp D.J. 1991: 71).

The intuition of *keeping options open* to avoid later obligations for unpredictable developments in the future has motivated the development of all kind option contracts in various contexts (Cox J.C., Rubinstein M. 1985: vii). Call options or *calls*, the option to acquire something and put options or *puts*, the option to sell something under predefined conditions, allow investors in all kind of settings to hold a choice open at the risk of losing the sunk costs for the option. A common theme in all of these option investments is the in the simplest case of a two-stage process of commitment (Bowman E.H., Moskowitz G.T. 2001: 773) The investor makes a limited investment to acquire the option and holds it open until the opportunity arrives or the option expires or becomes obsolete. By acquiring the option the investor trades short-term gains by the buying cost of the option for the possibility of long-term gains (Bowman E.H., Hurry D. 1993: 761). The analysis of strategic decision making as options was transferred from financial option pricing theory. Option pricing theory has its origins in applications for financial markets, where the underlying assets for options are priced and tradable commodities, stocks and liabilities (Black F., Scholes M. 1973, Merton R.C. 1973). Myers introduced the idea of option pricing into the context of financial strategies of corporations and valuation of investments under uncertainty (Myers S.C. 1977, Myers S.C. 1984). To emphasize the application of option pricing theory on real investment projects, the notion of *real options* is used. Since then, the real option approach was established by various contributors from academia and practice as a quantitative valuation method for investments under uncertainty and was proposed to substitute or complement traditional valuation methods like net-present value and discounted cash-flow (Trigeorgis L. 1996, Boer F.P. 2002b, Copeland T.E., Antikarov V. 2003). While the transfer of option pricing from financial markets to real-world investment projects seems reasonable and applicable for certain industries and specific settings, the acceptance of real option valuation in corporate decision making is still highly limited today. Copeland and Keenan argue, that there are three reason why real options valuation is not much used for the valuation of corporate investments: The idea is relatively new, the mathematics involved are complex, and the high demand for information, assumptions or estimations (Copeland T.E., Keenan P.T. 1998a: 40). It seems that real option valuation looses much of the appealing intuition of the underlying idea when formalized as a methodology (Bowman E.H., Moskowitz G.T. 2001: 774f). While the mathematical complexity and necessity for critical assumptions and estimations limits the acceptance of real options as a valuation method in business practice, the basic approach and mindset to see and design resource allocation decisions under risk or uncertainty as staged and compounded options found broad acceptance in the field of management (Kester W.C. 1984, Luehrman T.A. 1998b, Bowman E.H., Moskowitz G.T. 2001: 776).

Seeing the strategy concept through the option lens, as suggested by Bowman and Hurry, allows interpreting strategy formation and change over time as an interlinked series of identified, created, exercised or waived strategic options (Bowman E.H., Hurry D. 1993: 762ff). Analog to Raynor (Raynor M.E. 2007: 11) and Zhao and Zhang (Zhao D., Zhang R. 2008: 346), the authors distinguish regular or conventional investment options form strategic options. While exercising a conventional investment option does not affect the currently pursued strategy and intends to support or emphasize current competitive advantage, the notion *strategic* in strategic options implies a change, extension or renewal of the current strategy related to this option (Bowman E.H., Hurry D. 1993: 763). Williamson describes strategic options as *series of alternative launching pads* that the company can use to rapidly change its strategic direction in response to market developments (Williamson P.J. 1999: 118). A regular investment option, for example, could be the reserved option of a company to expand an already existing manufacturing plant, in the case that a produced good is more successful than forecasted. A strategic option for a company could be an initial investment in a joint venture or a limited equity investment within a new or emerging industry with the intention to enable and accelerate a potential later entry, if the industry is taking off. The limited equity investment of pharmaceutical or chemical incumbents in bio-tech start-ups can be regarded as strategic options.

A strategic option in business context is regarded as a possible choice between alternatives, which is somehow relevant to future competitive advantage of a firm. An option on the development of new or different forms and sources of competitive advantage, like a new market or product, can be regarded as truly strategic. Simply stated, a strategic option can be interpreted as an option on a changed, new or extended strategy and is therefore the option on a new or different strategic position. Essentially, a simple option consists of two basic elements: The act of buying, identifying or creating an option and the act of exercising an option, if it seems appropriate to do so. This simplest option is the possible choice between a change and the maintenance of the current status quo. More complex options can be imagined as parallel, sequential or compound combinations and chains of simple options. An option, regardless in which specific context, has therefore a typical pattern of staged and reversible commitment in decision making. A strategic option has a positive effect on the state strategic flexibility of an industrial organization, if the organization has explicitly or implicitly established the strategic option and also has the ability to exercise this potential. In the very moment an option is exercised, it is converted into a strategic commitment, which reduces flexibility. Between the identification and creation of a strategic option and its execution is usually a triggering event or episode, which allows the holder of an option to recognize, if an option should be exercised or not. This triggering event could be a signaling indicator or predictor, if the execution of the option will be advantageous for the firm. While a strategic call option, which is an option on a new or different source of competitive advantage, is the more obvious case, a strategic put option is the option to leave a current source of competitive advantage.

De Toni and Tonchia conceptually describe strategic options within an industry as a dynamic complement to the existing strategic position of a firm in the strategic space of an industry (De Toni A., Tonchia S. 2005:

532). The authors assume that in a specific industry only two competitive priorities exist (see Figure 3-7). The static strategic position of a firm in this two-dimensional strategic space is the mix of competitive priorities represented by its strategy. In the simplifying abstraction of a two-dimensional strategic space, strategic options can be described as the potential to leave the current strategic position. This ability is created by the two basic components of any option: The ability to identify and create options and the ability to exercise these options later. The assumption of a two-dimensional strategic space does usually not comply with the more complex situation in real industrial settings, but it clarifies one form of understanding for strategic positions and strategic options (De Toni A., Tonchia S. 2005: 534).

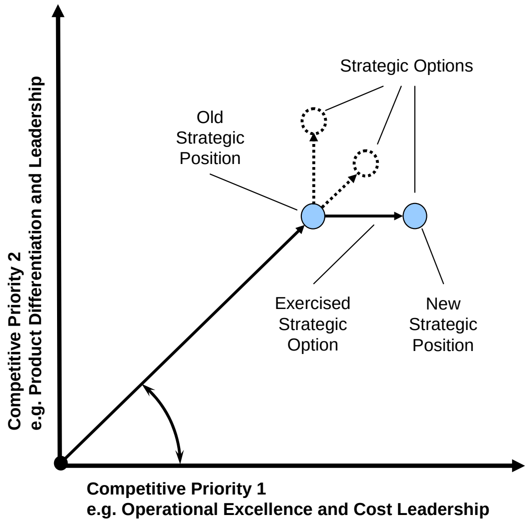


Figure 3-7: Strategic position and strategic options in a two-dimensional strategic space (adapted from De Toni A., Tonchia S. 2005: 532).

As emphasized by the authors, the notions of strategic option includes the option on a changed mix in competitive priorities (see Figure 3-7), the option on a new or alternative competitive priority (alternative or additional axis in Figure 3-7) and the option on an additional strategic space by entering a new product, business or industry (De Toni A., Tonchia S. 2005: 537).

Bowman and Hurry have introduced the notion of *shadow options* as a special kind of strategic options (Bowman E.H., Hurry D. 1993: 763). Shadow options are implicit options already available to an organization, which are not yet recognized by the organization. The conventional and intuitive logic of strategic options suggests that a company identifies a potential opportunity or threat related to a strategic change in its business context and intentionally creates a corresponding strategic option, which can be exercised later, when the opportunity or threat is actually occurring. Shadow options are strategic options, which are not intentionally created by an organization, but are available to it by some form of coincidental congruence of a company's competencies and an emerging opportunity in its business context. The notion *shadow* in shadows options indicates that these options have to be actively recognized and to be made explicit by the organization before the organizations can strike it.

3.2.2.3 Strategic Flexibility as an Organizational Capability

Many contributions to strategic flexibility describe or define it as an organizational ability, capacity or capability to successfully handle strategically relevant change in the business context. Evans, for example, emphasizes strategic flexibility as the capability of an enterprise to modify and change means and ends of intended strategies for anticipated and unanticipated changes (Evans J.S. 1991: 69, 77). What Evans basically suggests is that the ability of an organization to change its strategic goals and plans, when facing changes, is regarded as strategic flexibility. A summary of interpretations of strategic flexibility as organizational capability is presented in Table 3-5.

Table 3-5: Interpretations of strategic flexibility as organizational capability.

Authors	Strategic Flexibility as Organizational Capability
Aaker D.A., Mascarenhas B. 1984: 74.	Ability to adapt to change.
Bahrami H. 1992: 35f.	Ability to precipitate change and to respond and adjust to change.
Bierly P.E., Chakrabarti A.K. 1996: 370.	Ability to change strategic decisions.
Buckley P.J., Casson M.C. 1998: 23.	Ability to reallocate resources quickly and smoothly.
Evans J.S. 1991: 73f.	Ability to create and react to change and to change strategy.
Grewal R., Tansuhaj P. 2001: 72.	Ability to manage and respond promptly to change in a proactive or reactive manner.
Haasis H., Juechter H. 2007: 60.	The ability for proactive and reactive handling of change.
Hagen A., Hassan M., Wilkie M. 2005: 8, Hagen A., Tootoonchi A., Siddiqi S. 2006: 195.	Capability to identify and respond to changes and recommit resources.
Harrigan K.R. 1985: 1f.	Ability for strategic repositioning.
Hayes R.H., Pisano G.P. 1994: 78.	Capability to switch strategic positions.
Hitt M.A., Keats B.W., DeMarie S.M. 1998: 26f.	Capability to proact and to respond quickly.
Matusik S.F., Hill C.W. 1998: 682.	Ability to respond quickly to changes.
Nadkarni S., Narayanan V.K. 2007: 245.	Ability to precipitate changes, to adapt to changes and to shift strategies.
Shimizu K., Hitt M.A. 2004: 44.	Capability to identify changes and to recommit resources.
Weick K.E. 1982: 386.	Ability to observe the environment, to prepare responses to changes, and to modify current practices.

Central themes of the in the reviewed interpretations of strategic flexibility as organizational capability within various management disciplines include:

- A capability of an organization to recognize, observe and interpret strategically relevant changes in its business context before or during their occurrence.
- A capability of an organization to transform identified threats or opportunities related to strategically relevant changes into adequate initiatives of the organization.
- A capability of an organization to change its current strategy or strategic position and to reverse or change already made strategic decisions and resource commitments.
- A capability of an organization to do all these things in an adequate speed compared to the speed of strategically relevant change.

It is therefore concluded, that strategic flexibility should not be interpreted as a single organizational capability, but as a whole bundle of organizational capabilities or as meta-capability. It is also proposed that the needed capability of strategic flexibility may differ, if the strategically relevant change and its related impact on the organization can be anticipated or not.

3.2.3 Linking Strategic Flexibility to Dynamic Perspectives on Strategy

Although the preceding subchapters showed that there is no unique understanding and research agenda on the idea of strategic flexibility in the management literature, three dominant elements were identified. This chapter intends to relate strategic flexibility to existing but independent dynamic perspectives in strategy research. Three streams of literature were identified which share some commonalties and overlaps with the notion of strategic flexibility:

- The dynamic capabilities approach of strategy.
- Mintzberg’s patterns of strategy formation and change.
- The notion of hybrid strategies.

3.2.3.1 Strategic Flexibility and Dynamic Capabilities

Many independent contributions to strategic flexibility argue that strategic flexibility is an organizational capability, which allows changing the organization and its strategy parallel to strategically relevant changes in the business context. Rivoda and Kotha among others propose that eventually *a set of dynamic capabilities generates and maintains strategic flexibility* of an organization and enables it to create new competitive advantage in a changed business context (Rindova V.P., Kotha S. 2001:1275, Lau R.S. 1996: 14, Volberda H.W. 1996: 363). In dynamic settings, where the focus should be on renewing rather than protecting competitive advantage, only a firm capability, which explicitly addresses change, can be a repeated enabler of competitive advantage (Rindova V.P., Kotha S. 2001: 1275). Certainly, there is evidence that competitive advantage can also be sustained in the long-run, even in turbulent business environments, but the more salient point is, that the duration of sustainability is unpredictable in these environments and that the eventual substitution process may be very fast and unnoticeable (Eisenhardt K.M. 2002: 91). Long-term superior performance is not achieved through a protected competitive advantage, but by continuously developing and adapting new sources of temporary competitive advantage and thus being the fastest runner in the competitive race.

During the late 1990s, increasingly dynamic business environments in many technology-intensive industries challenged the original propositions of the resource-based view as being too static and neglecting the influence of changing environments (Wang C.L., Ahmed P.K. 2007: 32). While many global companies appeared to follow a basic resource-based strategy of accumulating valuable technology assets guarded by aggressive intellectual property protection, it is argued that successful companies must additionally demonstrate timely responses and rapid, flexible and sometimes experimental innovations driven by the management capability to effectively coordinate, redeploy, and develop internal and external competencies. It was remarked that some companies accumulate a large stock of valuable technological assets and still do not have any useful capabilities (Teece D.J., Pisano G., Shuen A. 1997: 515). If an enterprise possesses resources and competences but lacks dynamic capabilities, it has a chance to have competitive advantage and superior performance for a limited time period, but it cannot create new forms of competitive advantage in the long-run (Teece D.J. 2007: 1344). Collins and Porras argue that in an environment of increasing ambiguity and complexity the only truly reliable source of stability are not market positions, core competencies or other current sources of competitive advantage but a strong inner core of the organization, which is realized by core values and a core purpose, and the ability and willingness to change and adapt everything – including strategy – except this core (Collins J.C., Porras J.I. 2002). The ability of firms to achieve new forms of competitive advantage on a regular basis and therefore to sustain firm success is called dynamic capability in the late strategic management literature. While the term dynamic refers to the capacity to regenerate competence as business environment change over time, the term capability should emphasize the key role of strategic management in adequately adapting, integrating and reconfiguring internal and external competencies (Teece D.J., Pisano G., Shuen A. 1997: 515). The ambition of the dynamic capability approach to strategy is nothing less than to explain the sources of superior firm performance over time in today's turbulent business environment (Teece D.J. 2007: 1320).

The dynamic capability approach can be interpreted as a dynamic extension to the resource-based school of strategy. This new approach places less emphasis on the exploitation of a firm's current stock of resources and competences but focuses more on the firm's ability to continuously regenerate new or improved competences over time. The term dynamic capabilities also stresses the importance of path-dependency of current capabilities and the importance of a firm to renew, augment and adapt its capabilities in the future to sustain an adequate performance. A dynamic capabilities framework of strategy focuses on how a firm will build their core competencies over time and thereby develop new forms of competitive advantage. Emphasis is placed on the need for firms to continually improve themselves by upgrading and develop new and existing core competencies. It is argued that no static asset, resource, or market position can be a source for sustainable competitive advantage, because the advantage will eventually either become obsolete or gets imitated (Bierly P.E., Chakrabarti A.K. 1996: 368f).

Teece and colleagues offered one of the first conceptual discussions of the notion dynamic capabilities and offered a definition which is based on the work of Leonard-Barton (Leonard-Barton D. 1995). They define dynamic capabilities as the firm's ability to integrate, build, and reconfigure internal and external competences to address changing environments to achieve new forms of competitive advantage (Teece D.J., Pisano G., Shuen A. 1997: 513). Zollo and Winter define dynamic capabilities, quite generically, as a learned pattern of collective activity in an organization, through which it systematically generates and modifies its routines (Zollo M., Winter S. 1999: 10). Their view of dynamic capabilities can be interpreted second-order routines or as routines to modify routines. Winter also proposes that dynamic capabilities enable a company to demonstrate *generic flexibility* when facing unanticipated changes in high-velocity environments (Winter S.G. 2007).

Eisenhardt and Martin describe dynamic capabilities as a firm's processes that use resources – specifically the processes to integrate, reconfigure, gain and release resources – to match and even create market change and the organizational and strategic routines by which firms achieve new resources and configurations as markets emerge, collide, split, evolve and die (Eisenhardt K.M., Martin J.A. 2000: 1107). They argue that dynamic capabilities are identifiable and consist of specific strategic and organizational processes, routines and principles within product developing and strategic decision making. They further state that, opposed to core competencies, which are inherently firm-specific and not transferable, dynamic capabilities are somewhat generic in their principles and only firm- and context-specific in their details (Eisenhardt K.M., Martin J.A. 2000: 1108). This implicitly states that there could be a "best-practice" set of dynamic capabilities, which can be identified and recommended. Eisenhardt and Martin also emphasize that not dynamic capabilities themselves are sources of competitive advantages, but they enable a company to continuously reconfigure and add resources and competencies as sources of competitive advantage (Eisenhardt K.M., Martin J.A. 2000: 1117).

Wang and Ahmed define dynamic capabilities as a firm's behavioral orientation constantly to integrate, reconfigure, renew, recreate its resources and capabilities and most importantly upgrade and reconstruct its core capabilities in response to the changing environment to attain and sustain firms success (Wang C.L., Ahmed P.K. 2007: 35). They argue that the ability to apply capabilities sooner, more astutely and more fortuitously is at the heart of dynamic capabilities. If a firm is viewed as a bundle of resources and capabilities, dynamic capabilities underline the processes of transforming firm resources and capabilities into outputs of such form as products and services that deliver superior value to the customer. Such a transformation happens in a swift, precise and creative manner and in line with changes in the industry environment (Wang C.L., Ahmed P.K. 2007: 36).

A reasonable distinction between an *adaptive* and *absorptive* dimension of a dynamic capabilities emerged in the recent strategic management literature (Wang C.L., Ahmed P.K. 2007 37ff): *Adaptive capabilities* are seen as a firm's ability to capitalize on emerging opportunities and handle threats, which stress the firm's ability to adapt itself in a timely fashion through flexibility of resources and capabilities with environmental changes. Hence, the focus of adaptive capability is the realignment of an organization and its strategy to changed conditions. In contrast, *absorptive capability* is the ability of a firm to recognize the value of new, external information and to internalize and assimilate these new insights. It highlights the importance of taking in external knowledge combining it with internal knowledge and absorbing it for internal use. It is argued that the ability to evaluate and utilize outside knowledge is largely a function of the level of prior and related knowledge

(Cohen W.M., Levinthal D.A. 1990: 128). While conceptually different the notions of absorptive and adaptive dimensions of dynamic capabilities are highly linked in practice and are proposed to be two sides of the same coin. While any absorptive capability is of little value if adaptive capabilities cannot exploit it, the value of adaptive capabilities can be increased by improved absorptive capabilities.

While there is a lot of research work about dynamic capabilities currently in progress and no final theoretical concept or framework dominates, preliminary conclusions allow integrating the dynamic capability concepts into strategic management (Winter S.G. 2007, Teece D.J. 2007, Helfat C.E. et al. 2007). As shown in Table 3-6, the idea of a capability hierarchy allows for some further understanding of dynamic capabilities (Winter S.G. 2003: 992, Wang C.L., Ahmed P.K. 2007: 36). The authors basically distinguish the available resources and capabilities of an organization into four orders. Although they are not regarded as a direct source of competitive advantage, dynamic capabilities or third-order capabilities are proposed to be the highest and most generic capabilities an organization can possess.

Table 3-6: Hierarchies of organizational capabilities.

Order	Terminology	Source of Competitive Advantage	Firm Specificity
Zero-order capabilities	Simple factors of production	No	Unspecific
First-order capabilities	Resources	Yes, if distinctive resources;	Unspecific in principle, firm-specific in access and availability;
Second-order capabilities	Capabilities or competences	Yes, if core capabilities or competences (VRINE criteria);	Highly firm-specific, cumulative and path-dependent;
Third-order capabilities	Dynamic capabilities	No source of competitive advantage but the capability to develop new competitive advantage;	Generic in principle, firm-specific realization;

Although literature of the emerging field of dynamic capabilities does only occasionally refer do the older notion of strategic flexibility it is argued that the concepts of absorptive and adaptive dynamic capabilities are essentially equivalent to the already discussed notion of proactive and reactive strategic flexibility. Absorptive capabilities allow a firm to absorb information on strategically relevant future changes in the business context, to interpret it and transform related opportunities and threats into specific initiatives of the firm. Adaptive capabilities allow firms to adapt itself and its strategy when strategically relevant changes are occurring. It is therefore proposed that absorptive and adaptive dynamic capabilities of organizations are the basic enablers of strategic flexibility.

3.2.3.2 Strategic Flexibility and Mintzberg's Patterns of Strategy Formation and Change

One of the earliest and most substantial criticisms of the conventional and static notions of strategic planning and positioning was formulated by Henry Mintzberg (Mintzberg H. 1973, Mintzberg H. 1978). Already in 1973, Mintzberg concluded that flexibility within strategic plans and the flexibility to change strategic plans are necessary to react to changes in the environment (Mintzberg H. 1973: 53, Mintzberg H. 1987a: 73ff). In his later research on the strategy formation process, Mintzberg observed that the notion of strategy as an intended plan must be complemented by an additional concept to be able to fully analyze strategy content and process within organizations. While strategy and decision makers may actively formulate a strategy through a conscious process before beginning to implement it, strategy may also form gradually, incrementally and perhaps unintentionally in real-time as decisions are made one by one (Mintzberg H. 1978: 935). This integrated view of strategy may be more consistent with strategy in real-world settings and also helps to operationalize the concept of strategy for ex post analysis (see Figure 3-8).

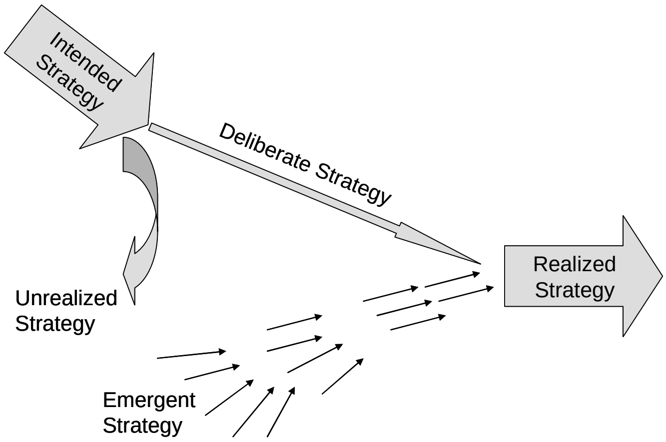


Figure 3-8: Deliberate and emergent strategies (adapted from Mintzberg H., Waters J.A. 1985: 258).

Basically Mintzberg proposes to distinguish five elements in the pattern of strategy formation and change over time (see Figure 3-8):

- *Intended strategies* which are implicitly or explicitly formulated strategic plans.
- *Deliberate strategies* which are strategies that are realized as intended. These strategies are executed as planned and formulated a-priori.
- *Unrealized strategies* which are intended strategies that are prepared but never executed.
- *Emergent strategies* are strategies which are realized but were never intended. These emergent strategies consist of strategies, which displace unrealized intended strategies and new strategies, which were never intended.
- *Realized strategies* are all ex post realized strategies.

Mintzberg's view of strategy formation and change over time revolutionized research on strategy by enabling an operationalization of strategy besides prescriptive planning routines. Analyzing the realization of strategy as a combination of deliberate and emergent strategies by identifying plans and actual decision patterns, enabled the historically observation of strategy in business environments. These observations of strategy formation do not automatically imply the notion of success and superior performance. There may be beneficial but unrealized strategies, which were formulated and communicated but never successfully implemented because of limited resources. There may also be emergent strategies, which were not beneficial but were not restricted and eventually became fully realized (Mintzberg H., McHugh A. 1985: 260). While in more stable environments the majority of realized strategies may be deliberate, in more turbulent environments emergent strategies may dominate. For a realized strategy to be completely deliberate, at least three conditions have to be satisfied (Mintzberg H., Waters J.A. 1985: 258):

- Existence and formulation of precise goals, objectives and intentions articulated in a relatively precise level of detail.
- Full adoption and acceptance of these intentions throughout the organizations or complete control over alignment and implementation.
- Perfect predictability of external forces in the business context or full control of these external forces.

The authors basically argue that theses assumptions are usually never fulfilled and that purely deliberate and purely emergent strategies are only extreme positions along a continuum of possible combinations. They propose that all observable strategy formation processes in real-world organizations are eventually combinations of deliberate and emergent strategies. Concluding from Mintzberg's observations of patterns in strategy formation and change, an organization should be able to:

- Consciously reformulate a new intended strategy.
- Permanently identify and evaluate intended strategies, which prove to be obsolete or unsuccessful.
- Fully implement and commit to successful intended strategies by eventually realizing them.
- Allow and stimulate the emergence of new or alternative strategies within the organization and enable adoption of promising ones.

When relating the notion of strategic flexibility to Mintzberg's observations, it can be concluded that strategic flexibility is related to both domains, intended and emergent strategies. Flexibility may be build-in into intended strategies as *flexible plans*, which allow management to incrementally commit, change, reverse decisions and eventually realize or not realize intended strategies (Mintzberg H. 1973: 53), or may be realized as *deliberate emergence* in the sense that management intentionally creates conditions under which unintended strategies can emerge (Mintzberg H., Waters J.A. 1985: 263).

3.2.3.3 Strategic Flexibility and Hybrid Business Strategies

Conventional strategy concepts argue that generic or pure strategies are prerequisites for superior firm performance and profitability, and a stuck-in-the-middle position, a non-generic, hybrid or non-pure strategy is always inferior to these generic strategies (Porter M.E. 1980, Porter M.E. 1985, Porter M.E. 1996). This argument was also made for alternative sets of generic or pure strategies, which are not as prominent and widely adopted as Porter's (e.g. Miles R.E., Snow C.C. 1978, Treacy M., Wiersema F. 1995). Porter strongly argues for strategic purity when he states (Porter M.E. 1985: 17):

> *"Becoming stuck in the middle is often a manifestation of a firm's unwillingness to make choices about how to compete. It tries for competitive advantage through every means and achieves none, because achieving different types of competitive advantage usually requires inconsistent actions."*

Additionally to these and similar compelling arguments, there is empirical evidence that emphasis of a generic strategy in contrast to hybrid strategies leads to superior performance in terms of financial results (Thornhill S., White R.E. 2007, Campbell-Hunt C. 2000). Applying a similar diction to the notion of generic or pure strategies of the market-based view of strategy, hybrid strategies are temporary or indefinite, sequential or simultaneous combinations of generic business strategies (e.g. Fleck A. 1995, Jenner T. 2000, Peters D. 2002). Empirical evidence suggests that firms, which pursue generic strategies, have higher economic performance in terms of profitability compared to firms, which do not pursue a pure strategy. (Thornhill S., White R.E. 2007: 560, Thornhill S., White R.E., Raynor, M.E. 2007: 5f). Additionally, the so-called *Bowman's Risk-Return Paradox* of strategic management suggests that the pursuing of a strategy, which maximizes financial return, is not or even negatively correlated with the involved risk (Bowman E.H. 1980). This negative association between expected financial return and risk is unusual, since higher returns are generally thought to require higher risks in most economic theories and models (Andersen T.J., Denkrell J., Bettis R.A. 2007). Taken together these arguments and empirical evidence, it is recommended that a company should pursue generic strategies to maximize return and lower its risk (Thornhill S., White R.E., Raynor, M.E. 2007: 5).

Contrary, recent research suggest that while generic strategies are related to higher financial returns there are also related to higher risk of severe failure. Because of a so-called survivor bias, which indicates that only results of companies that survived can be observed, traditional studies only recognize firms with generic strategies that survived (Thornhill S., White R.E., Raynor, M.E. 2007: 5). Thornhill and his colleagues showed that hybrid strategies yield survivor advantages. A hybrid strategy, called stuck-in-the-middle position by Porter (Porter M.E. 1980), may be a defensible and rational choice for managers who have taken the risk of failure in changing business environments into account. Raynor argues that the same strategy, which maximizes a firm's probability for superior financial performance, also maximizes the probability for total failure (Raynor M.E. 2007: 1). This *strategy paradox* is counter to the *Bowman paradox*, but consistent with the general wisdom of economics and finance. Figure 3-9 visualizes and summarizes the already existing empirical insights on hybrid business strategies (Thornhill S., White R.E. 2007, Thornhill S., White R.E., Raynor, M.E. 2007, Raynor M.E. 2007).

When assuming a two-dimensional strategic space of the two most prominent generic strategies of product differentiation and leadership and operational excellence and cost leadership (Porter M.E. 1980, Treacy M., Wiersema F. 1995), the strategic position of a firm in this strategic space is defined by the intensity and purity of its strategy (see Figure 3-9). Firms in sector A are pursuing pure and intensive enough product differentiation and leadership strategy. Firms in sector B pursue a pure and intensive enough strategy of operational excellence and cost leadership. Firms in sector C are pursuing some combination of the two generic strategies.

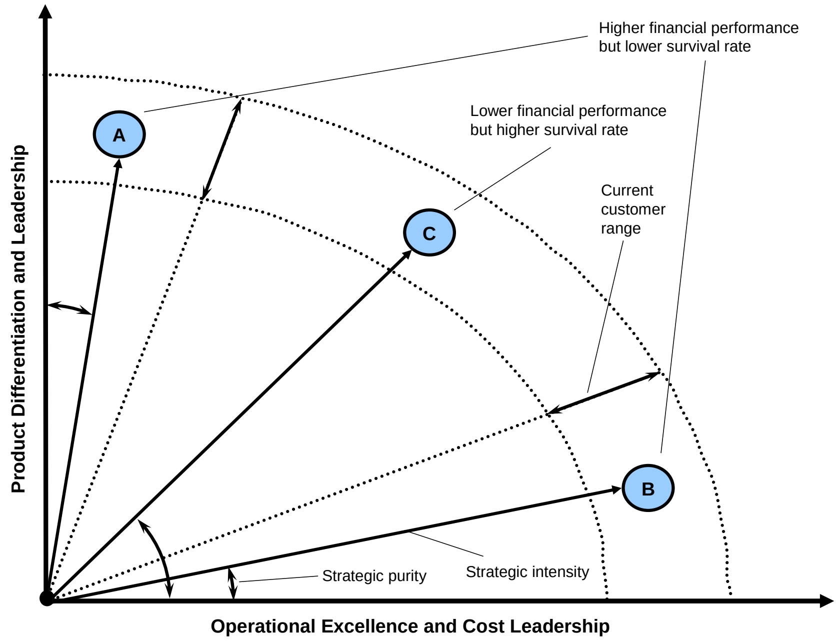


Figure 3-9: ***Strategic purity, financial firm performance and survival rate in a two-dimensional strategic space.***

The empirical evidence suggests that companies with generic strategies, show higher financial performance. Additionally the research showed, that generic strategic positions are significantly related with a higher mortality rate over time (see Figure 3-9):

- Firms with a generic product differentiation and leadership strategy (A) have, in average, a higher financial performance but a lower survival rate than companies with a hybrid strategy (C).
- Firms with a generic operational excellence and cost leadership strategy (B) have, in average, a higher financial performance but a lower survival rate than companies with a hybrid strategy (C).

- Firms with a hybrid strategy (C) have, in average, a lower financial performance but a higher survival rate than firms which pursue generic strategies (A, B).

This empirical evidence suggests that the goals of superior financial performance and firm survival are independent and sometimes even competing. Therefore, it is concluded that the focus of a firm on perfect strategic fit for a generic strategy is not maximizing the firm's probability for survival. The question remains, why firms with generic strategies have lower survival rates and why firms with hybrid strategies have higher ones. Thornhill, White and Raynor propose that firms, which are used to pursue hybrid strategies, are more robust, adaptable and flexible for changes in their business context. The authors conclude that companies with hybrid strategies may have a more diverse resource and capability base and therefore have better chances to survive changes in their business environments (Thornhill S., White R.E., Raynor, M.E. 2007: 22ff). At the opposite, companies, which commit to generic strategic positions, in average generate higher returns, but are in average more critically affected by environmental changes, because of their focused commitment on capabilities, resources and market positions, which exclusively support a pursued generic strategy. Although the young and emerging research on the advantages of hybrid strategies is not directly related to the notion of strategic flexibility, it is concluded that strategic flexibility and hybrid strategies are conceptually linked. Strategic flexibility may enable a company to pursue sequentially or simultaneously hybrid strategies and eventually ensures survival at the cost of reduced short-term financial performance, because of a sub-optimal strategic fit. At the opposite, the conscious pursuit of hybrid strategies by an organization may positively affect its strategic flexibility, as it is suggested that hybrid strategies demand a broader and more heterogeneous resource and capability base.

3.3 An A-Priori Construct for Strategic Flexibility

Although the literature and contributions to strategic flexibility are highly diverse, some common and central elements were identified, which serve as a basis for an a-priori construct of strategic flexibility. It is argued that the three dominant perspectives on strategic flexibility, which were identified in the reviewed management literature, are not mutual exclusive but complementary and interlinked aspects of the same phenomenon. For the rest of this work the following approach to strategic flexibility is adopted:

> ***Strategic flexibility*** *is a* ***state of intended or intentionally endured strategic misfit*** *between the currently attained or pursued strategic positions of competitive advantage, the current business context and the current resource and capability base of an organization. A state of strategic flexibility is* ***created by strategic call option****s on the future adoption of alternative or additional forms and sources of competitive advantage* ***and by strategic put options*** *on the future abandonment of currently pursued or attained forms and sources of competitive advantage. To maintain strategic flexibility, an organization needs* ***dynamic capabilities to absorb*** *strategically relevant upcoming change in its business context by identifying implied opportunities and*

threats and creating adequate strategic options, and ***dynamic capabilities to adapt*** *the organization to strategically relevant change by exercising these strategic options.*

This concluding interpretation suggests that strategic flexibility is a multidimensional construct and quite different in its realization in different contexts. Taking into account the general discussion on the strategy concept, strategic flexibility seems to be a complementary concept to the notion of strategic fit regarding the overall goal of sustainability and survival of a firm in turbulent environments. Reviewed research on the sustainability of competitive advantage and hybrid strategies suggest that today's financial performance is no adequate predictor for future survival. In stable business environments where competitive advantage is sustainable, current firm successes and superior performance is a sufficient criterion for sustainability and survival of a firm. In business contexts, which are affected by strategically relevant change, tomorrow's economic performance of a firm may be completely independent from today's strategic fit, as all competitive advantage is only temporary. There is a conflict of goals that does not exist in stable and predictable business environments and which has to be resolved by an adequate balance between strategic fit and strategic flexibility.

The goal of strategy to sufficiently create or maintain strategic fit must be complemented by strategic flexibility in turbulent environments (see Figure 3-10). Strategic fit is an organizational state of optimal alignment between the current business environment and a company's resources, capabilities and positions, which realizes or maintains competitive advantage. Analog to the state of strategic fit, strategic flexibility can be interpreted as the organizational state of alignment between a company's resources, capabilities and positions, the strategically relevant change in its environment and its strategic options on new forms and sources of competitive advantage. Strategic flexibility in this sense is some form of intentional *static strategic misfit* or *dynamic strategic fit* with the business environment.

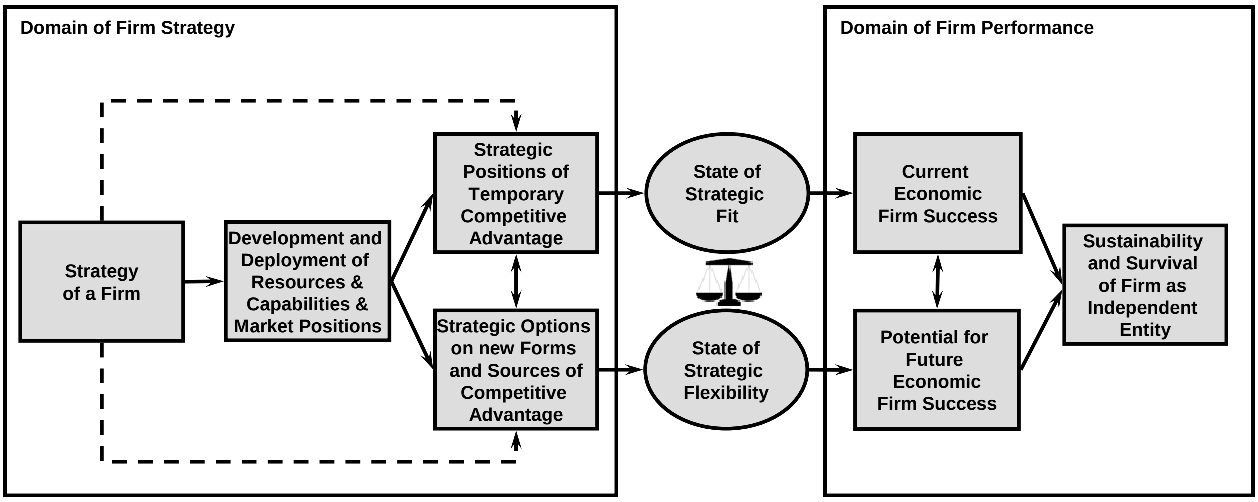


Figure 3-10: ***Integration of strategic flexibility into the strategy concept.***

As argued before, current strategic positions and existing strategic options are dynamically linked over time. Successfully exercised strategic options are transformed into committed strategic positions (strategic call options). Vice versa, current strategic positions can be transformed into strategic options, which prepare the eventually abandonment of strategic positions (strategic put options).

Adding the third perspective of strategic flexibility, a firm has to possess dynamic capabilities to identify, create and exercise adequate strategic options, which are relevant to the upcoming changes in its business context. These dynamic capabilities are part of the overall resource base of a firm. On the one hand, a company needs the ability to absorb upcoming strategically relevant changes by identifying related opportunities and threats to the company and by creating adequate strategic options. These absorptive capabilities allow a firm to transform insights on anticipated relevant change in its business context into strategic options. On the other hand, a company eventually needs the capability to adapt itself by exercising strategic options as soon as strategically relevant changes are affecting its business. These adaptive capabilities allow a firm to transform a strategic option into a committed strategic position.

Parallel to strategic fit with the current conditions in the business environment, strategies of firms in increasingly turbulent environments also have to support an adequate state of strategic flexibility. An optimal strategy creates an adequate balance between strategic fit and strategic flexibility depending on the degree of turbulence in the business environment (see Figure 3-11).

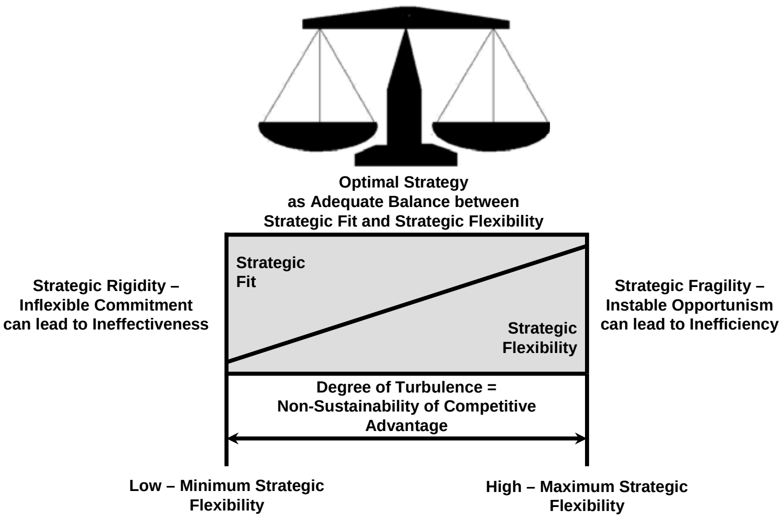


Figure 3-11: ***Optimal strategy creates an adequate balance between strategic fit and strategic flexibility depending on the degree of turbulence in a business environment.***

Applying Weick’s distinction between *total flexibility* and *chronic stability*, it is proposed that there should be a minimum level for both strategic fit and strategic flexibility in a strategy (Weick K.E. 1982). Even in very stable business environments an absolute emphasis of strategic fit in the long-run may lead to strategic rigidity. At the opposite, even in very turbulent business environment, a certain amount of strategic fit avoids inefficient strategic fragility.

4 TECHNOLOGY TURBULENCE IN BUSINESS CONTEXTS

Turbulence in business environments was described as the degree of non-sustainability of competitive advantage a company is facing in its business context because of strategically relevant change. Several authors argue that this turbulence is the reason why companies should complement strategic fit of their strategies with strategic flexibility. As this research is focusing on strategic flexibility in technology strategy, factors that affect the non-sustainability of technology-related competitive advantage are of primary interest. Although many of these factors are related to technological innovation and progress, the non-sustainability of technology-based competitive advantage is also affected by socio-economic and political trends and changes. This chapter reviews the most important empirical and conceptual contributions to the notion of technological change and innovation in business contexts and their impact on competitive advantage. It is aimed to identify why and how technological change and innovation affect the sustainability of competitive advantage in business environments. As a result of this chapter, the major issues related to non-sustainability of technology-based competitive advantage are summarized within an a-priori construct of technology turbulence. Following the proposed research design, this a-priori construct for technology turbulence identifies topics and issues of relevance for theoretical sampling and the data collection process. Figure 4-1 shows technology turbulence as the construct which represents the context of investigation for this research.

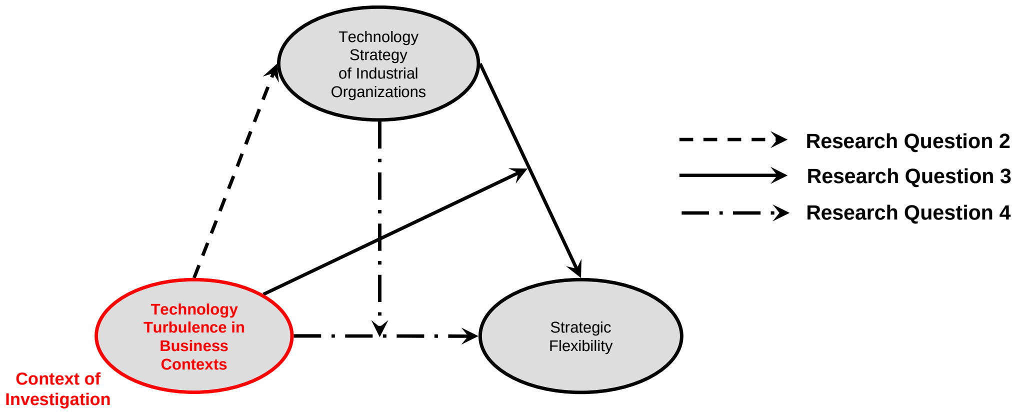


Figure 4-1: Technology turbulence as the investigated context in the overall research design.

4.1 Definitions and Conceptualizations of Technology

At this stage of this work the notion of technology, as it appears in existing management literature, is briefly reviewed. There is no unified and unique definition of technology, which is generally accepted across different scientific communities. In Table 4-1 some important contribution to the definition of technology and its interpretations are listed.

In microeconomic theory it is usual to use the notion of technology in terms of an industrial production function for goods. Therefore, primarily the domain of manufacturing technology is captured by these interpretations (e.g. Rosenberg N. 1972). Within this definition, technological innovation is interpreted as a more advantageous production function and as a shift of the production possibility frontier, which increases productivity of employed resources and factors of production (Dosi G. 1982: 151). As these interpretations of technology by microeconomic theory exclude technology as produced or sourced product functionalities or material characteristics, its application in business management context seems to be limited.

Table 4-1: Some definitions of technology in literature and their interpretation.

Author	Definition of Technology	Interpretation
Rosenberg N. 1972.	Technology can be defined as those tools, devices, and knowledge that mediate between inputs and/or outputs that create new products or services.	Production function.
Dosi G. 1982: 151.	Technology is a given set of factors' combination, defined qualitative and quantitative in relation to certain outputs.	Production function.
Dosi G. 1982: 151f.	Technology is a set of pieces of knowledge, both directly practical and theoretical know-how, methods, procedures, experiences of success and failures and also physical devices and equipment.	Artifacts, knowledge.
Sommerlatte T., Walsh I.A. 1983: 299.	Unter Technologie soll die Anwendung eines naturwissenschaftlichen Wissensbereichs auf industrielle Problemstellungen verstanden werden, wobei ihre Nutzung eine spezialisierte Fachkenntnis erfordert und daher eine Zugangsbarriere aufweist.	Industrial application of scientific knowledge.
Zörgiebel W.W. 1983: 11.	Das Wissen über die naturwissenschaftlichen und technischen Zusammenhänge, die zur Lösung technischer Probleme genutzt werden können und sich dadurch in Produkten und Verfahren niederschlagen.	Knowledge, artifacts.
Ketteringham J.M., White J.R. 1984: 502.	To be a useful concept for analysis, a technology should fit the form: "We know how to ______(verb) ______ (noun). Example: "We know how to formulate PVC resins."	Application of know-how.
Perillieux R. 1987: 12.	Das Wissen über naturwissenschaftliche und technische Zusammenhänge, soweit es Anwendung bei der Lösung technischer Probleme finden kann.	Scientific and technical knowledge.
Abetti P.A. 1989: 37.	A body of knowledge, tools and techniques, derived from both science and practical experience, which is used in the development, design, production and application of products, processes, systems and services.	Artifacts, knowledge.
Adler P.S. 1989: 26.	Reproducible capabilities, whether these capabilities are embodied in procedures or equipment.	Capabilities.
Burgelman R.A., Rosenbloom R.S. 1989: 2.	Technology is defined as the ensemble of theoretical and practical knowledge, know-how, skills and artefacts that are used by a firm to develop produce and deliver its products and services. Technology can be embodied in people, materials, facilities, procedures, and physical processes.	Artifacts, knowledge.
Saad K.N., Roussel P.A., Tiby C. 1991: 27.	Die Anwendung von wissenschaftlichen und technischen Kenntnissen, um ein praktisches Ergebnis zu realisieren.	Application of technical and scientific know-how.
Cleemann L., Pfeiffer S. 1992: 113.	Naturwissenschaftlich-technische Wissensbasis für Produkt- und Verfahrensinnovationen.	Scientific and technical knowledge.
Itami H., Numagami T. 1992: 119.	Technology is a systematic body of knowledge about how natural and artificial things function and interact which is embodied in human brains and muscles, machines, software and standard operating procedure of the organization.	Knowledge.

Author	Definition of Technology	Interpretation
Khalil T.M. 1993: 64.	All the products, processes, tools, methods and systems employed in the creation of goods or in providing services.	Employed artifacts.
Van Wyk R.J. 1993: 2.	A set of means created by people to facilitate human endeavor.	Set of means.
Vernet M., Arasti M.R. 1999: 295.	Technology is a combination of scientific and technical knowledge and know-how that is embodied in a product, service, process, information system or a management method.	Embodied knowledge.
Gerpott T.J. 2005: 17.	Allgemein wissenschaftlich fundierte Kenntnisse über Ziel-Mittel Beziehungen, die bei der Lösung praktischer Probleme von Unternehmungen angewendet werden können.	Scientific knowledge.
Shane S. 2009: 4.	The application of tools, materials, processes, and techniques to human activity.	Application of artifacts.

While an adequate and generally accepted definition of technology would certainly help to specify the unit of analysis for further use in management routines of technology management, the provided diverse definitions in Table 4-1 and other research suggests that the notion of technology and its use are highly context sensitive (Gerpott T.J. 2005: 19). The notion of technology is often used differently, depending on the context of a certain industrial or firm setting. While in recent years there has been a tendency in popular media and every day language to use the phrase technology when actually talking about digital information and communication technology, this is not the case in this work (Shane S. 2009: 4).

Most of the reviewed definitions for technology have significant overlaps, but some definitions are quite contradictory: While Itami and Numagami emphasize that technology has both a tacit and explicit component (Itami H., Numagami T. 1992: 119), others define technology as knowledge, which is always embodied in tangible artifacts (Vernet M., Arasti M.R. 1999: 295). Alternatively, different authors describe technology simply as scientific and technical knowledge (Cleemann L., Pfeiffer S. 1992: 113). Following the example of other scholars in the domain of technology management, both is avoided: The exclusive adoption of an existing definition and the formulation of an additional one (Lichtenthaler E. 2002: 7). For this research a pragmatic interpretation of technology is adopted. This includes pure forms and combinations of scientific and technical knowledge, practical experience and know-how, whether completely, partly or not embodied in tangible artifacts. This implies technologies that are integrated into manufactured goods (product and material technologies) and technologies integrated into the routines that manufacture these goods (process and material technologies).

A meta-analysis of various definitions and interpretations of technology reveals that diversity in technology definitions also created multiple dimensions for categorizing and classifying technology. Gerpott's meta-analysis of reviewed conceptualizations and categorizations of technology is presented in a modified and extended form in Table 4-2 (adapted from Gerpott T.J. 2005: 26f).

Table 4-2: Forms of technology categorization in the literature (adapted from Gerpott T.J. 2005, 26f).

	Attribute of Differentiation	Realization of Attribute	Authors
Technology related	Area of application.	Process technology Product & service technology Material technology Organizational and management technologies	Utterback J.M., Abernathy W.J. 1975, Abernathy W.J., Utterback J.M. 1978, Teece D.J. 1986, Huber F. 1990.
Technology related	Realization as artifact.	Embodied technology Disembodied technology	Dosi G. 1982, Nicholls-Nixon C.L. 1995, Burgelman R.A., Rosenbloom R.S. 1989.
Technology related	Degree of appropriability and transferability.	Implicit, tacit technology Explicit, codeable technology	Teece D.J. 1986, Freeman C., Soete L. 1997, Bone S., Saxon T. 2000, Gerpott T.J. 2005.
Industry related	Degree of product or functionality relevance.	Core technology Peripheral (non-core) technology	Contractor F.J., Narayanan V.K. 1990.
Industry related	Relationship to other technologies in the industry.	Substitutive technology Complementary technology Supplementary technology	Servatius H. 1985, Perillieux R. 1987, Perillieux R. 1991, Gerpott T.J. 2005.
Industry related	Technology significance and industry importance.	Base technology Key technology Pace technology Emerging technology	Little A.D. 1981, Servatius H. 1985, Saad K.N., Roussel P.A., Tiby C. 1991, Floyd C. 1997, Chiesa V. 2001.
Industry related	Industry specificity.	Cross-industry technology Industry-specific technology	Perillieux R. 1987, Wolfrum B. 1991, Perillieux R. 1991.
Industry related	Position in technology life-cycle.	Emerging technology Developed technology Mature technology	Perillieux R. 1987, Perillieux R. 1991.
Firm related	Technology rareness and diffusion.	Distinctive technology Basic technology External technology	Ford D. 1988.
Firm related	Source of competitive advantage.	Core technology Non-core (me-too) technology	Burgelman R.A., Rosenbloom R.S. 1989.
Firm related	Technology attractiveness and company's position.	Core technology Left-over technology Dead-end technology	Jolly D. 2003.

One important issue in defining and categorizing technologies along a certain dimension is to be able to conceptualize it for further analysis. The abstract notion of technology itself is difficult either to disembody or conceptualize for analysis (Clarke K., Ford D., Saren M. 1989: 228). A classic distinction of technologies is between process and product technology, which is emphasized by various authors. Product technology centers on the design, substance and function of what is sold, while production technology is concerned with being able to produce products consistently at an appropriate level of quality (Ford D. 1988: 85). It is easily recognized that the distinction between product and process technology is not absolute, but depends always on the position in the value chain. The product technology of an equipment manufacturer or tool-maker is the process technology of the buyer of equipment and tools. Because of their rising importance, various authors propose material technologies and organizational and management technologies as additional and distinctive categories. Technologies can also be distinguished by their relationship to already employed technologies in a firm. While substitutive technologies compete with already employed technologies, because they fulfill similar functions in the product or process, complementary technologies create some form of synergistic value, if combined or bundled. Supplementary technologies have a neutral position to already used or employed technologies. A broad analysis of the categorization of technologies along different dimensions reveals, that technologies are roughly distinguished by criteria, which are either inherent to the technology itself, specific to a certain industry or specific to the perspective of a single company.

4.2 Technological Change and Innovation in Business Environments

Technological innovation can be seen as the process of configuring and employing knowledge, tools, materials, processes, and techniques to come up with new solutions to problems (Shane S. 2009: 6). Adopting Freeman's interpretation, this process includes the technical, design, manufacturing, and commercial activities involved in the innovation of a new or improved technical product or the first use of a new or improved manufacturing process or equipment (Freeman C., Soete L. 1997). The following subchapter reviews widely accepted models and conceptual frameworks for technological change and innovation in business environments, to identify potential forms of technology turbulence relevant to this research.

4.2.1 The Notion of Technology Paradigms and Trajectories

Technological evolution within and across industry boundaries depends on the process through which scientific advance occurs. New advances are made as answers are searched for current technical problems, building on prior knowledge that has accumulated. It seems plausible that technological progress in business environments does not happen within in a closed system around the object of innovation, like an existing product technology, but within a certain, currently valid, technology paradigm. A technology paradigm could be described as the interrelated and over time accumulated system of know-how and frameworks within which technical problem emerging and solving occurs (Shane S. 2009: 19). This interrelated and accumulated system is a model and a pattern of solutions for selected technological problems based on selected principles derived from natural sciences and on selected material technologies (Dosi G. 1982: 152). The notion of technological paradigms is extending the view of technology in industrial business contexts. Technology in business context is not only a distinguishable entity, as proposed by some of the above definitions, but is also always embedded in a bundle of technologies or a wider and interrelated technological system within and across industries (Rycroft R.W., Kash D.E. 2002). The technology configuration of a firm at a certain time can be seen as the sum of all technology paradigms it integrates in its activities (Clarke K. 1992: 34). Analog and chemically based photography, for example, can be interpreted as a technology paradigm. It consists of a bundle of know-how, tools, methodologies and technologies and was accumulated in a path-dependent process of research, development and engineering over a period of time. The shift to digital technology made many components of this technology paradigm obsolete. In industry contexts a bundles of product and process technologies have to interact to enable a certain application or to fulfill a desired functionality. Although the development and potential of a single technology is of interest, its impact on and interaction within the overall technology configuration is very important.

While the development of a technology paradigm itself does not follow a simple pattern but is very complex and in most cases can only be analyzed ex post, stages in the evolution of technology paradigm can be identified. Hamilton identified three stages in the evolution of a technology paradigm, each dominated by a different driving force for technological progress (Hamilton W.F. 1990: 142). Figure 4-2 shows these shifts in relative importance of each of these drivers, namely scientific research, technology development and engineering of commercial applications.

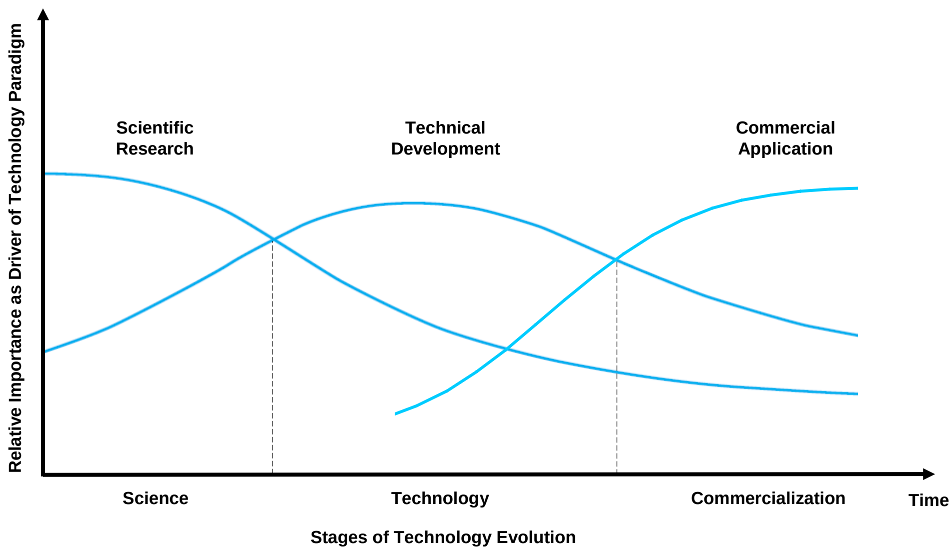


Figure 4-2: ***Stages in the evolution of a technology paradigm (adapted from Hamilton W.F. 1990: 142).***

The early phase in the evolution of a technology paradigm is driven by pure scientific research. When basic scientific principles and feasibility are confirmed, necessary technology development and standardization are emphasized. In the commercialization phase application engineering is driving the creation and identification of exploitation possibilities for the underlying technology paradigm (Hamilton W.F. 1990: 142).

The tendency of technology innovators, regardless if researchers, scientists, engineers, firms or complete industries, to develop technological innovations within the frame of a currently valid technology paradigm leads to the creation of technology trajectories, which could be described as the path of improvement and progress of a certain technology along certain dimensions. While a technology paradigm can be described as the immediate technological system in which a specific technology is embedded, a technology trajectory can be seen as the currently followed vector of improvement. Dosi defines this trajectory as the direction of advance within a technological paradigm and as a pattern of normal problem solving activity or progress on the ground of a technology paradigm (Dosi G. 1982: 148, 152). The development of analogue photography along the dimensions of picture quality in terms of resolution, sharpness, contrast and color quality or the development of microprocessors along dimensions of speed, energy consumption, size, and heat emission can be seen as a technology trajectory. It is important to recognize that this evolution of technology is not only driven by scientific advance. The path, along which a technology paradigm develops, its technology trajectory, is heavily influenced by social, economic and political forces in business environments (Shane S. 2009: 19). Although technology paradigms and trajectories have an important function in focusing innovation and research efforts in an industry, they have also a downside: Existing and strong paradigms and trajectories tend to limit the alternatives that R&D personnel are willing to consider in their innovation efforts and consequently could keep researchers and engineers from identifying fundamentally different but maybe better alternatives (Dosi G. 1988). It is concluded that the technology configuration of a company is a combination of single technologies and technology paradigms, which develop along certain and currently valid technology trajectories. If a pursued or attained strategic fit of a company is significantly based on the current technological configuration, obsoleteness or substitution of technology paradigms and changes in the direction of technology trajectories are affecting competitive advantage. By forestalling insights from the collected empirical data, Case vignette 4-1 gives an example for a change in technology paradigm and trajectory in an industry.

Case vignette 4-1: Changing technology paradigms and trajectories in business environments.

The automotive industry is currently experiencing a parallel change in technology paradigms and trajectories. While the dominating technology paradigm for automotive engines, the internal combustion engine driven by gasoline or diesel fuel, is threatened by alternative engine concepts (diverse variants of hybrid engines, electrical engines, hydrogen engines, fuel cell and natural gas engines), the direction of the technology trajectory for automotive engines is also shifting. While technical performance dimensions, engine geometry and size attributes were initially the most dominating performance criteria, currently low emissions, low fuel consumption, and reduction of engine noise, vibration and harshness are becoming increasingly important. While the emergence of alternative technology paradigms for automotive engines is mainly based on technological innovation within and beyond the boundaries of the automotive industry (e.g. battery technology), the new trade-off and emphasis of relevant performance dimensions is based on global socio-economic trends like the environmentalism movement and new or stricter national and international emission regulations and policies of governments. Companies in the paper, pulp and steel and metal manufacturing and processing industries with plants in western high-wage countries are also experiencing a shift in technology trajectories based on a global trend of environmentalism and increasingly restrictive emission regulations. Today, holistic considerations on energy efficiency and minimization of emissions of plants are increasingly dominant drivers of technological innovation in these industries (see Appendix C # 1, 10, 23, 57, 61, 69, 84, 109, and 114).

4.2.2 General Patterns of Technology and Industry Evolution

The development of a technology trajectory for a single technology or technology paradigm along a certain dimension can be visualized as a two-dimensional graph. This S-curve concept for mapping the development of a technology or technology paradigm over cumulated R&D&E efforts and technology performance was introduced by Foster (Foster R. 1986). The notion S-curve follows the observed shape of the curve in the case of an ex post analysis of a successful technology (Shane S. 2009: 22). Figure 4-3 shows a generic technology S-curve. S-curves are often used as graphical metaphors for technologies and usually show the development of a technology paradigm along a certain relevant performance indicator over time or cumulated efforts.

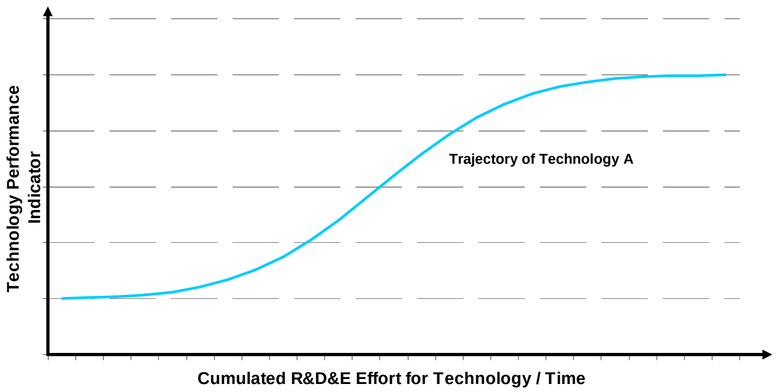


Figure 4-3: Technology trajectory along a specific performance dimension as S-curve.

The graphical representation of technology trajectories as S-curves can be interpreted as the life-cycle of a technology or technology paradigm. The early and late phases of a technology in its life-cycle show lower rates of marginal performance improvement over time, while the phase in between shows a higher frequency of technology improvements. In some cases successful technology paradigms in industries, embodied in products, services, and processes, develop a certain design architecture or a common way that most companies adopt in the industry. This valid architecture is called dominant design and emerges as a combination of proven concepts and product-class standards (Abernathy W.J., Utterback J.M. 1978, Tushman M.L., Anderson P. 1986: 441, Shane S. 2009: 29). Once a dominant design emerges, it becomes a guidepost for incremental innovations along a technological trajectory and for further product or process change (Abernathy W.J., Clark K.B. 1985). Anderson and Tushman empirically explored a cyclical model of technological change, which is presented in an adapted form in Figure 4-4 (Anderson P., Tushman M.L. 1990).

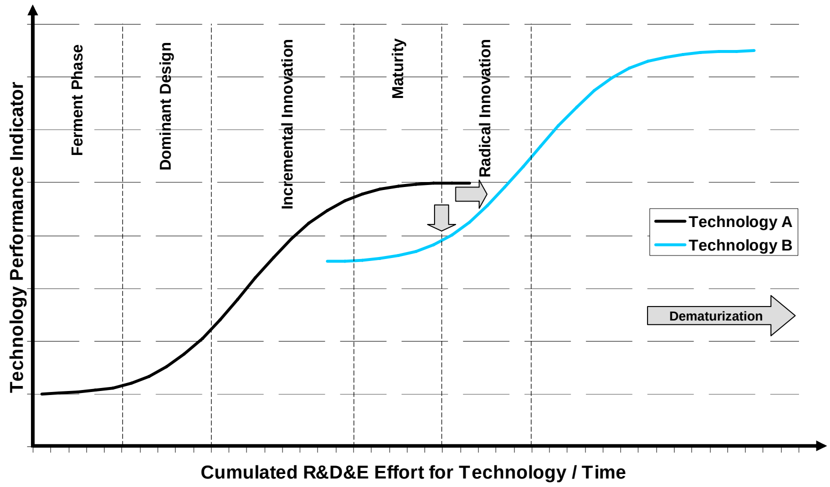


Figure 4-4: ***Technology development and transition in the S-curve model (adapted from Anderson P., Tushman M.L. 1990).***

An introduction of a new technology (technology A in Figure 4-4) in business environments is usually related to slow improvements in performance over cumulated efforts, as existing and new organizations either struggle to develop, adopt or fight the new technology. This ferment phase is dominated by competition between the new technology and the existing and mature technologies in the industry and by competition between variations of the new technology paradigm. In the case of success, this twofold competition ends with the emergence of a new dominant design. The dominant design is continuously improved by incremental innovations, which maintain the basic product architecture. The model proposes that most technology paradigms reach a limit in terms of science and technology specific boundaries and performance limitations. This is reflected by diminishing marginal performance improvements over necessary efforts for further improvements within the currently valid dominant design. This flattening of the technology trajectory may create opportunities for new or alternative technologies to substitute the currently valid technology paradigm by a radical innovation. This model and its visualization implicitly assume that that relevant and dominant performance dimension, represented by the y-axis in Figure 4-4, remains the same.

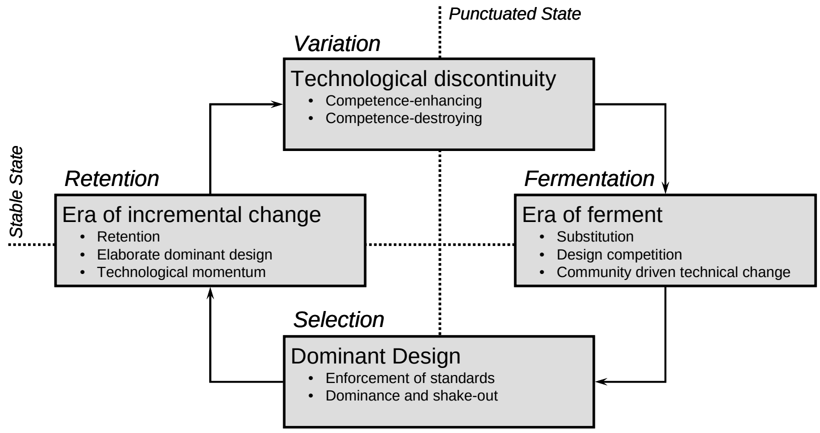


Figure 4-5: Cyclical patterns of technological change (adapted from Tushman M.L., Rosenkopf L. 1992).

Figure 4-5 is showing the cyclical patterns of technological change proposed by Tushman and Rosenkopf (Tushman M.L., Rosenkopf L. 1992). The dynamics of technological change in an industrial environment can be regarded as a closed cycle. A stable state of retention is punctuated by a technological discontinuity. This induces variation of technologies, products and firms and initiates a stable era of ferment, which includes a growth of new industry entrants. This era of ferment is terminated by the emergence of a dominant design, where selection and standardization of technologies starts to take place. After a shake out of abandoned technological concepts and related firms, a stable phase of incremental change within the dominant design begins.

Although many definitions, interpretations and categorization of technologies emphasize the distinction between process and product technologies, the notion of technology paradigms, trajectories and dominant designs, which were identified by studying the co-evolution of industries and technologies over time, indicate, that this distinction may not be practical. One important observation about technological innovation in business environments is on the relationship between product and process technology innovations within the development of a technology paradigm. While the S-curve represents the life cycle of a single technology or technology paradigm on an aggregated level, the model of Utterback and Abernathy explicitly distinguishes the patterns of product and process innovation to identify their inherent relationship in the development of a technology paradigm. Already in 1975 Utterback and Abernathy found evidence that this relationship follows a certain pattern over the development stages of eventually successful technologies (Utterback J.M., Abernathy W.J. 1975: 645). When a dominant design is emerging, the focus of technological innovation shifts from product to process technologies (Teece D.J. 1986: 289). This basic pattern is shown in Figure 4-6.

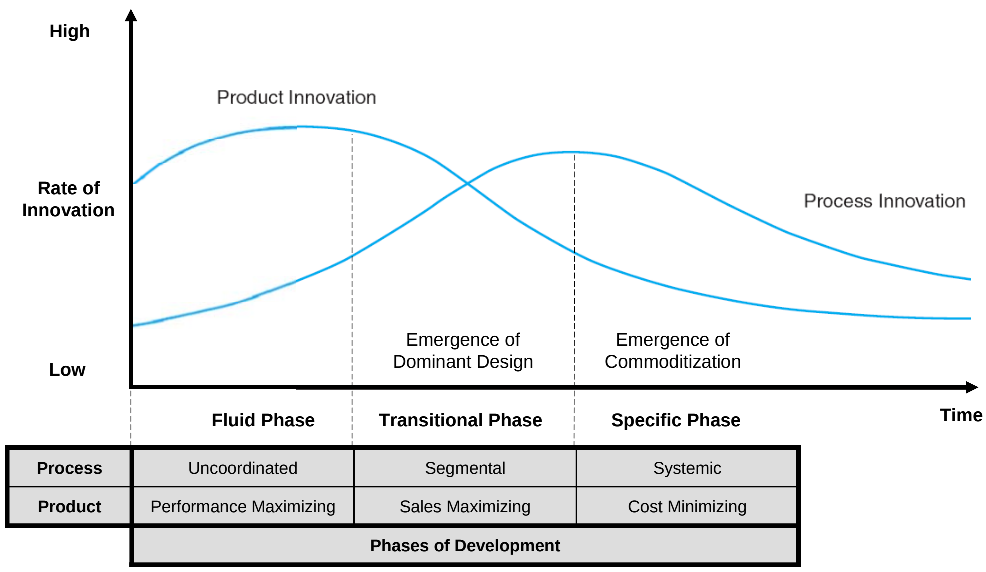


Figure 4-6: ***Rate of technological innovation and the development of a dominant design (adapted from Utterback J.M., Abernathy W.J. 1975: 645, Teece D.J. 1986: 289).***

In this model a product innovation is a new technology or combination of technologies introduced commercially to meet a user or market need, while a production process innovation is a innovation in the system of process equipment, work force, task specifications, material inputs and information flows that are employed to produce a product or service (Utterback J.M., Abernathy W.J. 1975: 641f). The main argument here is that technological innovations in product and process technology are strongly interdependent along the development of a dominant design and must be analyzed and addressed holistically (Utterback J.M., Abernathy W.J. 1975: 644, Abernathy W.J., Utterback J.M. 1978: 43, Kantrow A.M. 1980: 6). Abernathy calls this combination of product and process technologies, which should be addressed together, the *productive unit* (Abernathy W.J. 1978: 148). The model relates the rates of product innovations and process innovations within the development of a productive unit. Three phases, the fluid phase, the transitional phase and the specific phase are distinguished in this model (see Table 4-3).

Table 4-3: ***Patterns of process and product innovation within the evolution of a productive unit (Abernathy W.J., Utterback J.M. 1978: 40, Utterback J.M. 1994: 94f).***

Attribute	Fluid Phase	Transitional Phase	Specific Phase
Competitive emphasis	Functional product performance.	Product variation.	Cost reduction.
Innovation stimulator	Information on potential customers' and users' needs.	Opportunities created by expanding internal technical capabilities.	Pressure to reduce costs and improve quality.
Dominant type of innovation	Frequent major changes in products.	Major process changes required by rising volume.	Incremental for product and process, cumulative improvement in productivity and quality.
Product line	Diverse, often including custom designs.	Includes at least one product design stable enough to have significant production volume.	Mostly undifferentiated standard products.

Attribute	Fluid Phase	Transitional Phase	Specific Phase
Production process	Flexible but inefficient; major changes easily accommodated.	Becoming more rigid, with changes occurring in major steps.	Efficient, capital-intensive and rigid, costs of change are high.
Equipment	General purpose, highly skilled labor.	Some process islands of automation.	Special-purpose, mostly automatic with labor tasks mainly controlling and monitoring.
Materials	Inputs are limited to generally available material.	Specialized materials may be demanded from suppliers.	Specialized materials via market or vertical integration.
Plant	Small scale, near potential user and customer.	General purpose with specialized sections.	Large scale, highly specific assets.
Organizational control	Informal, entrepreneurial.	Temporary forms in projects and tasks.	Emphasis on structure, processes, goals and norms.

The links between a technology and its product or process applications need to be seen as a strong, entangled relationship with little concept of a single technology itself as a disembodied notion. One following implication is that the analysis of technology evolution in business environments needs to be oriented toward the concept of a technology cluster, bundle or paradigm rather than individual technologies (Clarke K., Ford D., Saren M. 1989: 224). The most central characteristic of dominant design is the emergence of a dominant product architecture, which allows changing the focus of R&D from product innovations to process innovations. The Abernathy-Utterback model does not characterize all technology developments in all industries. Most of the empirical observations for this model were made in the scale-intensive North-American automotive industry in the 1970s. (Abernathy W.J. 1978) Similar to the notion of dominant design itself, the model seems to be more suited for industries where economies of scale and learning curve economies are involved, like mass markets for durable consumer goods and assembled products.

The identified patterns of co-evolution of technologies and industries over their life-cycles in this chapter are based on historically ex-post analysis at industry level. They show that most industries go through dynamic cycles of technology development with stable and instable phases and a shifting focus between radical and incremental innovations of product and process technology. From the perspective of a single firm, which is in this co-evolutionary process of technological and industrial progress, it is concluded that a fraction of this technological evolution must take place within the organization to survive and to master cyclical patterns of technological change as a single firm. Forestalling insights from the collected empirical data, Case vignette 4-2 shows, how interviewed companies are acting before a clear dominant design can be identified.

Case vignette 4-2: Diversifying technology portfolio before dominant design emerges.

Some markets and industries of interviewed companies were in phases of fermentation and therefore before the emergence of a dominant technological design. In several cases no technology standards have emerged and several approaches were integrated until a clear "winner" was identified. While in some cases this technological diversity is also caused by different local *regulations, in other cases it is seen as a temporary competition for the best product or process architecture in an industry. Although Company 11 diversified its various technological competences to be able to build highway toll systems all over the world according to local standards, the company is also developing a new technology, which meets all national and international regulations and integrates the advantages of the existing and competing systems. Until a clear winner is identified, Company 17 technologically enables its products to work with multiple standards of wireless communication technology. Company 18 is involved in alternative approaches to produce bio fuel, until a dominant technology has emerged. Company 6 and Company 15 diversified into various technological competences on alternative engine and drivetrain concepts, until a new dominant design for the future automotive drive train can be identified (see Appendix C # 23, 48, 69, 81, and 85).*

4.2.3 Categorization of Technological Change and Innovation

Many categorizations of technological innovation follow the dichotomy, which is proposed in the technology life-cycle models presented in the previous subchapter. A cyclical change between phases of quasi-static and stable equilibrium and dynamic and unstable phases of discontinuity is reflected in most models of technological change in business environments (Utterback J.M. 1994, Tushman M.L., O'Reilly III C.A. 1997, Christensen C.M. 1997). The emergence and disappearance of technological paradigms and trajectories in business environments seem to be inherently related to discontinuities at technology, firm and industry level. In Table 4-4 the most prominent dichotomic categorizations of technological innovation in the business management literature are summarized.

While the continuous improvement process along a technology trajectory is described as an incremental innovation and an evolution of the existing technology paradigm, the substitution of an existing technology paradigm by a new one is considered as radical or revolutionary, because it makes big parts of existing technological assets, expertise and knowledge obsolete. The emergence of a new technology paradigm usually starts a new technology cycle and initiates the ferment phase. A variety of competing products and concepts, which are based on the new paradigms, also compete with products based on the old paradigm (Foster R. 1986). Additionally, a change in the driving and dominant performance dimension of a technology trajectory, which may be completely unrelated to technological progress, is also regarded as a discontinuity. This discontinuity in the relevant performance dimension of a technology trajectory, which could be based on a shift of market preferences, may trigger or enable a substitution of technologies or may lead to a realignment of the current technology configuration of an industry. It is concluded that technology discontinuities in business environments can be initiated by reasons completely unrelated to technological innovation.

Table 4-4: Suggested dichotomic categorizations of technological innovation in the literature.

Attribute of Differentiation		Realization of Attribute	Author
Technology related	Shift to an alternative or new technology paradigm.	Incremental innovation	Schumpeter J.A. 1934, Abernathy W.J., Utterback J.M. 1978, Freeman C., Soete L. 1997.
		Radical innovation	
	Emergence pattern of innovation.	Evolutionary innovation	Utterback J.M. 1994, Abernathy W.J., Clark K.B. 1985, Anderson P., Tushman M.L. 1990.
		Revolutionary innovation	
	Following an established technology trajectory.	Continuous innovation	Dosi G. 1982, Tushman M.L., Anderson P. 1986, Anderson P., Tushman M.L. 1990.
		Discontinuous innovation	
	Regarding the dominant design of process or product technologies.	Modular innovation	Henderson R.M., Clark K.B. 1990, Abernathy W.J., Clark K.B. 1985.
		Architectural innovation	
Industry related	Consequences for existing business models and industry architecture.	Sustaining innovation	Bower J.L., Christensen C.M. 1995, Christensen C.M. 1997.
		Disruptive innovation	
	Impact of disruptive technological innovation for industry incumbents.	Low-end disruptions	Christensen C.M. 1997, Christensen C.M., Raynor M.E. 2003.
		New-market disruptions	
	Origin of initial trigger for technological innovation.	Demand-pull innovation	Dosi G. 1982, Dodgson M. 2000, Gerpott T.J. 2005: 41.
		Technology-push innovation	
	Relationship to underlying technological competences in an industry.	Competence-enhancing innovation	Tushman M.L., Anderson P. 1986 Anderson P., Tushman M.L. 1990, Tushman M.L., O'Reilly III C.A. 1997.
		Competence-destroying innovation	
Firm related	Degree of permeability of innovation system during innovation process.	Closed innovation	Chesbrough H.W. 2003.
		Open innovation	

Abernathy, Clark and Henderson offer an additional distinction of technological innovation (Abernathy W.J., Clark K.B. 1985, Henderson R.M., Clark K.B. 1990). Based on the observation of technological innovations, which are based on the same core concepts of a technology paradigm but changed the principal architecture of the dominant design, the authors highlight the notion of architectural innovations. Additionally, they identify innovations where the core concept on module or component level of the dominant design is substituted by an alternative technology. While this observation offers an explanation how a new dominant design emerges by an architectural innovation based on a new technology paradigm, it also introduces a form of hierarchical structure to technological innovations. A modular design of a product may enable a company to absorb technological innovations as modular or architectural changes, which otherwise are considered to be radical innovations. Similarly, Tushman and Anderson distinguish technology discontinuities in competence-enhancing and competence-destroying (Tushman M.L., Anderson P. 1986). A competence-enhancing discontinuity replaces an existing technology, but is based on significant parts of existing knowledge related to the obsolete technology. A competence-destroying discontinuity occurs, when with the substitution of a technology all underlying knowledge and competence becomes obsolete. Similar to the approach of Henderson and Clark (Henderson R.M., Clark K.B. 1990), the distinction between competence-enhancing and competence-destroying seems to be a question of scope and level within the hierarchy of the technology configuration in an industry. While the first approach dismantles technologies and product designs in modules and components, the second approach differentiates between technology as technological artifacts in form of products and manufacturing assets and the underlying competence and knowledge within the industry.

Christensen and Bower introduce the notions of sustaining and disruptive technological innovations (Bower J.L., Christensen C.M. 1995, Christensen C.M. 1997).While sustaining innovations are consistent with incremental, evolutionary and continuous improvements along existing technology trajectories, disruptive and radical technological innovations are no equivalents. Radical technological innovations in a business environment are shifts to a new technology paradigm, which fulfills or is expected to fulfill existing performance demands better than the current one. Although disruptive technological innovations are also based on new technologies, they are initially inferior to the existing ones along the currently dominating performance dimensions. The authors observed cases where new, but initially inferior technologies sufficed for low-end, niche or low volume market segments, which are underserved, unattractive, ignored or simply missed by suppliers of the superior and dominating technology (see Figure 4-7). An initially inferior and alternative technology trajectory based on a new technology paradigm creates a disruptive potential, when sustaining innovations enable it to substitute and compete with the established technology in its main markets and applications. Christensen and Raynor described this form of technological innovation as low-end disruption (Christensen C.M., Raynor M.E. 2003: 47).

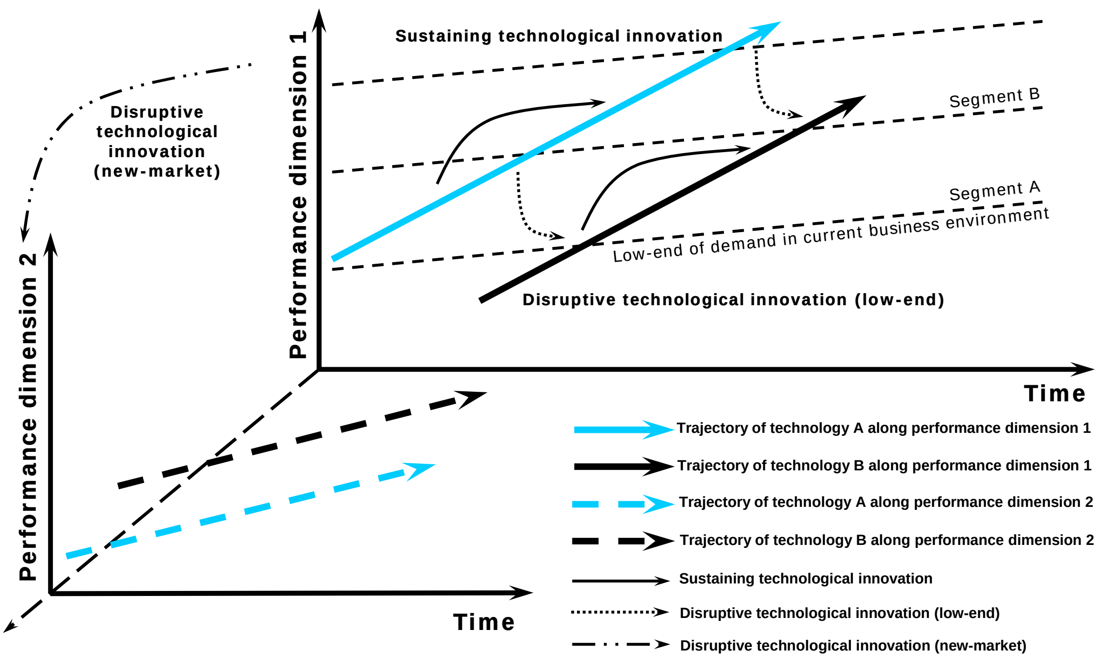


Figure 4-7: ***Sustaining and disruptive technological innovations (adapted from Christensen C.M. 1997, Christensen C.M., Raynor M.E. 2003).***

Another identified form of disruption occurs, when a shift or new trade-off in relevant performance dimensions of a technology trajectory is reversing the preference for technologies. These new-market disruptions may start as side-branches of a technology trajectory, which eventually becomes superior to the main trajectory as well. The authors emphasize that the distinction between new-market and low-end disruption is along a continuum and not discrete (Christensen C.M., Raynor M.E. 2003: 48). Christensen's notion of an *innovator's dilemma* refers to the dilemma situation that established and innovative incumbents in an industry tend to fail on disruptive technologies for the very same reasons they are successful in sustaining technological innovations.

It is concluded that the kind of relationship of a technological innovation to existing and accepted technologies, technology paradigms and trajectories and business models may have a significant impact on competitive advantage in industries. Discontinuities in form of shifts in technology paradigms or trajectories may drive complete substitutions of technologies or simply make technologies obsolete. Again, Case vignette 4-3 forestalls some evidence from the collected empirical data to clarify the phenomena of low-end technology disruptions.

Case vignette 4-3: Low-end disruptions in mature industries.

Technology disruptions are not phenomena that are limited to high-tech or "rocket science" industries: The partly substitution of fully-integrated steel plants by the so-called mini-mill technology in the steel-producing industry, the substitution of electrolytic zinc coating by hot-tip galvanization in the steel processing industry and the substitution of electric discharge machines by high-speed milling in the tool and mold making industry were experienced as low-end disruptions by incumbent firms with strong positions in the established and initially dominant technology. All three disruptive technologies started by displacing the established technology in low-end and niche segments of the relevant markets. Sustaining improvements eventually allowed the disruptive technologies to compete for the core business of the incumbent technologies, as performance demands of existing customers remained relatively stable over time. In many cases a successful substitution started with cost advantages of the disruptive technology in market-segments with lower quality requirements. Gradual performance improvements of disruptive technologies eventually satisfied the demands of most important customer segments (see Appendix C # 12, 38, and 104).

4.2.4 Technology Adoption, Diffusion and Commoditization

Although inherently related, technology adoption and diffusion are different concepts (Gerpott T.J. 2005: 121). Technology adoption is the decision of an entity to purchase, employ or enact a new technology or technological innovation in its technology configuration. Adoption of a new technology in an industry is measured by the amount of adopters over a period of time or the cumulated amount of adopters over time (see Figure 4-8). At individual firm level there are two perspectives on technology adoption in business environments: First, a firm has to question if, when, and how fast it adopts a technological innovation in its products or manufacturing processes compared to the first emergence of a technological innovation and compared to other companies in the industry. This question is valid, regardless if the technological innovation comes from external sources or is a result of an internal innovation or imitation processes. Secondly, a firm is interested in if, when, which, and how many customers will adopt a technological innovation it is offering to them. Figure 4-8 is showing a generic pattern of technology adoption. Roger's concept is proposing, that the distribution of adopters over time is, as many patterns in human behavior, normally distributed (Rogers E. 1983). While this model for technology adoption was empirically validated for different technological innovations in business-to-consumer and business-to-business industries (Shane S. 2009, Weiber R. 1992, Milling P., Maier F. 1996), there are also studies which show different non-symmetric distributions (Weiber R. 1995). Shane showed that both the adoption of digital cameras in consumer markets and adoption of computer tomography scanner equipment by hospitals followed a normal distribution (Shane S. 2009: 47ff). Weiber identified negatively skewed asymmetric distribution of adopters over time in the consumer industry for information and communication technology (Weiber R. 1995).

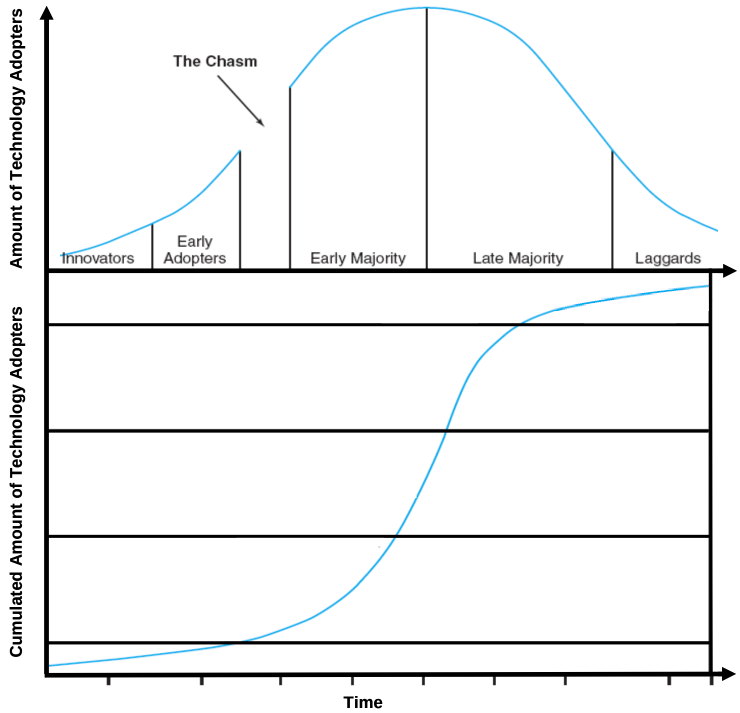


Figure 4-8: ***Pattern of technology adoption and groups of adopters over time (adapted from Rogers E. 1983 and Moore G. 1991).***

Depending on the timing of adoption, adopters can be segmented in different groups. It is proposed that the individual reasons for adoption vary across groups of adopters. Moore is proposing that the transition from the phase of early adopters to early majority is a critical one and has emphasized the notion of crossing *the chasm* (Moore G. 1991). It is argued that the reasons for adopting a technological innovation are very different for innovators and early adopters compared to the majority of eventual adopters (Shane S. 2009: 53). In many cases innovators and early adopters have an experimental interest in the technology itself, while the majority seeks a complete solution or value proposition for an existing problem or demand, and not only a piece of interesting technology. The adoption of a technological innovation by an early majority is very often related to the successful diffusion of a technology into main-stream or mass markets and high volume segments.

Technology diffusion is the ratio of actual to potential technology adopters in a defined environment, like a market, market segment or industry (see Figure 4-9). Speed and pattern of diffusion of technological innovations within the overall value network of a company may have a significant impact on the competitive position of a company.

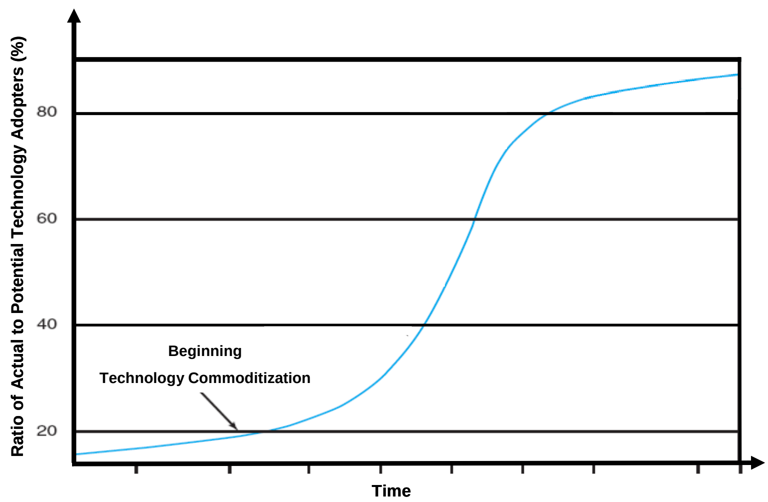


Figure 4-9: ***Technology diffusion in a business environment as ratio of actual to potential technology adopters over time.***

Diffusion into dominant markets or market segments usually initiates a process of technology commoditization, with severe impacts on the originating business environment around the technological innovation. Technological commoditization is the transition of a technological product, functionality, application or service from being a niche or premium to being a commodity business. Commoditization of technology products is specifically their transition to high-volume markets (De Neufville R., Pirnar A. 1999: 76). Commoditization is a threat and opportunity to the manufacturers of technological products. Table 4-5 shows possible impacts of technology commoditization on businesses.

Table 4-5: ***Typical attributes of a technological commodity and non-commodity business (adapted from De Neufville R., Pirnar A. 1999: 75ff).***

Attribute	Commodity	Non-commodity
Industry structure	Competitive	Few competitors
Gross margin	Low	High
Volume	High	Low
Revenue growth	High	Low
Market	Mass	Niche, premium
Supply chain	Outsourced, disintegrated	Vertically integrated
Distribution	Indirect	Direct

Attribute	Commodity	Non-commodity
Service	Low	High
Product differentiation	Low	High
Product brand	Unimportant	Important
Product standard	Open, established	Proprietary
Industry interdependence	High	Low

It is concluded that patterns and speed of adoption and diffusion of technological innovations in a business environment may have various effects on currently pursued competitive advantage of a single firm. Diffusion of a technological innovation in form of fast imitation or easy adoption by competitors may have a direct impact on the sustainability of competitive advantage. A fast pace of adoption of a new complementary or substitutive technology by customers or a positively skewed distribution of adoption may directly threaten a firm, which has no early position in this technology. In a business environment where technological innovations are quickly adopted, either by competitors or customers, technology-based competitive advantages are less sustainable. Although commoditization of a technology in a high-volume main-stream market may offer new opportunities for competitive advantage, it may make existing ones obsolete. Case vignette 4-4 forestalls some evidence from the collected empirical data to clarify the impact of technology adoption and diffusion on competitive advantage.

Case vignette 4-4: Adoption and diffusion of technological innovations in industries.

The impact of technological innovation on competitive advantage of incumbent firms is not only related to the degree of discontinuity of a technological innovation, but also to the speed and pattern of adoption and diffusion in the business environment. The fast adoption of carbon fiber composite materials for structure and body parts of aircrafts was an unpleasant surprise to producers of aluminum components. Alternatively, the manufacturers of railway vehicles adopted aluminum and related manufacturing technologies faster than anticipated by the aluminum industry. Similar, the adoption of cars with hybrid engines from Japanese automotive OEMs by customers all over the world was unexpected by many competitors. Also, the fast adoption of technological innovations by regulating authorities and institutions, which can promote technological innovations to a mandatory quasi-standard, may affect current technological advantages. The relatively prompt adoption of diesel particle filters for car diesel engines by the authorities of the European Union was surprising to many incumbents in the automotive industry (see Appendix C # 7, 9, 26, 54, and 72).

4.2.5 Technology Convergence

Technology convergence describes the convergence of initially unrelated technology and technology paradigms within and across different industries (Figure 4-10). Although already observed by research on the increasing interrelationship between computing and telecommunication industry during the 1970s (Farber D., Baran P. 1977), technology convergence is still a young phenomenon within the domain of technology management. Today the notion of technology convergence is very often related to consolidation and integration processes of products, functionalities, services and applications within the information and communication industry (Yoffie D.B. 1996: 33, Wirtz B.W. 1999: 15, Bores C., Saurina C., Torres R. 2003: 1). Several researchers also emphasize the general phenomenon of technology convergence, which includes the increasing diffusion, integration and relevance of digital information and communication technology in other industries and the convergence of technology and technology paradigms within and across industries in general (Adner R., Levinthal D.A. 2000: 64, Choi D., Välikangas L. 2001: 426).

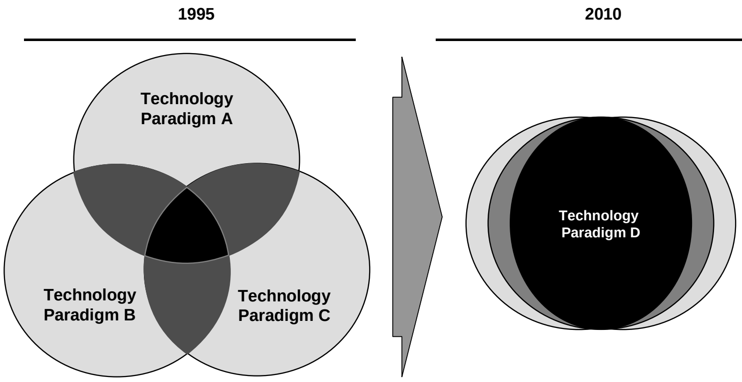


Figure 4-10: ***Generic view of technology convergence as an integrative combination of initially different technology paradigms.***

Technological convergence denotes the transition of a convergence in knowledge into a potential for technological innovation, allowing inter-industry knowledge spillovers to facilitate new technological combinations (Hacklin F. 2008: 60). General drivers for technology convergence can be seen in the behavior and efforts of technology-intensive organizations to transfer their technological knowledge and competences beyond current industry boundaries (Svendsen G.T., Fai F.M. 2003) and in generic megatrends like globalization of markets, digitalization of products or deregulation of markets (Prahalad C.K. 1998, Choi D., Välikangas L. 2001). It is concluded that a process of technology convergence of initially unrelated or independent technologies affects technology-based competitive advantage in industries, which include one or more converging technology paradigms in their current technology configuration. Case vignette 4-5 forestalls insights from the collected empirical data to clarify the phenomena of technology convergence.

Case vignette 4-5: ***Convergence of sensor, information and communication technology within automobiles and street infrastructure.***

Although somehow related, the technological overlaps and complementarities between a provider of toll systems infrastructure for highway and urban applications and an engineering and manufacturing company of automobiles were limited in the past. With the convergence of wireless short and long range communication technologies and the diffusion of various sensor and *interface technologies into cars and street infrastructure, a continuous infrastructure-to-car and car-to-car communication is possible, with an innovation potential for both automotive suppliers and providers of electronic street and highway infrastructure. New imaginable services and applications for both providers and users of street infrastructure, which are based on wireless communication and information technology, are enabled by the convergence of prior unrelated industries and technologies (see Appendix C # 46, 71).*

4.2.6 Industry Categorization by Technological Considerations

Similar to the concept of industry clockspeed, which categorizes industries regarding the level of overall turbulence in the industry, there are frameworks for categorizing an industry by its technological configuration and patterns of technological change. Ansoff is proposing a model based on the patterns of the industry (or market), technology and product life-cycles (Ansoff H.I. 1987a, see Figure 4-11). Ansoff calls industries with no significant technological change over the life-cycle of the industry or a market, low-tech industries. Incremental improvements along the dominating technology trajectory with low frequency and marginal impact are reflected in new product generations, which are triggered by non-technical considerations. In industries like this technology turbulence is low, because technology change is infrequent and incremental and technology or technological innovations are usually not considered as sources of competitive advantage.

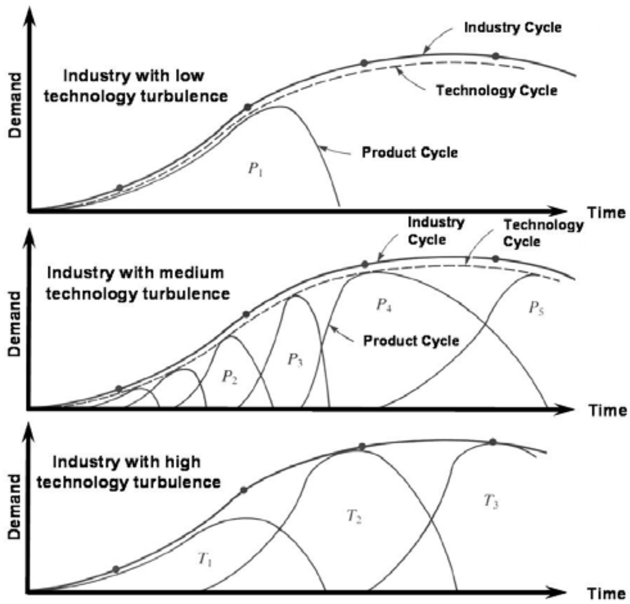
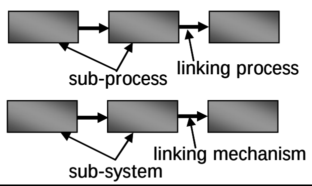
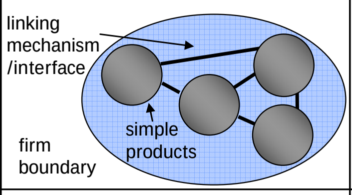
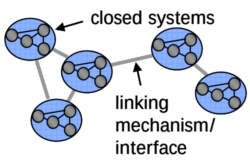


Figure 4-11: Categorization of industries regarding the patterns of industry, technology and product life cycles (adapted from Ansoff H.I. 1987a: 33)

Industries with more dynamic technology development along a technology trajectory are considered as industries with medium technology turbulence. The underlying technology paradigms offer high potential for further development and improvements. Although technological leaps also occur, the fast pace of incremental technological innovations triggers new products or product generations. Technology and technological innovations are considered as a source of competitive advantage, and technology-based competitive advantage is partly sustainable. Industries with high technology turbulence are dominated by regular radical technological innovations and discontinuities. Some technologies are substituted before their full potential is exploited. Technology leaps are making existing technological knowledge obsolete and it is critical to anticipate or recognize these shifts in technology paradigms. It is argued that these pure forms of industry environment seldom exist in reality, neither at a certain point in time, nor over the complete life-cycle of an industry. Over time, all industries and markets may experience periods when a dominating and very stable technology paradigm is adopted by all competitors within the industry and does not allow competing on any form of technology-based advantage. Additionally, many companies are involved in multiple industries and market-segments and are therefore confronted with different and changing degrees of technology turbulence across their businesses.

A categorization of technology-intense industries, proposed by Tushman and Rosenkopf, is based on attributes of an industry's technological configuration (Tushman M.L., Rosenkopf L. 1992). They argue that scope and form of a dominant design, which emerges in an industry, depends on the complexity of its technology configuration. Tushman and Rosenkopf identified three basic categories of industries (see Table 4-6). Depending on the technology configuration of the industry, a dominant design is constituted by bundle of product and process technologies and its progress is driven by different factors. In all three industry types identified by Tushman and Rosenkopf, product, process or material technologies and technological innovations are potential sources of competitive advantage.

Table 4-6: Technology configuration and dominant designs (adapted from Tushman M.L., Rosenkopf L. 1992)

	Technology Configuration	Driver of Progress	Basis of Dominant Design	Arbiter of Dominant Design
Non- & simple assembled products		• Sub-process elimination • Material substitution • Component substitution	Technical superiority	Single or focused practitioner community
Closed assembled system		• Subsystem substitution • New subsystem dominant design • Subsystem elimination • New linking technology	Competition among alternative designs with diverse dimensions of merit	Professional, organizational communities
Open systems		• Subsystem substitution • New subsystem dominant design • Subsystem elimination • New linking technology	Competition among alternative interfaces and designs with diverse dimensions of merit	Multiple, diverse organizational, professional, government communities

In Table 4-7 Pavitt's categorization of industries based on various attributes of technological change within these industries is shown (Pavitt K. 1984: 354, Pavitt K. 1990: 20). Based on difference and similarities across these attributes of technological change, Pavitt identified five types of industry. Scale intensive, science-based and specialized suppliers industries were identified as manufacturing industries, where technology and technology innovations in product and process are important sources of competitive advantage.

Table 4-7: Categorization of industries regarding sectoral patterns of technological change (adapted from Pavitt K. 1984: 354, Pavitt K. 1990: 20)

	Scale Intensive Industries	Specialized Suppliers Industries	Science Based Industries	Information & Service Intensive Industries	Supplier Dominated Industries
Typical Sectors	Basic materials, durable consumer goods, bulk materials, automotive, energy	Machinery, instrumentation, software	Electronics, chemicals, pharmaceuticals	Finance, retailing, publishing, travel	Agriculture, housing, private services, traditional manufacture
Main Source of Technological Innovation	Production and product engineering, specialized suppliers	Design and co-development with advanced users	R&D, laboratories, universities, other basic research, public science	IT departments, Software and hardware system suppliers, integrators	Suppliers, production learning, big users
Driver of Technology Trajectory	Cost-cutting and product design – Efficient and complex production and related products	Product design – Improve specialized producers goods (reliability and performance)	Mixed – Synergetic new products, applications engineering	Efficient and complex information processing and complementary products	Cost-cutting – marginal cost of performance improvement.
Customer	Price sensitive	Performance sensitive	Mixed	Timing sensitive	Price sensitive
Strategic Intent Regarding Technologies	Incremental adoption of proven technologies	Monitor user needs	Product development, control of complementary assets	Customer service, efficiency, knowledge management	"Sweating" the capital, technology re-enforces other competitive advantages

4.3 An A-Priori Construct for Technology Turbulence

The preceding subchapters presented widely accepted and empirically validated models and concepts for technology and technological innovation in industrial settings. These models and concepts help to identify the most important factors that constitute the level of technology turbulence in an industry. As a conclusion of this chapter, five interrelated but distinguishable factors are identified, which influence the level of technology turbulence a company is facing in its business environment:

- Technology Complexity
- Technology Diversity
- Technology Intensity
- Technology Velocity
- Technology Discontinuity

These five elements constitute the a-priori construct of technology turbulence for this research and guide the theoretical sampling of adequate companies for the empirical study.

Technology Complexity

Technology complexity reflects the amount of different technologies, technology paradigms and trajectories and their interrelationship, which a company is integrating in its current technology configuration. Technology complexity does not represent technology change, but is regarded as a multiplier for the impact, which technology change and innovation in one or more elements has on the overall technology system of a company. The amount of integrated technologies and their mutual linkages affects the relevance and magnitude of all forms of technological change and innovation for an organization. If a high amount of distinctive technologies is integrated in a production process, a product, or service, it is proposed that technology change in one technology has a potential impact on all other technologies of the process, product or service. Technology complexity is increasing, if new technologies diffuse or converge into the existing technology configuration. It is therefore proposed that, if all other things being equal, technology turbulence, which a company is facing in an industry, is higher at higher levels of technology complexity as compared to lower levels of technology complexity.

> ***Technology complexity*** *is the amount of different technologies and their interrelationships which a company has integrated in its current technology configuration.*

It is therefore concluded that companies, which adopt and integrate diverse technologies in their products and processes are, on average, more affected by technology turbulence and should be in the focus of this research. To clarify the notion of technology complexity, Case vignette 4-6 refers to cases in the collected empirical data.

Case vignette 4-6: Increasing technology complexity by adoption and diffusion of complementary technologies.

> *The adoption and diffusion of electronics, information and communication technology and embedded digital systems by so-called "old economy" manufacturing industries is regarded as an increase of technology complexity. Various interviewed firms emphasized that with electronic control systems and embedded digital systems, which often serve as user interfaces, completely new technology paradigms were integrated into already existing products. In some cases these newly adopted and integrated technologies eventually turned out to be critical for differentiation in the market place (e.g. simplicity and usability), and also affected the overall product architecture of the initial product. Additionally, the companies were confronted with a before unknown high pace of technology change in the newly adopted technologies. The diffusion of an additional or complementary technology into an industry may threaten sustainability of existing*

technology-based competitive advantages, but may also offer new possibilities for future technology-based competitive advantages (see Appendix C # 3, 14, 52, 66, 71, 80, 92 and 94).

Technology Diversity

Technology diversity in an industry is the variety of existing and potential technologies or technology bundles, which deliver the same or a very similar functionality or added value in the underlying processes and products of this industry and therefore offer possibilities for substitution. Technology diversity is about the current state of the overall technological environment of an industry, which a company is facing. Similar to technology complexity, technology diversity has a multiplying effect: The higher the diversity of alternative technologies, the higher the probability that a relevant technological change or innovation in one of these alternative technologies occurs. Technology diversity in an industry is considered to be high, if competitors offer their products by employing different product, process or material technologies. It is argued that in industries where no dominant technological paradigm or no dominant design is present, technology diversity is relatively higher. It is therefore proposed that technology turbulence increases with technology diversity in an industry, all other things being equal. While technology diversity may primarily exist between competitors within an industry and their way of producing their goods, technology diversity may also exist within a single company by offering alternative technological realizations of a functionality or application. Increasing technology diversity also increases the probability that existing technology-based competitive advantage may not be sustainable.

Technology diversit*y is the amount of competing and alternative technologies a company is facing in its business environment, regarding its current technology configuration.*

It is therefore concluded that companies, which have to act in business environments of technology diversity should be in the focus of this research. To clarify the notion of technology diversity, Case vignette 4-7 refers to cases in the collected empirical data.

Case vignette 4-7: Increasing technology diversity in material technology.

While there are cases for nearly complete substitutions of established technologies by new ones, in many cases established technologies are only partly and incrementally squeezed out of specific markets, market segments or niches. In the long-run, a balanced technology diversity is established, which shifts with incremental innovations or is destabilized by break-through innovations in one technology. The simultaneously complementary and substitutive relationship of certain material technologies, reported by various interviewees, serves as a vivid example. Aluminum alloys, various steel grades, magnesium, carbon-fiber composite materials and ceramic *materials represent not only alternative materials but also different industry sectors, which develop technologies for producing and processing these materials. A steel producing and processing company must develop a certain expertise in aluminum, and a aluminum producing and processing company must develop expertise on how to integrate steel, aluminum and hybrid materials. The principal ability to produce a part, component or module which fulfills the same functionality by alternative materials increases the technology diversity in a business environment. Although the "pure" aluminum car (e.g. Audi A2) was no market success, the overall share of aluminum in automobiles was increased by this initiative. As an answer, steel producers developed new steel grades and hybrid components (tailor-welded blanks,) which combine different materials and their properties. While around 1990, only 2 basic steel grades dominated the manufacturing of car bodies, today 10 steel grades and various combinations are necessary to satisfy the demands of automotive OEMs and to compete successfully with alternative materials. New carbon-fiber composite materials substituted parts of the core-business of aluminum processing companies in the aircraft industry. As a response, new aluminum and light metal alloys are developed, which again increased the overall diversity in material technologies. Also ceramic materials were reported as a new alternative for steel in several applications. Maintenance- and lubrication-free ceramic blades and knives increased the technology diversity in affected industries. Advances and innovations in necessary manufacturing technologies and material conditioning treatments enabled the application of magnesium as a material for automotive engine and drivetrain components in high-volume series production and triggered the substitution of conventional material and manufacturing technologies. High diversity in available material technologies and related manufacturing technologies within a business environment may limit sustainability of existing technology-based competitive advantage (see Appendix C # 9, 25, 29, 40, 51, 67, 70, 103 and 115).*

Technology Intensity

Technology intensity can be described as the relative amount of competitive advantage a company is attaining or pursuing, which is based on technology, technological know-how and expertise. In the diction of the resource-based view, technology intensity is represented by the relative amount of core competences, which is mainly technology-based. While technology intensity alone does not represent any dynamic of technology change in an industry, it reflects the level of importance and criticalness technology and technological innovation has for competitive advantage and therefore for performance and success in an industry. Technology intensity basically affects the impact of technology change on competitive advantage. It is proposed that, ceteris paribus, technology turbulence is higher in an industry, if technology intensity is higher, compared to an industry with lower technology intensity.

***Technology intensity** indicates which share of competitive advantage a firm is pursuing in its business environment is based on technology.*

It is therefore concluded that technology-intense companies should be in the focus of this research. To clarify the notion of technology intensity, Case vignette 4-8 refers to cases in the collected empirical data.

Case vignette 4-8: Changing technology intensity by alternative product architecture.

As many manufacturer of automotive vehicles, which produce in western high wage countries, Company 21, a manufacturer of fire fighting vehicles, outsourced many me-too technologies. The in-house share of value added was shrinking because manufacturing technologies like grinding and welding for the frame construction of vehicles were completely externalized. Technology intensity was relatively low because manufacturing technologies did not provide any possibilities for a competitive edge. Competitive advantage was more based on product attributes and non-technical issues. A technological innovation, which changed the architecture of the product and employed alternative and more sophisticated manufacturing and material technologies, like laser cutting and welding, adhesive bonding and canted aluminum sheets, significantly increased technology intensity of Company 21. Most manufacturing processes are in-house again and the new, more adaptable product architecture and new process technologies are regarded as new competitive advantage. This parallel increase of technology intensity and diversity affects initial competitive advantage in one of Company 21's core markets (see Appendix C # 99).

Technology Velocity

Technology velocity can be regarded as the average rate of continuous and evolutionary technological progress and incremental improvements in the underlying process, product, service and material technologies, which a company is facing in its business environment. Applying the already discussed S-curve model, which represents a single technology trajectory over time, technology velocity of an industry may be seen as the average slope of the various S-curves of the employed or produced technologies of a company. In this context technology velocity represents the rate of continuous technology change, and is of different quality than technology intensity, complexity and diversity. Additionally to the speed of technological progress, technology velocity in a business environment is affected by the speed of technology adoption and diffusion by various players in the industry. It is proposed that technology turbulence a company is facing in its business environment increases with the velocity of adopted technology improvements, all other things being equal.

***Technology velocity** is the speed and frequency of adopted technological innovations along a technology trajectory, which a company is facing in its business environment.*

It is therefore concluded that companies, which face high speed and frequency of technology innovation and adoption in their businesses, should be in the focus of this research. To clarify the notion of technology velocity, Case vignette 4-9 refers to a case from the collected empirical data.

Case vignette 4-9: Increasing technology velocity by fast technology imitation and innovation of competitors.

Company 13, a producer of pulp and cellulose fiber, reported a significant reduction in the sustainability of advantages realized by incremental improvements in product and process technology of its asset-intensive main businesses. Especially the number of Asian competitors and their ability to promptly imitate and adopt newly developed technologies and technological innovations is dramatically increasing. The sustainability of technology-based competitive advantage and existing technology leadership positions are increasingly threatened with the ever shrinking duration of exclusive appropriation and exploitation of technological innovations. As the overall technology velocity within the current dominant design is increasing, the sustainability of technology-based competitive is decreasing (see Appendix C # 56).

Technology Discontinuity

Technology discontinuity is the rate of discontinuous technology innovations in the underlying processes, products and material technologies of an industry. While technology discontinuity may be triggered by radical and revolutionary technological developments in- or outside the current industry boundaries, it may also be caused by non-technological reasons. A discontinuity caused by technology substitution is realized, if an employed technology or technology paradigm in an industry is partly or completely substituted by an emerging distinct technology or technology paradigm. While technology substitution may be triggered by a significant improvement of a competing technology along existing performance indicators in an industry, it may also caused by a shift in customer preferences, which eventually changes relevant performance indicators. Applying the technology S-curve model, which shows the development of a technology paradigm along a certain trajectory, the discontinuity could either be realized by a new or improving technology paradigm along the same trajectory (additional S-curve representing an alternative technology) or by a change of the relevant performance indicator for a technology, which is represented by a new technology trajectory (changing y-axis).

Technology discontinuity *is the rate of shifts in technology paradigms or trajectories, which a company is facing in its business environment.*

It is therefore concluded that companies, which face technological discontinuities in their business context should be in the focus of this research. To clarify the notion of technology discontinuity, Case vignette 4-10 refers to cases in the collected empirical data.

Case vignette 4-10: Technology discontinuity in material and manufacturing technology.

It was already mentioned that technology discontinuities in form of fast and complete substitutions of technologies are seldom. Even analog photography, the music cassette (MC) or the vinyl LP survived in certain market segments and niches and the substitution process was gradual. A nearly complete substitution was experience by Company 9's piping system division. Initially a producer of metal piping systems, all of its current products, pipes, fittings, valves are made of various kinds of plastic. Company 9 emerged from this substitution process of copper, cast iron, steel and related manufacturing technologies as one of the most successful companies in the industry. Although Company 9 was founded as a copper and iron processing company and therefore had enormous assets and competences in related product and process technologies, the company was able to cannibalize its own metal piping business and its existing manufacturing assets. After nearly 150 years of producing cast iron and copper piping systems, Company 9 was one of the first companies, which successfully introduced plastic piping components during the 1960s. 20 years later, plastic piping systems were dominating all relevant market segments served by Company 9's piping systems division (see Appendix C # 39).

Figure 4-12 is summarizing the insights of the literature review and analysis. It is proposed that five interrelated but distinguishable elements constitute the technology turbulence that a company is facing in its business context. The higher the turbulence a company is facing in its business environment, the more the firm's strategy should complement its strategic fit with strategic flexibility. Analog to this notation, technology turbulence is defined as the degree of non-sustainability of technology-based forms and sources of competitive advantage. It is proposed that strategic flexibility in technology strategy is becoming more critical, when technology turbulence is high. Technology turbulence is increasing when one or more of the identified factors are increasing, all other things being equal.

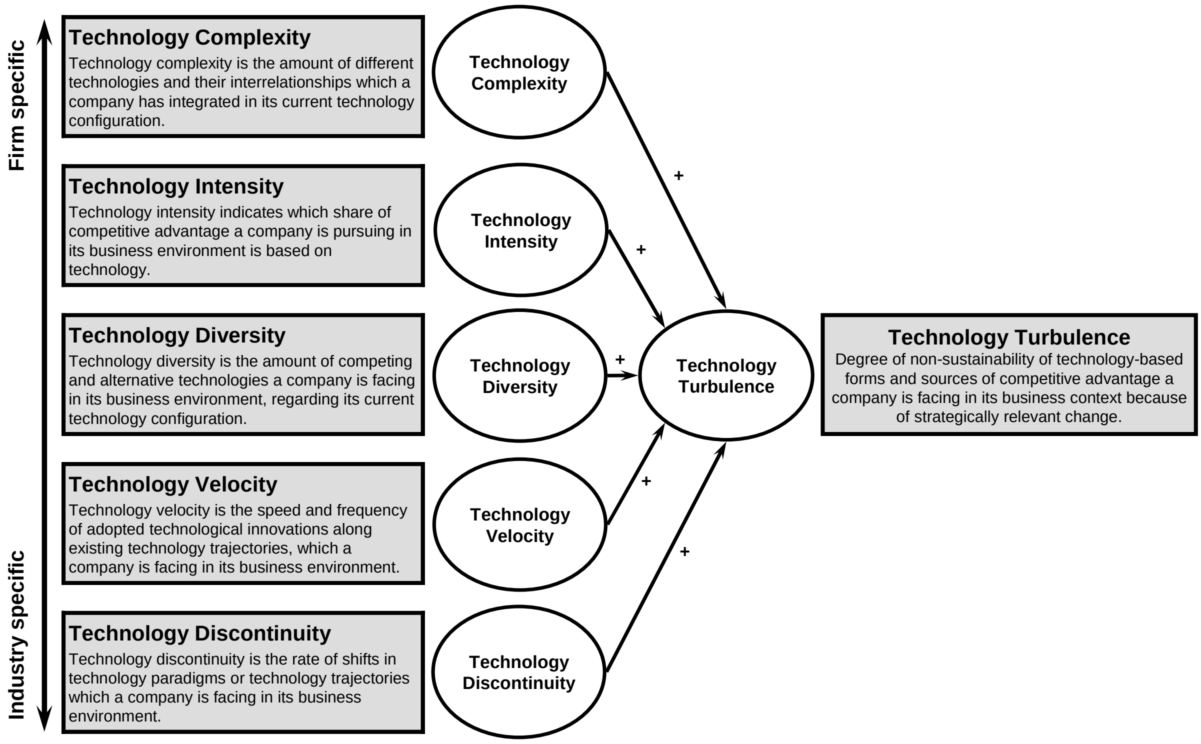


Figure 4-12: A-priori construct of technology turbulence for this research.

Following the proposed ideas of chapter 3, it is therefore concluded that the probability to identify forms of flexibility in the technology strategy of a company is high, when the company is facing technology turbulence in its business context. All of the identified five elements are therefore explicitly integrated into the interview guide by specific but open-ended questions and are regarded as a preliminary starting point for analyzing technology strategy under technology turbulence (see Appendix A). Applying theoretical sampling, preliminary information on technology turbulence that a company is facing was also considered for identifying relevant companies for this study. All companies in the study develop, engineer and manufacture products or systems which integrate various product and process technologies and all companies consider technology and technology innovation as one, if not the most important source of competitive advantage in their industries. Therefore, the a-priori construct for technology turbulence, based on the review of relevant literature, had both influence on the sampling of companies and influence on the content and design of the interview guide. Table 4-8 is summarizing the explicit consideration of the developed a-priori construct of technology turbulence and its elements in the conduct of this research.

Table 4-8: ***Explicit consideration of a-priori construct of technology turbulence in conduct of research.***

Element	Explicit Consideration in Conduct of Research
Technology Complexity	o Theoretical sampling of companies with technology complexity in product or process technologies. o Expert interviewee's appraisal (e.g. question 3 in interview guide, Appendix A).
Technology Intensity	o Theoretical sampling of technology-intense companies based on product, process or material technologies. o Expert interviewee's appraisal (e.g. question 2 and 8 in interview guide, Appendix A).
Technology Diversity	o Expert interview: Factual and anecdotal questions on technology diversity in the business environment (e.g. question 4 in interview guide, Appendix A).
Technology Velocity	o Expert interview: Factual and anecdotal questions on technology velocity in the business environment (e.g. question 5, in interview guide, Appendix A).
Technology Discontinuity	o Expert interview: Factual and anecdotal questions on technology discontinuities in the business environment (e.g. question 6, in interview guide, Appendix A).

5 TECHNOLOGY STRATEGY OF INDUSTRIAL ORGANIZATIONS

In this chapter existing literature and conceptualizations of technology strategy of industrial organization are reviewed. First, various definitions and interpretations of technology strategy are discussed. Based on a meta-analysis of existing prescriptive and conceptual approaches to technology strategy, its core elements and dimensions are identified. Although it is impossible to discuss all contributions in detail, this chapter intends to give an overview over the most influencing and holistic work related to technology strategy in the management literature. The goal of this chapter is to develop an a-priori construct of technology strategy and to identify the major elements and dimensions of the unit of analysis of this research (see Figure 5-1). The identified construct of technology strategy developed in this chapter serves as underlying framework for the development of the interview guide on technology strategy in industrial organizations under technology turbulence.

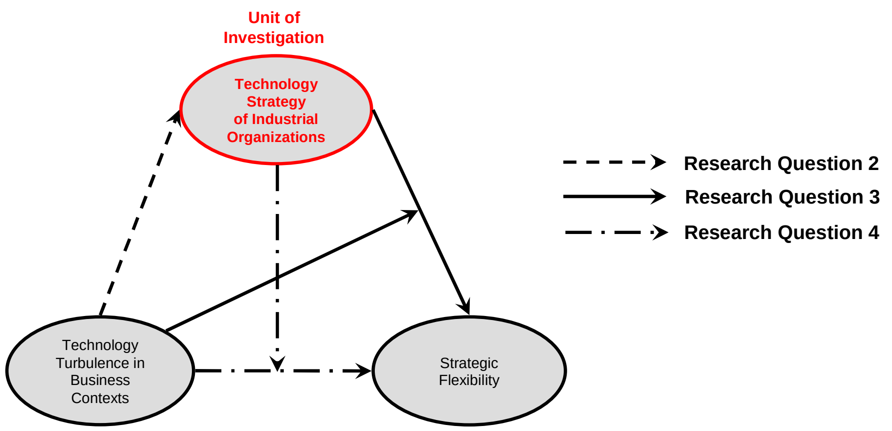


Figure 5-1: Technology strategy as unit of analysis in the overall research design.

5.1 Definitions and Interpretations of Technology Strategy

Although technology strategy is considered one of the most important functional strategies in today's business environment (Hax A.C., Majluf N.S. 1996: 360ff), there are few holistic and integrated discussions and concepts of technology strategy. One reason is that the technology function as a distinctive functional and organizational unit does usually not exist in organizations. Technology strategy is regarded as an interface function, which relates the domains of business and corporate strategy with research, development, engineering, manufacturing and the overall technology context of an organization (Morone J. 1989: 95). The concept of technology strategy has implicitly been addressed since the early 1980s in the management literature, but has not emerged as a distinctive field of managerial interest and academic research until the early 1990s, when it attracted attention of management practitioners and consultants. However, it seems to remain a quite complex entity and the varieties of ideas has not yet converged towards a single holistic concept or an integrated knowledge-base (Davenport S., Campell-Hunt C., Solomon J. 2003: 481f, Rieck R.M., Dickson K.E. 1993: 397).

There is still much academic debate about how to define technology strategy. Existing definitions range from quasi-synonyms to R&D strategy, specially focusing on internal technology development, to very broad knowledge-management and competence based definitions (Davenport S., Campell-Hunt C., Solomon J. 2003: 482). One of the first definitions of technology strategy was provided by Adler in describing technology strategy as a pattern of decisions that sets the technological goals and the principal technological means for achieving both those technological goals and the overall goals of the organization (Adler P.S. 1989: 26). This definition describes technology strategy as a bundle of not necessarily linked and aligned strategic decisions about goals and means without mentioning how and which decisions are specifically included as a part of a technology strategy.

Maidique and Patch define technology strategy as a portfolio of choices and plans that a company uses to address the technological threats and opportunities in its external environment (Maidique M.A., Patch P. 1982). Besides a set of necessary choices, they include plans how to address external technological threats and opportunities in their definition of technology strategy. This implicitly suggests a kind of a more or less formal planning process behind the concept of technology strategy. Burgelman and Rosenbloom propose that technology strategy consists of a company's inter-related decisions on technology choice, level of technology competence, level of funding of technology development, timing of technology introduction in new products or services, and organization for technology application and development (Burgelman R.A., Rosenbloom R.S. 1989). These authors again emphasize that technology strategy consists of decisions, but they explicitly name the kind of decisions which are part of technology strategy, and that these decisions are not independent or individual but inter-related. Obviously, these earlier definitions were quite specific about framing the content of technology strategy as set of necessary choices and decisions on technology development to reach overall and technological goals of an organization.

Beginning with the introduction of the resource-based view of strategy and conceptualizations of firms as knowledge- and competence-systems, definitions of technology strategy evolved, which emphasized technological knowledge as source of competitive advantages. However, there appears to be some confusion in the literature between technology strategy and knowledge strategy (Davenport S., Campell-Hunt C., Solomon J. 2003: 482). Ford's definition, shown in Table 5-1, is one example of a very early knowledge based view of technology strategy. Ford also explicitly emphasizes that technology strategy is not the same as R&D strategy which is concerned only with developing and acquiring technology through in-house activities (Ford D. 1988: 85). Even further, Clarke and colleagues insist on a much broader focus of technology strategy, compared to a company's R&D strategy, its product development policies or its manufacturing strategy (Clarke K. et al. 1995: 171).

Zahra and colleagues define technology strategy as a long-term and multi-dimensional plan that guides a company's resource commitments to and use of technology (Zahra S.A., Sisodia R.S., Das S.R. 1994: 173). They describe technology strategy as plan and specify a long-term time frame in which this plan controls investments and exploitation levels of technology. Rieck and Dickson describe technology strategy as the process by which firms utilize their technological resources to achieve corporate objectives (Rieck R.M., Dickson K.E. 1993: 398), while Coconete et al. define technology strategy as a set of interrelated decisions such as technology choice, funding for R&D, methods of acquisition and exploitation, timing of technology introduction into new products, services and processes (Coconete D.E., Moguilnaia N.A., Sankara Narayanan E.M. 2004: 360). Wolfrum states that technology strategy is the answer to the questions which technology from which source is when and at which proficiency level used to reach certain goals (Wolfrum B. 1991: 72). Dodgson summarizes the problem to define technology strategy by writing (Dodgson M. 1991: 96):

> *"What technology strategy is, is by no means straightforward […]. There are numerous difficulties in satisfactorily defining technology strategy: What is technology, product, process, actual artifacts or ways of doing things? What functions does it incorporate – is it research, development or engineering, is it manufacturing? What is strategy – is it formulation, formation, content, technique? […] Technology strategy involves an understanding within a corporation – manifest amongst senior management, but diffused throughout the organization – of the importance and potential of technology for its competitive position, how in the future that potential is to be realized, and how this complements the other aspects of strategy, such as finance, marketing and personnel."*

Table 5-1 offers an overview of different definitions of technology strategy and their interpretation. This analysis of definitions and descriptions of technology strategy should give an overview, but also intends to classify the frameworks, models and concepts of practitioners and academics with different backgrounds.

Table 5-1: Definitions of technology strategy and their interpretation.

Authors and Publication	Definition or Description of Technology Strategy	as set or pattern of decisions	as generic strategic positions	as plans and planning routines	as a set of objectives and goals	as management procedure	as emerging formation process	as methodology
Little A.D. 1981.	… based on the dimensions scope and leadership, there are four major types of technology strategy: technology leadership, niche strategy, follower strategy, technology rationalization.		X					
Pappas C. 1984: 31.	Technology strategy is a complex and challenging four-step planning process involving technological situation assessment, technology portfolio development, technology and corporate strategy integration and setting technological investment priorities.			X		X		X

Authors and Publication	Definition or Description of Technology Strategy	as set or pattern of decisions	as generic strategic positions	as plans and planning routines	as a set of objectives and goals	as management procedure	as emerging formation process	as methodology
Ford D. 1988: 85.	… is that aspect of strategy which is concerned with exploiting, developing and maintaining the sum total of the company's knowledge and abilities. … consists of policies, plans and procedures for acquiring, managing and exploiting that knowledge and ability within the company for profit.	X		X		X		
Maidique M.A., Patch P. 1982.	… as a portfolio of choices and plans that a company uses to address the technological threats and opportunities in its external environment	X		X				
Adler P.S. 1989: 27.	… a pattern of decisions that sets the technological goals and the principal technological means for achieving both those technological goals and the business goals of the organization.	X			X	X		
Clarke K. et al. 1995:171, Clarke K., Ford D., Saren M. 1989: 216.	… the technology-strategy interrelationship as a strategic perspective of technology that requires that managers develop a strategy for acquiring, managing and exploiting their technology.	X			X			
Burgelman R.A., Rosenbloom R.S. 1989:1-5.	… is a process that emerges from organizational capabilities, shaped by environmental forces and tempered by experience. The environmental forces are strategic behavior, organizational context and industry context. … consists of a company's inter-related decisions on technology choice, level of technology competence, level of funding of technology development, timing of technology introduction in new products or services, and organization for technology application and development.	X				X	X	
Stacey G.S., Ashton W.B. 1990: 395.	A broad approach to achieve organizational goals through sustained technology advantages in the expected competitive environment.				X	X		
Wolfrum B. 1991: 72.	… is the answer to the questions which technology from which source is when at which proficiency level used to reach certain goals	X						
Rieck R.M., Dickson K.E. 1993: 398.	… technology strategy is the process by which firms utilize their technological resources to achieve corporate objectives.				X	X	X	
Zahra S.A., Sisodia R.S., Das S.R. 1994:173.	... a formal plan that guides long-term decisions on technology development, acquisition, deployment and investment.	X		X				
Chiesa V., Manzini R. 1998a: 115.	… means defining the trajectory by which technological resources are accumulated, acquired and used.	X				X		
Bone S., Saxon T. 2000: 50.	Technology strategy is both an analytical and creative process. It is best implemented as a continuous and creative business process.			X		X		
Carrie A.S. et al. 2000: 100.	… the two distinct elements of technology strategy are the technology portfolio, representing the what of technology strategy and the technology management procedures representing the how of technology strategy.					X		X

Authors and Publication	Definition or Description of Technology Strategy	as set or pattern of decisions	as generic strategic positions	as plans and planning routines	as a set of objectives and goals	as management procedure	as emerging formation process	as methodology
Davenport S., Campell-Hunt C., Solomon J. 2003: 483.	…encompasses the acquisition, management and exploitation of technological knowledge and resources by the organization to achieve its business and technological goals.				X	X		
Coconete D.E., Moguilnaia N.A., Sankara Narayanan E.M. 2004: 360.	…can be defined as a set of interrelated decisions such as technology choice, funding for R&D, methods of acquisition and exploitation, timing of technology, introduction into new products and services.	X						
Shane S. 2009: 9.	The approach that a firm takes to obtaining and using technology to achieve a new competitive advantage or to defend an existing technology-oriented competitive advantage against erosion.				X			

5.2 Approaches to Technology Strategy

Since the 1980s strategic management literature is accepting technology as a key strategic variable. Before, technology was primarily treated as a pure implementation issue: A firm determined its strategy and technology was regarded as one dimension for implementing this strategy. Technology and technology innovations were not regarded as sources of competitive advantage (Friar J., Horwitch M. 1985). Since then various contributions accepted technology's strategic importance in business environments. The key problems addressed by integrated contributions to technology strategy are:

- The relationship and alignment between technology strategy and corporate and business strategy.
- The identification of the content and formulation process of technology strategy.

The following sub-chapters review holistic and integrated contributions to the notion of technology strategy, which were identified in the literature and which address both aspects. Following Chiesa's practice, the reviewed integrated approaches to technology strategy are categorized into approaches which are based on the market-based view of strategy, the resource-based view of strategy, and approaches which advocate a more dynamic and longitudinal perspective of technology strategy (Chiesa V. 2001).

5.2.1 Market-based Approaches to Technology Strategy

The market-based, positioning (Chiesa V., Manzini R. 1998a) or hierarchical (Zahra S.A., Sisodia R.S., Matherne B. 1999) approach to technology strategy emphasizes the development and maintenance of generic technology strategies or strategic technology positions which support a generic business strategy in its implementation. Additionally, common attributes of this approach to technology strategy are the hierarchical, top-down perspective, from corporate via business to functional strategies, and the use of portfolio matrices and tools to identify preferable strategic positions of competitive advantage. Table 5-2 is summarizing identified generic technology strategies suggested by market based-approaches of technology strategy. Most of these generic technology strategies are either related to the timing of technology adoption or the level of commitment for a technology. This section reviews some prominent market-based approaches to technology strategy.

Table 5-2: Suggested typologies of market-based generic technology strategies.

Authors	Generic Technology Strategies
Ansoff H.I., Stewart J.M. 1967.	First-to-Market
	Follow the Leader
	Application engineering
	Me-too
Maidique M.A., Patch P. 1982.	First-to-Market
	Second-to-Market
	Late-to-Market
	Market Segmentation
Zörgiebel W.W. 1983.	General Technology Leadership
	General Cost Leadership
	Specific Technology Leadership
	Specific Cost Leadership
Porter M.E. 1983, Porter M.E. 1985.	Technology Leadership
	Technology Followership
Pappas C. 1984.	Bet
	Draw
	Cash in
	Fold
Perillieux R. 1991.	Technology Leadership
	Technology Followership
Zahn E. 1986.	Pioneer Strategy
	Imitation Strategy
	Niche Strategy
	Cooperation Strategy
Little A.D. 1981, Saad K.N., Roussel P.A., Tiby C. 1991, Floyd C. 1997.	Build technology
	Nurture technology
	Maintain technology
	Repair technology
	Selectively invest in technology

5.2.1.1 Porter's Approach to Technology Strategy

Based on his frameworks for business and competitive strategy, Porter developed an approach to technology strategy (Porter M.E. 1980, Porter M.E. 1983, Porter M.E. 1985). The basic elements of Porter's framework for strategy at the business level are the identification of a favorable competitive environment and the identification of a strategic position, which achieves sustainable competitive advantage. Porter argues that technology is a determinant of the industry structure and therefore affects the overall profitability of an industry (Porter M.E. 1983: 2ff). He also emphasizes that technology affects a firm's potential for competitive advantage and can be at the basis of the firm's positioning within the business area (Porter M.E. 1985: 166ff). It is argued that a firm's technological policies for product and process technology should be derived from the chosen generic business strategy (see Table 5-3).

Table 5-3: Technology strategy for product and process technology and generic business strategies (adapted from Porter M.E. 1983: 11, Porter M.E. 1985; 178).

	Technology Strategy for	
Generic Business Strategy	**Product Technology**	**Process Technology**
Cost Leadership	Product development to reduce product costs by lowering material content; facilitating ease of manufacture; simplify logistical requirements;	Learning curve process improvement to reduce material usage or lower labor input; process development to enhance economies of scale;
Differentiation	Product development to enhance product quality, features, deliverability, or switching costs.	Process development to support high tolerances, greater quality control, more reliable scheduling, faster response to orders, and other dimensions that raise buyer value.
Focused Cost Leadership	Product development to design in only enough performance from the target segment's needs.	Process development to tune the value chain to a segment's needs in order to lower the cost of serving the segment.
Focused Differentiation	Product design to meet the needs of a particular segment better than broadly-targeted competitors.	Process development to tune the value chain to segment needs in order to raise buyer value.

Based on the identification of a generic business strategy by a firm, Porter suggests that a technology strategy is constituted by three key elements, which correspond to three strategic decisions (Porter M.E. 1985: 177ff):

- The selection of technologies to adopt.
- The timing of technology adoption.
- The external exploitation of mastered technologies.

The selection of technologies, which should be adopted, is based on two criteria. The first is the coherence of the technological choices with the firm's generic business strategy. The strategic fit of a technology with the pursued strategic position is at the very core of technology strategy. The question is, how a certain technology is supporting the type of competitive advantage a firm is trying to achieve or trying to maintain. The second criterion for the adoption of a technology is the test, whether a technological change in the industry initiates an overall technological change in the industry and if it is desirable for the firm. A technological change is desirable, when the effects on the overall industry structure are favorable to the firm. Porter emphasizes that many firms do not pay adequate attention to structural changes generated by technology change in an industry. Although an initiated technological change my generate advantages for a firm within its industry, such a change may reduce the overall profitability of the whole industry.

Porter argues that the decision on the timing of technology adoption is based on three factors: The sustainability of technology leadership, the advantages of being a first mover and the disadvantages of being a first mover. The sustainability of technology leadership is based on various context specific criteria. At industry level, Porter argues that if the source of a technological innovation is within an industry, a technological leadership position can be easier sustained. Additionally, the rate of technology diffusion among competitors and the rate of technology adoption by customers may exogenously affect the sustainability of technology leadership. At firm level, economies of scale and scope in R&D and relative advantages in technological know-how compared to competitors may allow to sustain a technology leadership position. Table 5-4 summarizes Porter's arguments for and against a first-mover strategy.

Table 5-4: Technology first-mover advantages and disadvantages (Porter M.E. 1985: 186ff).

First-Mover Advantages	First-Mover Disadvantages
o Reputation for innovation o Preempting a position o Switching costs of customers o Selection of distribution channels o Learning curve effects o Access to resources o Definition of standards o Institutional barriers o Initial profits	o Pioneering costs o Uncertainty of demand o Changing customer demands o Specificity of early investments o Technological discontinuities o Low-cost imitation

The third and last technology strategy decision advocated by Porter is on the external exploitation in form of technology selling or licensing. Porter argues that a technology should be externally exploited when technology licensing offers opportunities, which otherwise would remain unexploited. If a company can access markets which are otherwise not available or can establish a de-facto standard in an industry, Porter recommends external technology exploitation. Based on the pursued generic business strategy and the described environmental factors which influence technology timing decisions, Porter is suggesting generic technology strategies (see Table 5-5).

Table 5-5: ***Generic technology strategies (adapted from Porter M.E. 1983: 13, Porter M.E. 1985: 181.)***

	Generic Technology Strategy	
Generic Business Strategy	**Technology Leadership**	**Technology Followership**
Cost Leadership	First mover on lowest-cost product or process technology. Pioneer the lowest-cost product design. Be the first down the learning curve.	Lower cost product or process through learning from leader's experience. Avoid R&D costs through imitation.
Differentiation	First mover on unique product or process that enhances product performance or creates switching costs.	Adapt product or delivery system more closely to market needs (or raise switching costs) by learning from leader's experi-ence.
Focused Cost Leadership	First mover on lowest-cost segment tech-nology.	Alter leader's product or process to serve particular segment more efficiently.
Focused Differentiation	First mover on unique product or process tuned to segment performance needs, or creates segment switching costs.	Adapt leader's product or process to per-formance needs or particular segment or create segment switching cost.

Finally, Porter is also proposing a sequence for technology strategy formulation which creates strategic fit of a firm's technology portfolio with the pursued or attained competitive advantage and the industry structure (see Figure 5-2).

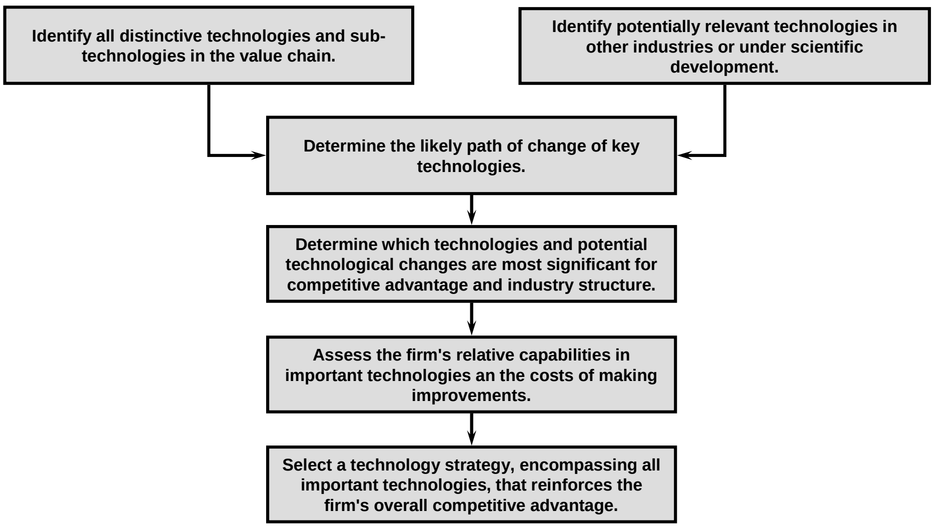


Figure 5-2: ***Sequential steps in formulating technology strategy proposed by Porter (adapted from Porter M.E. 1985: 198ff).***

Concluding Porter's approach to technology strategy, it can be summarized that the suggested content, formulation process and methodology of technology strategy emphasized by Porter is aimed to establish an optimal strategic fit between a pursued or attained generic strategic position, external factors like industry structure and technology change and the development and adoption of technology. Technology strategy is not regarded as a procedure to identify or prepare strategic options on new forms and sources of competitive advantage and to create or maintain strategic flexibility (see Table 5-6).

Table 5-6: Summary of Porter's Approach to Technology Strategy.

Attributes of Technology Strategy Approach	Porter's Approach to Technology Strategy
Function of Technology Strategy	Strategic fit between a generic business strategy, the industry structure and the internal technology configuration of firm.
Preliminaries of Technology Strategy	Generic business strategy and identified forms of competitive advantage.
Elements of Technology Strategy	Technology selection and adoption, technology timing, additional external technology exploitation;
Formulation of Technology Strategy	Hierarchical and linear sequence of steps.
Explicit Tools of Technology Strategy	o Five-forces framework. o Value-chain analysis. o Generic business and technology strategy matrices.

5.2.1.2 Hax, Majluf and No's Approach to Technology Strategy

One of the most holistic, integrated and consistent approaches to technology strategy was contributed by Hax, No and Majluf (Hax A.C., No M. 1992, Hax A.C., Majluf N.S. 1996: 360ff). Based on the market-based view and on Porters framework, their concept emphasizes technology strategy as multidimensional construct. They highlight a process and methodology for technology strategy formulation, define content of technology strategy and specifically address organizational issues of technology strategy. The authors suggest a list of elements and topics which are at the very core of technology strategy (Hax A.C., No M. 1992: 9f):

Technology Selection

Technology selection addresses all aspects of selecting technologies and the ways in which they will be embodied in the firm's product or processes. Some of the issues, which should be explicitly recognized, are the potential of technologies for innovation in existing products and processes, congruency between technology development, business maturity and life-cycle and desired business strategy, and the identification of appropriate priorities, which guides all future technological efforts.

Technology Timing

Technology timing involves the decisions whether to lead or to lag behind in the adoption of innovations in product or process technologies compared to competitors. Issues of interest to these decisions are the identification of risks and benefits related to technology leadership or followership and the congruency of the timing strategy to the generic business strategy.

Technology Acquisition Mode

Technology acquisition modes address the decisions how and by which sources a company is establishing access to technologies and technological innovations. While the main decision is whether to rely on internal development capabilities or to source technology externally, various hybrid forms and organizational modes exists how to acquire technologies: Internal development, merger and acquisition activities, licensing, internal and external ventures, joint ventures and strategic alliances.

Horizontal Technology Strategy

Horizontal technology strategy is focused on identifying and communicating exploitation opportunities for technologies and technological innovations that exists across distinct businesses, products and product groups, facilities and plants within the overall organization. It is the mechanism by which strategic technology aspects across organizational units are aligned. A basis for a horizontal technology strategy could be common product, process or material technologies or interfaces and interrelationships among products in application and functionality.

Technology Strategy Organization and Leadership

Technology strategy organization and leadership aspects are oriented towards the identification and establishing of an organizational structure for the technology strategy function. It includes vertical and horizontal coordinating mechanism in formulating and implementing technology strategy and issues considered in leading, motivating, developing and organizing technical professionals in organizations.

Technology Intelligence

Technology intelligence summarizes all efforts of an organization to gather external information concerning the current and future state of technology development in the relevant business environment of an organization. The main tasks include the identification and analysis of relevant or new technologies, detection of the focus of innovation for relevant technologies and a continuous monitoring of technology innovation activities of competitors.

Technology Valuation

Technology valuation's principal concern is the appropriate allocation of resources to technology and technology innovation projects to support the overall strategy. Issues for consideration are primarily the organizational routines and the criteria for resource allocation decisions for technology development and innovation.

Additionally to their list of elements of technology strategy, the authors also structure these elements in a hierarchical top-down technology strategy formulation process (see Figure 5-3). This process starts with the identification of technical requirements derived from corporate and business strategies. This step provides the mechanism that establishes an effective linkage between corporate, business and technology strategies. The core elements of their formulation process are (Hax A.C., Majluf N.S. 1996: 361ff):

Identifications of Strategic Technological Units (STUs)

The authors emphasize the importance of the identification of appropriate units of analysis for the overall technology strategy. Consistent with the arguments in the previous chapter on technology paradigms, productive units, dominant designs and the problems when separating product and process technology, the authors suggest not just to list the sub-technologies embodied in products and processes. They describe STUs as the skills and disciplines that are applied to the firm's products and processes and which are relevant to technological advantage. The authors also suggest that STUs should be broad enough to include not employed or emerging technologies, but focused and limited enough to serve as a specific, closed and understood unit of analysis. Therefore STUs may represent sets, bundles, clusters or systems of technologies which are highly linked and integrated.

Technology Internal Scrutiny

The internal scrutiny aims to recognize strengths and weaknesses related with each STU and analyzes the current and expected contribution of technological competencies to competitive advantage. For each STUs critical success factors and drivers of technology innovation are identified. The performance of the company in these factors in each STU compared to direct competition is analyzed. The current and aspired technology position in each STU is summarized in a profile for each STU.

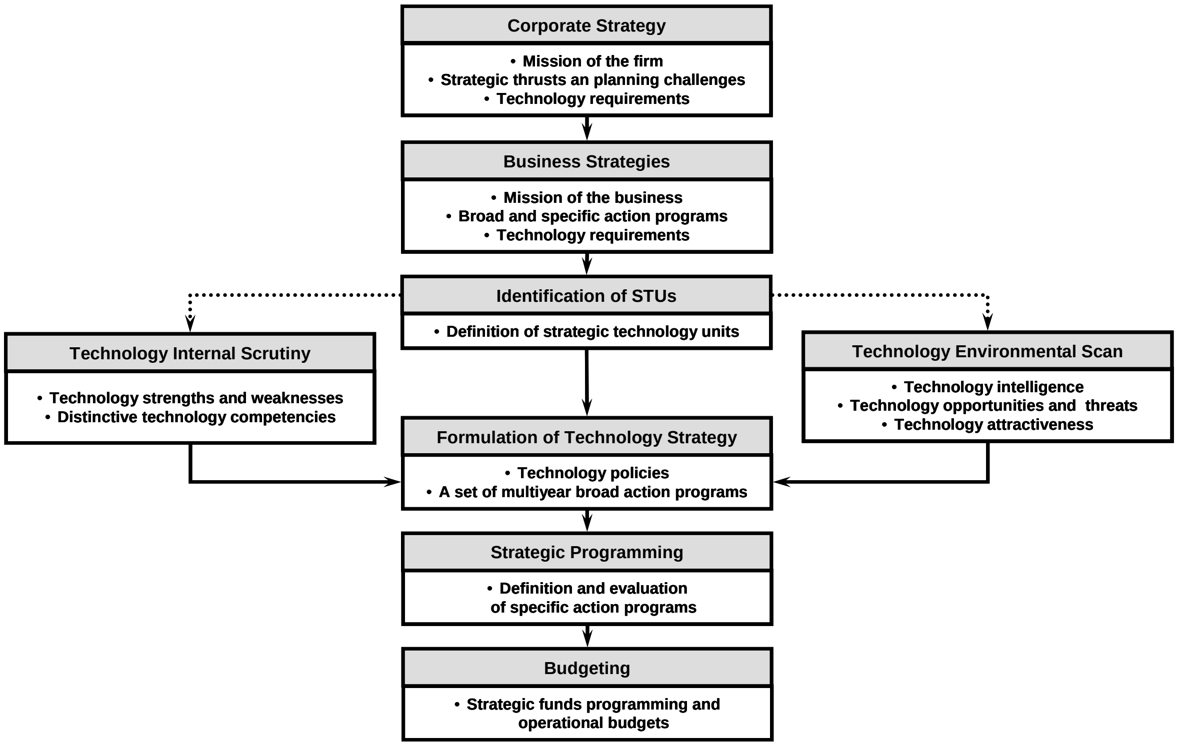


Figure 5-3: ***Technology strategy formulation process proposed by Hax and No (adapted from Hax A.C., No M. 1992: 13 and Hax A.C., Majluf N.S. 1996: 361).***

Technology Environmental Scan

The environmental scan is aimed at identifying technological threats and opportunities and is based on the STUs previously defined. This includes the analysis of the performance and innovation potential of technologies and the attractiveness of these technologies for the organization. Attractiveness of a technology is determined by the expected contribution to competitive advantage and the impact of a technology on the overall industry structure. The authors also suggest identifying potential sources for relevant technologies and technological innovations within and beyond current industry boundaries. Result form the internal scrutiny and the environmental scan are summarized in a suggested technology portfolio matrix (see Figure 5-4).

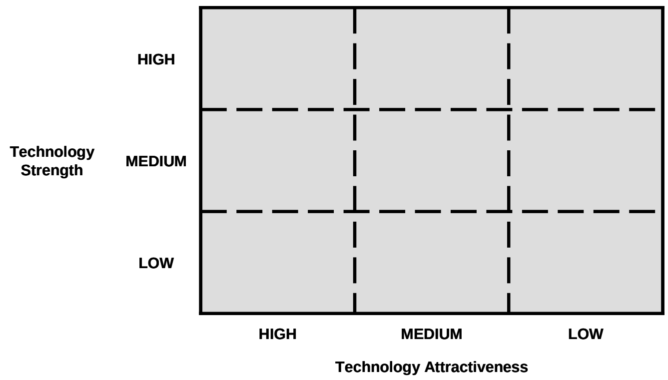


Figure 5-4: Technology portfolio matrix proposed by Hax and Majluf (adapted from Hax A.C., Majluf N.S. 1996: 370).

Formulation of Technology Strategy

The formulation of a technology strategy is articulated into three major decisions: Selection of technologies to develop, the timing of new technology introductions, and corresponding modes of technology acquisition and development. These set of decisions leads to the definition of a multiyear agenda for each STU. This desired agenda is programmed into specific technology programs and projects by yearly budgeting routines of the organization.

Compared to other contributions, Hax, Majluf and No's approach to technology strategy provides more guidance on what technology strategy is, how it is formulated, which methods and tools are necessary to do so and identifies organization and leadership issues related to technology strategy. But conceptually, the approach is based on the same foundations as Porter's: Technology strategy is enabler of corporate and business strategy and a state of strategic fit is established by a one-way and top-down alignment of the technology portfolio with the requirements of corporate and business strategies. The approach to technology strategy by Hax, Majluf and No is summarized in Table 5-7.

Table 5-7: Summary of Hax, Majluf and No's approach to technology strategy.

Attributes of Technology Strategy Approach	**Hax, Majluf and No's Approach to Technology Strategy**
Function of Technology Strategy	Strategic fit between current corporate and business strategy and technology portfolio.
Preliminaries of Technology Strategy	Corporate and business missions and strategies.
Elements of Technology Strategy	Technology selection, technology timing, technology acquisition mode, technology strategy organization and leadership, horizontal technology strategy, technology intelligence.

Attributes of Technology Strategy Approach	Hax, Majluf and No's Approach to Technology Strategy
Formulation of Technology Strategy	A hierarchical and linear sequence of steps.
Explicit Tools of Technology Strategy	o Technology valuation tools o Technology portfolio matrix o Checklists

5.2.1.3 Durrani, Carrie and Martowidjojo's Approach to Technology Strategy

Over a series of co-authored publications, Durrani, Carrie and Martowidjojo offer a technology strategy formulation approach, which also adopts a market-base view (Durrani T.S. et al. 1998a, Durrani T.S. et al. 1998b, Durrani T.S. et al. 1999, Carrie A.S. et al. 2000, Martowidjojo A., Carrie A.S. 2002). The core elements of their approach are shown in Figure 5-5.

Corporate Objectives and Strategic Advantage

Based on the current overall corporate objectives, derived form the value propositions of the firm, the intended corporate growth strategies and from specific business strategies and missions, the authors propose to identify the pursued forms of strategic advantage which should be reflected in technology strategy. The company should identify the adequate drivers and trajectories for its technologies and technological innovations based on these aspired forms of advantage. This approach to technology strategy, which derives the criteria for technology assessment from currently pursued strategies, indicates a market-based approach to technology strategy.

Technology Advantage

At this stage it can be assessed, how and how strong existing and already employed technologies contribute to the identified forms of strategic advantage. Additionally to this internal evaluation and based on the identified requirements for strategic advantage, a technology assessment routine for not employed or produced technologies is recommended by the authors (Durrani T.S. et al. 1998b: 605, Durrani T.S. et al. 1999: 524). New and emerging technologies are assessed by their potential to support the currently pursued strategic advantage, employing the same market-based criteria, which are used to evaluate already produced or employed technologies.

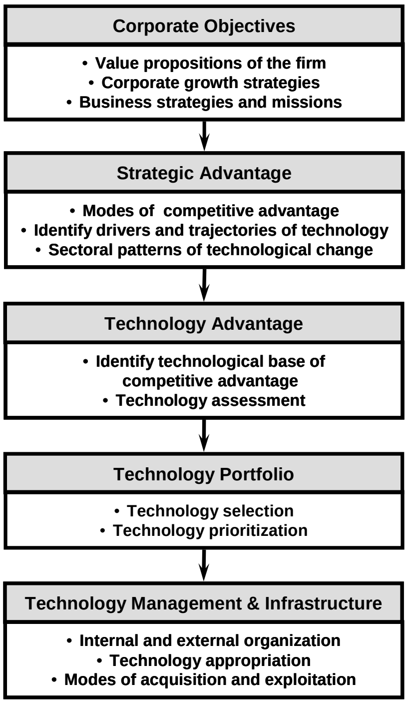


Figure 5-5: ***Technology strategy formulation process proposed by Durrani, Carrie and Martowidjojo (adapted from Martowidjojo A., Carrie A.S. 2002: 9, Carrie A.S. et al. 2000: 101, Durrani T.S. et al. 1998a: 16).***

Technology Portfolio

The technology portfolio is a list of internal and external technologies, which are currently contributing or show the potential to significantly contribute to the pursued strategic advantage of a firm. Based on this relative importance, technology acquisitions and investments are prioritized. Accordingly, the set of technology selection and prioritization decisions should also indicate the efforts for technological innovation a company should aspire in already adopted product and process technologies.

Technology Management and Infrastructure

The authors emphasize the importance to establish adequate procedures, routines and organizational structures to enable the organization to adequately implement strategic technology decisions. This includes technology appropriation, R&D funding and budgeting routines, adequate qualification of personnel, establishing of internal and external organizational linkages, and the management of internal and external technology development, acquisition and exploitation efforts.

Table 5-7 is summarizing Durrani, Carrie and Martowidjojo’s approach to technology strategy. It is easily recognized that their approach is conceptually based on the market-based view of strategy. The overall function of technology strategy is a one-way alignment of the firm’s technology base and portfolio with currently pursued corporate objectives. Although emphasizing external technology monitoring as a preliminary to technology assessment of potentially relevant technologies, technology assessment is using existing corporate and business strategies as a strong filter for these monitoring activities. While focusing on the description of the formulation process, the authors do not provide distinctive tools and methods which support steps in this process.

Table 5-8: Summary of Durrani, Carrie and Martowidjojo's approach to technology strategy.

Attributes of Technology Strategy Approach	Durrani, Carrie and Martowidjojo's Approach to Technology Strategy
Function of Technology Strategy	Strategic fit between corporate objectives and technology portfolio decisions.
Preliminaries of Technology Strategy	Corporate and business strategies and missions
Elements of Technology Strategy	Technology assessment, technology selection and prioritization, technology acquisition mode, technology strategy organization and leadership.
Formulation of Technology Strategy	A hierarchical and linear sequence of steps.
Explicit Tools of Technology Strategy	None.

5.2.1.4 Practitioners' Approaches to Technology Strategy

Beginning with the identification of technology as a key competitive variable, strategy consultants paid increasing attention to technology strategy. Their focus is on tools and action models to develop recommendations for strategic technology decisions, mainly for technology adoption and timing decisions. Two practitioner approaches to technology strategy are briefly reviewed.

A.D. Little's Approach to Technology Strategy

Already in 1981 A.D. Little proposed a structured sequence for formulating a firm's technology strategy (Little A.D. 1981), which was later refined (Saad K.N., Roussel P.A., Tiby C. 1991, Floyd C. 1997). Figure 5-6 shows the sequence, which is supported by various decision tools in form of portfolio matrices.

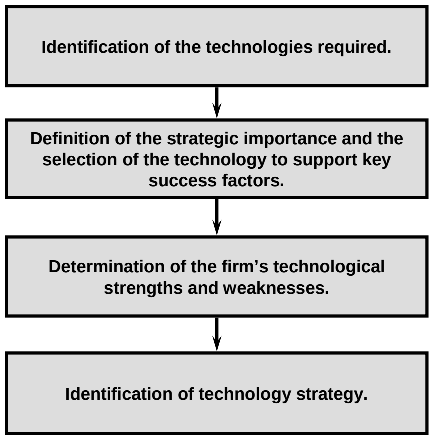


Figure 5-6: ***Sequential steps in formulating technology strategy proposed by A.D. Little (adapted from Saad K.N., Roussel P.A., Tiby C. 1991, Floyd C. 1997).***

In the first step, technologies of relevance for the offered products are identified. Based on the pursued business strategy, key factors of success in the industry are identified. Identified product and process technologies are assessed, if and how critical their contributions to these key factors of success are. These key factors of success may be product attributes like size, weight, price, power consumption and are highly context sensitive and industry and product specific. In the second step, the identified critical technologies are classified along potential competitive impact and their life cycle position. Technologies are categorized in base, key, pacing and emerging technologies. Analog to this procedure, the firm's technological competences in critical product and process technologies are classified into five categories: leader, strong, favorable, tenable, and weak. Based on these two assessments, one of the following generic technology strategies is chosen: build, nurture, maintain, repair, and invest selectively (see Figure 5-7).

<table>
<tr><th></th><th colspan="5">Level of Technological Competence</th></tr>
<tr><th>Technology Significance</th><th>Clear Leader</th><th>Strong</th><th>Favorable</th><th>Tenable</th><th>Weak</th></tr>
<tr><td>Base</td><td colspan="2" rowspan="2">Alarm signal for waste of resources – Maintain Technology</td><td rowspan="4">Industry average – Nurture Technology</td><td colspan="2" rowspan="2">Alarm signal for short-term survival – Repair Technology</td></tr>
<tr><td>Key</td></tr>
<tr><td>Pacing</td><td colspan="2" rowspan="2">Alarm signal for future opportunities – Build Technology</td><td colspan="2" rowspan="2">Alarm signal for future competitiveness – Invest selectively</td></tr>
<tr><td>Emerging</td></tr>
</table>

Figure 5-7: ***Generic Technology Strategies proposed by A.D. Little (adapted from Saad K.N., Roussel P.A., Tiby C. 1991, Floyd C. 1997).***

It is concluded that the approach of A.D. Little to technology strategy is completely based on the currently valid key factors of success derived from business strategy and is focused on creating a strategic fit between the current technology portfolio and current business strategy. Although the consideration of technology life-cycles enables a dynamic perspective, this perspective is highly limited by two factors. First, the pool of potentially relevant technologies, which is considered, is highly determined by the current dominant design of produced and employed technologies. Second, future opportunities are only considered, if a technology has the potential to positively contribute to the currently valid strategic fit. Strategic options on technologies which may offer new forms and sources of competitive advantage are not considered.

Booz-Allen & Hamilton's Approach to Technology Strategy

Booz-Allen and Hamilton developed a framework for technology strategy, which is also based on portfolio matrices and strategic positioning of the firm across limited number of generic technology strategies (Booz-Allen & Hamilton 1981, Pappas C. 1984). The underlying principle for their four step procedure to develop a technology strategy is that congruence of technology investments and pursued business strategy is essential to the company's success. The proposed sequence is presented in Figure 5-8.

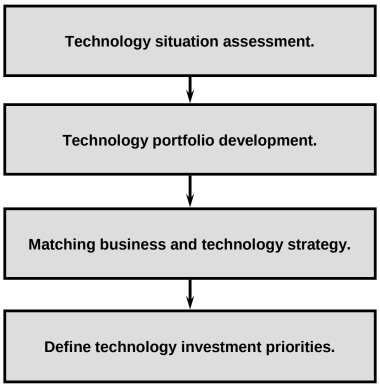


Figure 5-8: ***Sequential steps in formulating technology strategy proposed by Booz-Allen & Hamilton (adapted from Booz-Allen & Hamilton 1981, Pappas C. 1984).***

The technology situation assessment consists of the identification of technologies within a product/business area and the analysis of their importance to the product and the company's relative position compared to competitors. In the step of technology portfolio development, appropriate technology strategies of the business are identified, according to technology importance and the relative technology position. In a joint consideration of the business portfolio and the developed technology portfolio, business and technology strategy are matched and aligned. Result of this alignment process is a clear set of priorities for future technology investments. Booz-Allen & Hamilton suggest a set of portfolio matrices to support this decision making process (see Figure 5-9).

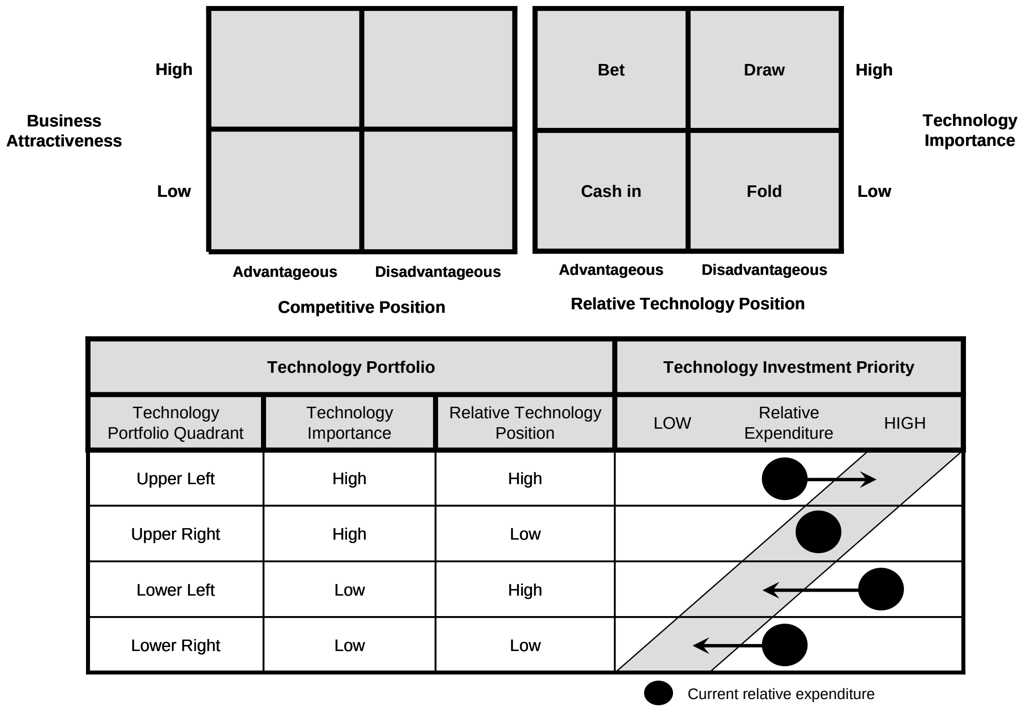


Figure 5-9: ***Technology portfolio approach by Booz-Allen & Hamilton (adapted from Pappas C. 1984: 33).***

In the advocated approach to technology strategy by Booz-Allen & Hamilton, the cognition and evaluation of technologies by a firm are highly dominated by already employed technologies in the company. Technology importance and position are mainly based on the criticalness of current technology for a current product and by a comparison with competitors employing the same technology.

Table 5-9: ***Summary of practitioners' approaches to technology strategy.***

Attributes of Technology Strategy Approach	Practitioners' Approach to Technology Strategy
Function of Technology Strategy	Strategic fit between current business strategy and technology portfolio.
Preliminaries of Technology Strategy	Business strategy and currently employed product and process technologies.
Elements of Technology Strategy	Technology selection and prioritization.
Formulation of Technology Strategy	Hierarchical and linear sequence of steps.

Attributes of Technology Strategy Approach	Practitioners' Approach to Technology Strategy
Explicit Tools of Technology Strategy	o Various portfolio matrices. o Checklists. o Technology maturity and life-cycle position.

5.2.1.5 Concluding Summary

All market-based approaches to technology strategy share some common characteristics. The suggested frameworks emphasize the existence and specificity of corporate and business strategies as prerequisites to technology strategy. Criteria for evaluating already employed or new technologies or technological innovations are directly derived from currently pursued or attained generic strategic positions and forms of competitive advantage. The unit of analysis for technology strategy is identified by existing configurations and dominant designs of product or process technologies and their current contribution to the pursued competitive advantage. This hierarchical, top-down and one-way view is also reflected in the proposed technology strategy formulation processes and its focus on reaching an optimal strategic fit. Additionally, most approaches transfer the idea of generic strategies from business strategy level to technology strategy level in form of generic technology strategies and corresponding tools like portfolio matrices are also adopted. Generic technology strategy appears to be the instrument how a top-down developed, market-based strategy is implemented in the technology domain of the firm. As generic competitive strategies were criticized to be quite static and misleading, when business environments are becoming more turbulent, the same arguments may be true for generic technology strategies. The question remains, if companies do actually really think about being a technology leader or follower in a specific technology discipline a-priori (Morone J. 1989: 97). The basic underlying theme for all market-approaches to technology strategy can be simplified and summarized as follows: If a technology is supporting an attained or currently pursued competitive advantage, the company should either extended an existing position in a technology or should establish an early position in a new technology. If a technology provides no support for the current business strategy, a company should reduce its commitments or should not include it in its technology portfolio at all.

5.2.2 Resource-based Approaches to Technology Strategy

Unlike the market-based or positioning approach to technology strategy, the resource-based view emphasizes the already existing resource and capability base of an organization as an at least equal driver and starting point for all technology strategy considerations. The basic assumption is that firm-specific factors like a firm's competences and resource base are the real sources of competitive advantage, which provide explanation for significant performance differences among firms. While market-based approaches to technology strategy regard the technology base and portfolio of a firm more as an endogenous variable, which has to be aligned with corporate and business strategy, resource-based approaches to technology strategy see the current technological resource base, technology change and innovation within a firm and within its business environment as both an exogenous variable and an endogenous variable for managerial action. Resource-based approaches to technology strategy see technology strategy as a two-way alignment process between corporate and business strategy and the technology base and portfolio of a firm. Different to generic technology strategies based on market-based approaches, which are mostly related to timing of technology adoption, generic technology strategies based on resource-based approaches are related to the level and form of intended technological competence and know-how. Table 5-10 is summarizing generic technology strategies based on resource-based approaches. The following subchapters briefly review some prominent resource-based approaches to technology strategy.

Table 5-10: Suggested typologies of resource-based generic technology strategies.

Author	Generic Technology Strategies
Bitondo D., Frohman A. 1981, Frohman A.L. 1985.	Technology Inventor
	Technology Innovator
	(Minor or Major) Technology Applier
	Technology Avoider
Goodman R.A., Lawless M.W. 1994.	Technological Commodity Search
	Preemption
	Productive Efficiency
	Producer Preference
	Production Flexibility
	Customer Preference
	Product Pioneer
	Vertical Integration
	Complementary Technology
Hayes R.H., Pisano G.P. 1994.	Low Cost
	High Quality
	Fast Response
Freeman C., Soete L. 1997.	Defensive
	Imitative
	Offensive
	Opportunist
	Traditional
	Dependent
Chiesa V., Manzini R. 1998a, Chiesa V. 2001.	Competence deepening
	Competence fertilizing
	Competence complementing
	Competence destroying
	Competence refreshing

5.2.2.1 Frohman and Bitondo’s Approach to Technology Strategy

Frohman and Bitondo’s approach to technology strategy is one of first consistent frameworks that emphasizes that technology strategy is not only a question of avoiding strategic misfit and of a one-way alignment process between corporate and business strategies and the technology configuration of a firm. They highlight that technology strategy is also a question of avoiding missed or ignored opportunities, which are based on company's existing technology competence (Frohman A.L. 1985: 49f). Frohman substitutes the hierarchical and stringent notion of strategic fit or alignment by *strategic balance.* He refers to a balanced state between technology as driver, implementer and enabler of a firm's overall strategy (Frohman A.L. 1980: 22). Over a series of published contributions on the topic, the authors developed a technology strategy formulation process and a supporting set of tools (Frohman A.L. 1980, Frohman A.L., Bitondo D. 1981, Bitondo D., Frohman A. 1981, Frohman A.L. 1984, Frohman A.L. 1985). Frohman and Bitondo's early ideas already anticipated basic elements of the resource-based view of later years. Figure 5-10 summarizes the Frohman and Bitondo's framework for technology strategy development.

Identifying Distinctive Technological Competencies (DTCs)

The authors propose an internal technological analysis of the firm, which should identify technological strengths relative to its technological peers. A distinct technological competence has three aspects: It consists of a set of technologies and technological skills. It describes how these skilled are applied. It refers to the object, the product or process, to which they are applied. A DTC should always be defined in terms of all these three aspects. While DTCs are in many cases directly relevant to competitive advantage, this aspect is not in the focus of this internal analysis. The more important issue is, if the organization has a set of superior technological competencies compared to its peers, and not if these competencies are directly perceived or valued by current customers.

Identifying Strategic Technology Areas (STAs)

The external technological analysis, suggested by the authors, identifies current and potentially future technologies, technological aspects or functionalities, which are expected to support the reasons why a customer buys or will buy the product or service. In desirable instances, a STA will directly correspond to a DTC. In some cases, a STA may refer to a DTC which is weak, perhaps because the STA was missed or ignored in the past or because it is new. A company may also recognize that a DTC is irrelevant to all identified STAs in its current markets. By looking at both STAs and DTCs, a company can identify various forms of mismatch.

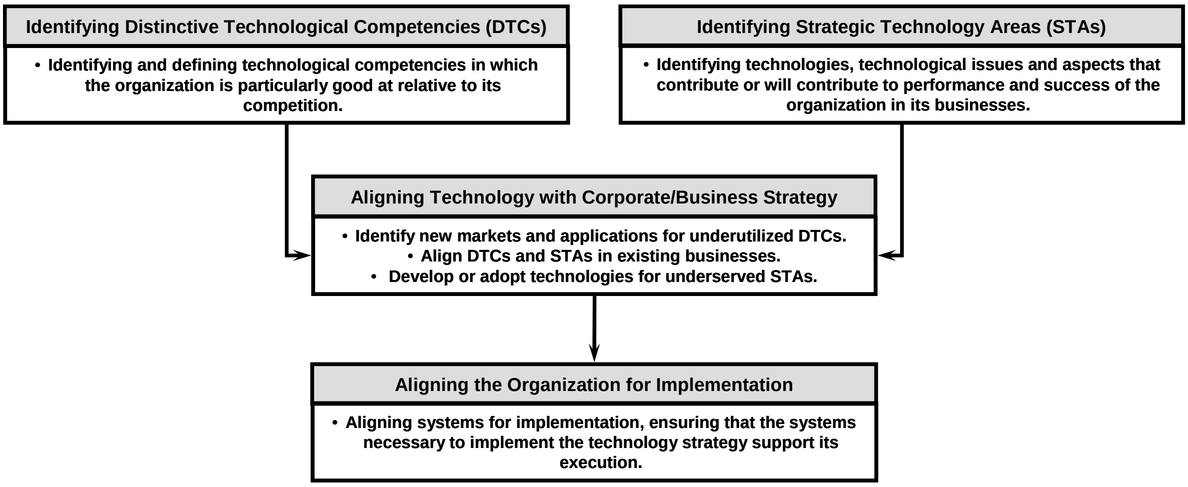


Figure 5-10: Technology strategy formulation process proposed by Frohman and Bitondo (adapted from Frohman A.L. 1984: 37ff, Frohman A.L. 1985: 50ff).

Aligning Technology with Business and Corporate Strategy

Three forms of in-balance between DTCs and STAs make a mutual alignment of technology, corporate and business strategy necessary. If a DTC is diagnosed, which does not address a STA in an existing business, new opportunities for exploitation or an option on leaving the DTC are necessary. If existing DTCs correspond with one or more STAs, a relative alignment of resource allocation intensity for a DTC should be in focus. If an identified STA is not considered by current DTCs, this issue should be addressed by a dedicated technology development imitative. Frohman and Bitondo also propose various tools how balance between DTCs and STAs could be restored. (Frohman A.L., Bitondo D. 1981, Bitondo D., Frohman A. 1981)

Aligning the Organization for Implementation

The last step proposed by the authors is the alignment of the organization for the identified measures. They suppose a list of issues, which are relevant to a successful organizational implementation: People, organizational structure and routines, external linkages, policies and norms of the organization, reward systems and performance measurement.

The core ideas of Frohman and Bitondo's approach to technology strategy are summarized in Table 5-11. It can be concluded that their approach to technology strategy and especially their distinction between DTCs and STAs enables bi-directional alignment between technology, corporate and business strategy. Their approach is emphasizing that technology strategy should also allow a company that its existing technological resource base is driving and directing the overall strategy of a firm.

Table 5-11: Summary of Frohman and Bitondo's approach to technology strategy.

Attributes of Technology Strategy Approach	Frohman and Bitondo's Approach to Technology Strategy
Function of Technology Strategy	Strategic balance between market-based and technology-based considerations in corporate and business strategy.
Preliminaries of Technology Strategy	External and internal analysis of technological competencies and requirements.
Elements of Technology Strategy	Technology selection, technology acquisition mode, technology strategy organization and leadership;
Formulation of Technology Strategy	Parallel consideration and integration of market-based and technology-based aspects into corporate and business strategy by a sequence of steps.
Explicit Tools of Technology Strategy	o Technology portfolio tables o Checklists

5.2.2.2 Ford, Clarke, Saren and Thomas' Approach to Technology Strategy

Over a series of co-authored and complementary contributions, these four authors developed an integrated approach to technology strategy (Ford D. 1988, Clarke K., Ford D., Saren M. 1989, Saren M. 1991, Clarke K. 1992, Clarke K. et al. 1995, Ford D., Thomas R. 1997). This includes prescriptive concepts on the content and formulation process of technology strategy based on descriptive and qualitative empirical research in form of case studies. The authors identified three core elements of technology strategy (see Figure 5-11).

Technology Acquisition

The authors emphasize technology acquisition as a core element of a sound technology strategy. It requires a careful integration of various different modes like in-house R&D, licensing-in, contracted out R&D, arms-lengths procurement and joint ventures or alliances. Factors, which are affecting the technology acquisition decision, are the company's own competence in the relevant technology, urgency of acquisition, level of commitment, technology life cycle position and the competitive criticalness of a technology.

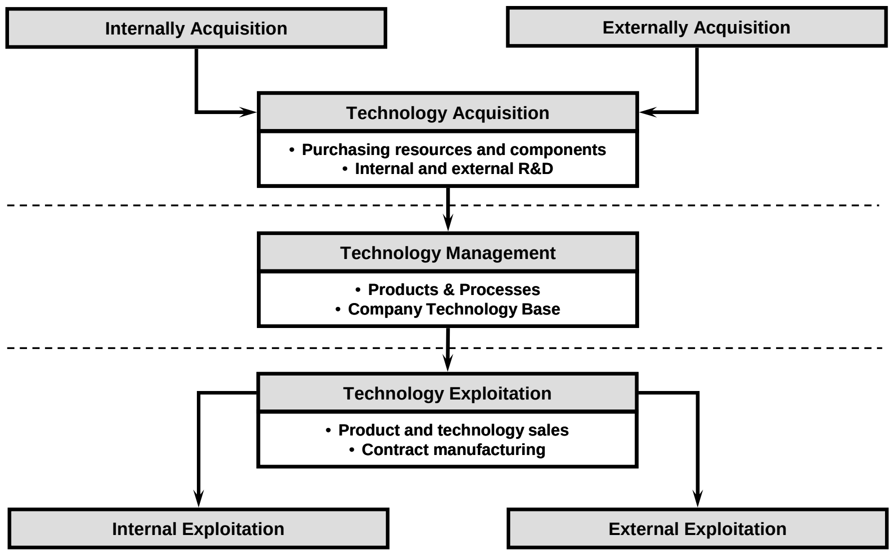


Figure 5-11: ***Elements of technology strategy proposed by Ford, Clarke, Saren and Thomas (adapted from Ford D. 1988:85, Clarke K. et al. 1995:172, Ford D., Thomas R. 1997: 601)***

Technology Management

The second element of technology strategy, suggested by the authors, consists of a number of different aspects. Generally spoken, it includes all those activities, which together enable a company to make and implement its technology acquisition and exploitation decision. The authors emphasize that it is primarily an organizing activity. They suggest routines for internal technology transfer, technology innovation policies and internal and external technology analysis procedures. It is also highlighted that the establishing of a designated technology strategy unit or function may support technology strategy formulation and implementation within the company.

Technology Exploitation

Technology exploitation involves similar considerations as technology acquisition. It involves various possibilities for exploiting a mastered technology internally or externally. The authors suggest possibilities like employment of a technology in own products or processes, contract manufacturing for other firms, or exploiting technologies in joint ventures or a licensing-out contracts. Factors, which are affecting technology exploitation decisions, are the company's own technological competence, unique windows of opportunities for technology exploitation, the necessity for complementary technologies, intended risk and commitment, technology maturity and competitive criticalness and the scope of potential applications.

Additionally to the suggestion on the content of technology strategy, the approach also includes a framework for technology strategy development (see Figure 5-12). Following a resource-based approach, technology strategy takes into account technological opportunities along with market-based considerations and the boundaries of limited internal capacities. It is suggested that technology is developed within a technology audit process of the company. This audit should not just be a once-and-for-all exercise but a continuous and managed process.

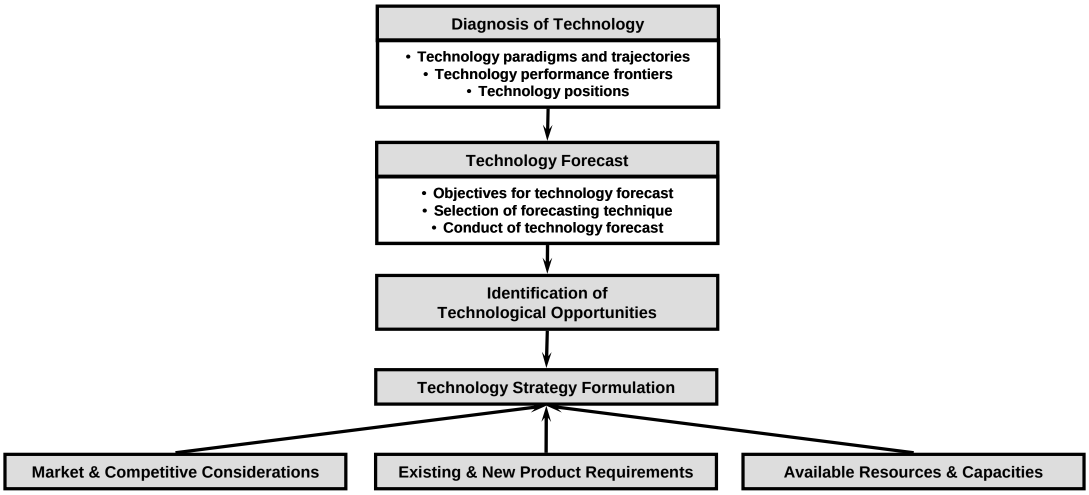


Figure 5-12: Technology strategy formulation process proposed by Saren (adapted from Saren M. 1991: 12).

Diagnosis of Technology

The authors highlight the importance of identifying the right unit of analysis for technology strategy formulation. While in the early versions of the approach, they propose to adequately integrate process and product technologies to *technology bundles* and *clusters* (Ford D. 1988: 94, Clarke K., Ford D., Saren M. 1989: 224), later version talk of *multiple sets of technologies* and *technology systems* (Ford D., Thomas R. 1997: 601, Clarke K. 1992: 34, Clarke K. et al. 1995: 184ff). Saren adopts Dosi's notion of technology paradigms and trajectories (Dosi G. 1982) and emphasizes that a firm has to identify and diagnose the relevant technology paradigms and trajectories, its own position and the frontier of technological innovation along these trajectories (Saren M. 1991:9ff).

Technology Forecasting

Based on the identification and diagnosis of relevant technology paradigms and trajectories, the firms' own position, the position of the firm's competition, and the frontier of technological progress along these trajectories, the authors suggests various extrapolative and normative forecasting techniques. The result of these forecasting efforts will lead to the identification of specific technological opportunities for the firm – for technology acquisition and exploitation, which provides a direct input for the formulation of technology strategy.

Together with market-based consideration, technological requirements of business and product strategies and the limitations of the firm's resources, the identified technological opportunities are used to formulate a firms' technology strategy. The result is a set of decisions on which and how technologies are acquired and exploited how to prepare the overall organization for successful implementation of these decisions. Table 5-12 is summarizing the characteristics of Ford, Clarke, Saren and Thomas' approach to technology strategy.

Table 5-12: Summary of Ford, Clarke, Saren and Thomas' approach to technology strategy.

Attributes of Technology Strategy Approach	Ford, Clarke, Saren and Thomas' Approach to Technology Strategy
Function of Technology Strategy	Mutual alignment of resource-based and market considerations in a firm's technology system.
Preliminaries of Technology Strategy	Technology analysis and forecasting.
Elements of Technology Strategy	Technology analysis and forecasting, technology intelligence, technology acquisition mode, technology exploitation mode; organizational issues of technology strategy.
Formulation of Technology Strategy	A sequence of steps to identify technological opportunities and a parallel consideration of market-based requirements.
Explicit Tools of Technology Strategy	o Portfolio tables and matrices

5.2.2.3 Chiesa and Manzini's Approach to Technology Strategy

Based on the approach of Hax, Majluf and No and on the emerging literature on resource-based strategy, Chiesa and Manzini developed a framework for technology strategy, which combines compatible and complementary parts of both domains (Chiesa V., Manzini R. 1998a, Chiesa V. 2001). While the authors agree on the basic dimension of technology strategy (technology selection decisions, technology timing decision and technology acquisition mode) they propose a different scope, process and different criteria for how these decisions are made. Their approach is based in the overall criticism of the market-based view. They argue that in today's more complex and dynamic business environment, current product-market combinations are no adequate underpinning for strategy making. Frameworks, tools and methods of market-based approaches to technology strategy start with analyzing current corporate and business strategies, which are mostly based on industry analysis and the actual competitive environment. This assumes that industry structure and boundaries and existing market, product and technology paradigms are stable over time. Chiesa and Manzini's argument is that superior firm performance cannot be sustained by focusing on the existing competitive environment. If the unit of analysis for technology strategy is derived from corporate and business strategy and is embodied in existing products or manufacturing process, the analysis and scope of technology strategy is highly restricted and limited to existing paradigms of products and production processes (Chiesa V., Manzini R. 1998a: 111ff). Following the argument of the resource-based view, the authors propose a technology strategy formulation process, which is based on an internal and external analysis and is not strictly limited by the current scope of existing product-market combinations (see Figure 5-13).

External Analysis

External analysis is the analysis of the complete environmental context of the organizations and its change. It is conducted in three steps:

- Identification of the current and future value to the customer and its evolution over time in existing markets.
- Identification of critical future skills and technological capabilities corresponding to these needs.
- Identification of new potential markets and industries.

The current product provided to the customers should be seen as a transient vehicle for a provided functionality or a technological solution to the satisfaction of customer needs. Currently dominant technological solutions always implicitly guide this external analysis, but they may not represent an absolute reference for all possible future solutions. Additionally to the analysis of the current markets, their evolution and the identification of necessary skills and capabilities to face future needs, external analysis is also searching for new potential markets and industries for exploiting already existing technological competences.

Internal Analysis

The authors emphasize that the internal analysis should focus on a more stable unit of analysis than existing product-market combinations. They propose to shift from output-oriented units (e.g. products) to units which are more stable over time and represent the technological competencies, expertise and resources of an organization. The authors suggest mapping the technological skills and competencies, to benchmark them against other technological peers from within and beyond the industry boundaries and to identify distinctive and especially critical skills. The company should also identify potential application and exploitation opportunities of existing distinctive technological skills.

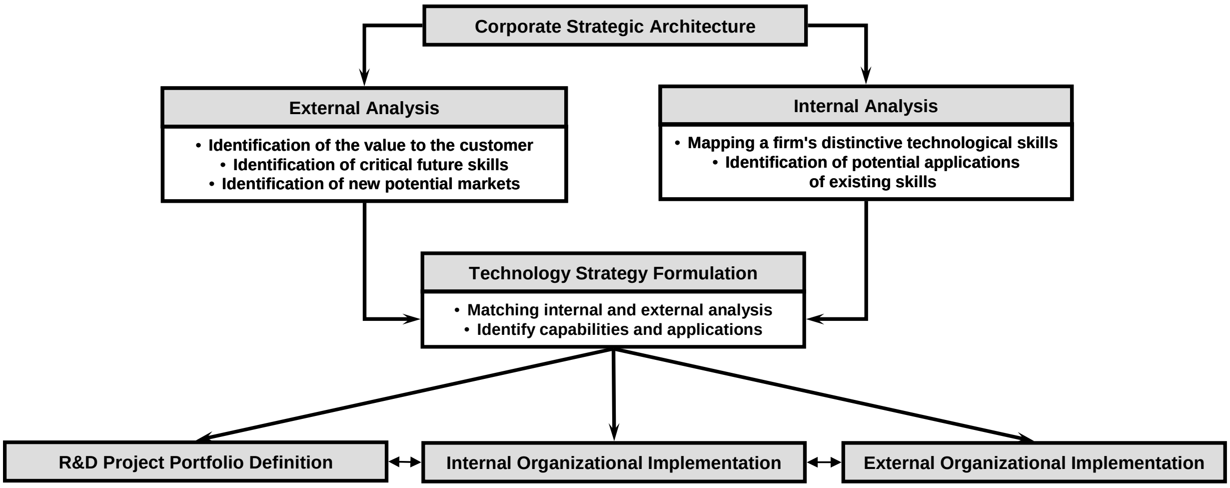


Figure 5-13: Technology strategy formulation process proposed by Chiesa and Manzini (adapted from (Chiesa V., Manzini R. 1998a: 116 and Chiesa V. 2001: 57).

Technology Strategy Formulation

Similar to already discussed approaches, the matching and compilation of internal and external analysis results in the formulation of the technology strategy of the organization. The insights are matched within four domains:

- Existing technology competences are employed in existing applications.
- Existing technology competences are used to enter new applications.
- New technology competencies are necessary to compete in existing applications.
- New technology competencies are necessary to enter new applications.

These four domains are represented in a suggested portfolio matrix which is related to set of generic technology strategies (see Figure 5-14). The generic technologies strategies proposed by Chiesa and Manzini are defined by their relationship to already existing technological competences within the company and not by their technology timing or positioning in the industry.

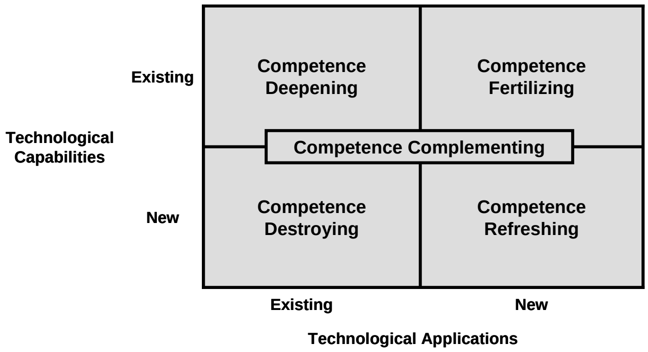


Figure 5-14: Generic technology strategies suggested by Chiesa and Manzini (adapted from Chiesa V., Manzini R. 1998a: 118).

R&D Project Portfolio Definition

Once a technology strategy is formulated, which indicates the technologies that are critical for the firm's competitiveness, more detailed plans of action have to be defined. The formulated technology strategy should be articulated into a R&D project portfolio. The R&D project portfolio definition includes tasks like (Chiesa V. 2001: 113):

- Determine the R&D budget
- R&D project definition
- R&D project evaluation
- R&D project selection
- R&D project portfolio analysis

Internal Organizational Implementation

Based on the intended technology strategy and the already existing organization and infrastructure of the company, the company should align the organizational structure and procedures of research and development. The approach suggests that the following structural dimension should be affected by intended technology strategy (Chiesa V. 2001: 149ff):

- The organizational structure and routines of research, development and engineering units and departments.
- The hierarchical distribution and positioning of these units, especially the degree of centralization and decentralization.
- The horizontal and geographical distribution of internal R&D resources.

External Organizational Implementation

One of the most emphasized decisions within technology strategy is on the balance between internal or external resources for technology exploration and exploitation and how to organize and mange these external technological relationships. The authors highlight the choice between various forms of external technology relationships depends on the goal and objective of the involved R&D project and the typology of potentially relevant external partners (Chiesa V., Manzini R. 1998b, Chiesa V., Manzini R., Tecilla F. 2000).

Table 5-13 is summarizing the main aspects of Chiesa and Manzini's approach to technology strategy. It is concluded that their approach is providing more guidance and details than other resource-based approaches.

Table 5-13: Summary of Chiesa and Manzini's approach to technology strategy.

Attributes of Technology Strategy Approach	Chiesa and Manzini's Approach to Technology Strategy
Function of Technology Strategy	Bi-directional and mutual strategic alignment between corporate, business and technology strategy.
Preliminaries of Technology Strategy	The overall existing corporate strategic architecture.
Elements of Technology Strategy	Technology intelligence, technology selection, technology timing, technology acquisition mode, technology strategy organization and leadership;
Formulation of Technology Strategy	A parallel process of internal and externals considerations on market-based and technology-based requirements and limitations.
Explicit Tools of Technology Strategy	o Technology strategy tables and matrices. o Various tools for technology project evaluation and selection. o Various tools for technology forecasting and intelligence.

5.2.2.4 Concluding Summary

Resource-based approaches to technology strategy can be interpreted as a conceptual counter-movement to the overemphasis of purely market-based considerations in technology strategy formulation. Most of them complement the role of technology in industrial organizations as a pure enabler of corporate and business strategies with the perspective, that technological assets, expertise and know-how should also drive corporate and business strategy. Technological capabilities of an organization are considered to be more sustainable as sources of competitive advantage and should therefore be in the very center of strategic considerations. The reviewed resource-based approaches to technology strategy therefore add strategic considerations on how the internal and external technology context of an organization should influence corporate and business strategy to the conventional top-down approach of establishing a strategic fit between the current strategy and the technology portfolio of an organization. Based on these ideas, the resource-based approach to technology strategy introduces at least two new aspects: First, as technology is considered to be a potential source of sustainable competitive advantage, technology strategy should also seek for technologies beyond the scope of current corporate and business strategies and beyond the immediate boundaries of the industry and its value chain. Second, technology strategy should also guide the search for additional exploitation opportunities for already mastered technological competences, which go beyond current products, markets, and industries and therefore beyond currently valid strategies. These two aspects complement the more traditional and market-based aspect, that existing technological assets and all research, development and engineering efforts should be perfectly streamlined for current strategic fit.

5.2.3 Dynamic Perspectives on Technology Strategy

Although many writers on technology strategy of industrial organizations generally emphasize the impact of technological change and innovation as determinants of industry structure and competitive advantage, proposed conceptual models of technology strategy rarely reflect patterns of dynamic change in technology strategy of a firm over time (Hamilton W.F. 1990: 141). A dynamic perspective on technology strategy has two major implications: First, the notion dynamic implies that the concept of technology strategy is not regarded as static posture, but is observed over time, and second, internal and external changes in the technology context of a company over time may impact the efficiency and/or effectiveness of a pursued or established strategic fit of technology strategy. Already in 1989, it was proposed that the idea of technology strategy also needs to be related to Mintzberg’s view of the nature of strategy in general (Clarke K., Ford D., Saren M. 1989: 217). While most proposed concepts of technology strategy are focused on establishing and maintaining strategic fit for the currently pursued business and corporate strategies in the functional domains of research, development, engineering and manufacturing, there are some contributions that explore and observe various dynamic aspects of technology strategies in firms. Although there is no coherent and consistent research agenda, several authors coined the notion of *dynamic technology strategy* (Chiesa V., Manzini R. 1998a, De Neufville R., Pirnar A. 1999). This notion of dynamic technology strategy primarily reflects the efforts to transfer the insights of recent strategic management research, like dynamic capabilities, strategic flexibility and strategic options into the concept of technology strategy. Four distinguishable clusters of dynamic perspectives on technology strategy were identified in the literature, which are briefly reviewed:

- Technology strategy as response strategy.
- Evolutionary perspectives on technology strategy.
- Dynamic strategic planning of technology strategy.
- Technology strategy as a portfolio of and sequence of options.

5.2.3.1 Technology Strategy as Response Strategy

Already in 1976 Cooper and Schendel identified response strategies of established incumbent firms to technological threats in their industries (Cooper A.C., Schendel D. 1976). While the response strategies varied from doing nothing, selective market exit and fighting it legally or by exploiting existing market power, one observed and successful strategy was increasing the overall organizational flexibility proactively to be able to respond and commit gradually to the new technology (Cooper A.C., Schendel D. 1976: 66ff). As a major result, the authors conclude that a main reason for the low rate of success and survival of incumbent firms when facing massive technological threats is the firm's inability to change their overall strategy (Cooper A.C., Schendel D. 1976: 69). One implication is that management should allow and enable an organization to adopt experimental strategies regarding threatening technologies and should very carefully monitor the approaches of other industry incumbents and new entrants. Appraising the strategies of new competitors, which are based the new technology, is especially important (Cooper A.C., Smith C.G. 1992: 69).While different patterns of resource commitment to the new technologies and some pitfalls were identified in the studied cases, no clear success or enabling factors for incremental participation strategies in new and threatening technologies were identified. The authors conclude that there is no *single best way* for an established incumbent firm to develop strong competitive position in the emerging technology (Cooper A.C., Smith C.G. 1992: 66).

By asking why some established firm's survive technological discontinuities in their industries and other die, Nicholls-Nixon proposed that successful responsiveness of a firm to a threat or opportunity in form of a technological discontinuity is a function of the organization's overall absorptive capacity (Nicholls-Nixon C.L. 1995: 2). This absorptive capacity, which is influenced by the level of internal R&D efforts and the amount and quality of existing external technology linkages and networks, can be interpreted as the ability of companies to transform identified technological threats and opportunities into designated strategic options and initiatives (Cohen W.M., Levinthal D.A. 1990).

Hatfield and colleagues observed that technology strategies of firms, which are designed like hedges, lead to higher survival rates and market-shares of these firms in the long-run (Hatfield D.E., Tegarden L.F., Echols A.E. 2001). A firm pursues a hedging technology strategy, when it simultaneously makes multiple but limited investments in competing technologies (Collingridge D. 1983). The authors showed that firms in the PC industry, which pursued competing technologies in parallel until a dominant technology design eventually emerged, had a significant lower mortality rate than their competitors which were focusing on and committing to one technology path (Hatfield D.E., Tegarden L.F., Echols A.E. 2001: 72). While in this case the competing technologies were mainly sourced externally, Gardner and Buzacott showed the advantages of hedging in a technology strategy for a specific investment decision in competing process technology innovations (Gardner D.T., Buzacott J.A. 1999). Although hedging makes the best case scenario impossible, in which a firm luckily bets on the eventually prevailing technology, it shows how the design and timing of strategic technology decisions as a hedge allows for successful decision making in identified risk situations.

Some general conclusions from these contributions on how established companies responded or should respond to technological discontinuities in their industries are:

- Gradual and experimental adaption to an uncertain technological discontinuity seems to be advantageous in many cases.

- Timely and proper responses of firms to technological discontinuities in their industries are enabled or facilitated by an existing absorptive capacity, which should already exist before discontinuities occur.
- If technological discontinuities create an anticipated risk situation between two or more competing alternative technologies in an industry, hedging is a dominant strategy in many cases.

5.2.3.2 Evolutionary Perspectives on Technology Strategy

Similar to the research on the general strategy concept in competitive business environments, technology strategy content research was dominating technology strategy process research until the flaws, pitfalls and limitations of strategic planning routines in more turbulent business environments became evident (Mintzberg H. 1981, Mintzberg H. 1993, Mintzberg H. 1994a, Mintzberg H. 1994b). Burgelman and Rosenbloom first transferred a dynamic and evolutionary perspective into the domain of technology strategy (Burgelman R.A., Rosenbloom R.S. 1989). Similar to Mintzberg's rejection of seeing a firm's strategy only as a plan or planning procedure, they describe technology strategy also as a pattern of interrelated decisions and an evolutionary learning process within an organization. In Figure 5-15 they conceptualize this cyclic learning process of technology strategy as feedback-loop between the technological capabilities of a firm and the application and enactment experience of these technological capabilities.

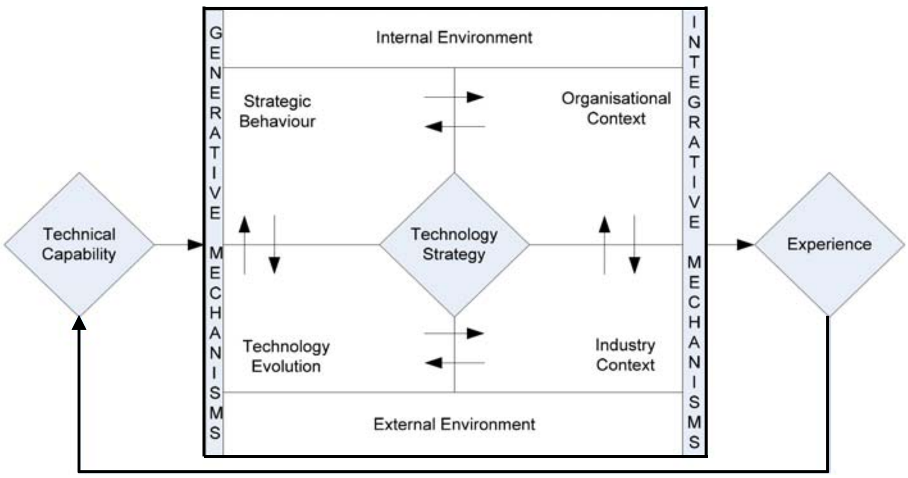


Figure 5-15: ***Burgelman and Rosenbloom's evolutionary process framework for technology strategy (Burgelman R.A., Rosenbloom R.S. 1989: 6).***

In summary, the authors propose that technology strategy emerges from organizational capabilities, shaped by generative forces of the firm's strategic behavior and evolution of the technological environment, and by the integrative mechanisms of the firm's organizational context and the environment of the industries in which it operates. The authors argue that, from an evolutionary perspective, a firm's technology strategy cannot be described as a generic technology strategy as proposed by most approaches to technology strategy. Technology strategies of successful firms are parallel and sequential combinations of technology leadership and followership, cost leadership and differentiation (Burgelman R.A., Rosenbloom R.S. 1989: 12f). The authors emphasize that evidence suggests that successful firms are able to operate within some sort of dynamic and harmonious equilibrium of the internal an external forces and mechanism sketched in Figure 5-15. Major changes in one domain, as the emergence of technological discontinuities, have to be matched by successive adaption in the others. Burgelman and Rosenbloom propose that these evolutionary modes of adaption should be in the very focus of technology strategy (Burgelman R.A., Rosenbloom R.S. 1989: 20). In their explorative study on the dynamics of technology strategy in eight technology-intensive firms in New Zealand, Davenport and colleagues confirm the dynamic concept of technology strategy of Burgelman and Rosenbloom (Davenport S., Campell-Hunt C., Solomon J. 2003). While the generalization of their results may be limited, their results highlight that a dynamic view of technology strategy is required in increasingly dynamic business contexts. They conclude that technology strategy has to be re-conceptualized as an empirical or experimental learning process rather than a strategic planning procedure (Davenport S., Campell-Hunt C., Solomon J. 2003: 497).

One of these approaches, which propose that technology strategy at firm level must be as dynamic as the evolution of the technological context, was formulated by McCarthy (McCarthy I.P. 2003). He emphasizes the analogy to biological evolution in nature and transfers fours basic elements of the concept of evolution into the domain of technology strategy (McCarthy I.P. 2003: 738f):

- *Struggle for Survival*: Like a species, a company is usually driven by the permanent overall goal of its own survival in its businesses context. The basic selection mechanism in competitive business environments is competition for resources and customers under changing environmental conditions.
- *Variation/Mutation*: This is the evolutionary process which generates technological variety in a company. To enable technology strategy as an evolutionary process within an organization, intentional or blind variation (mutation) must be reflected by a technology strategy, which explores new or additional technologies.
- *Selection*: The evolutionary process, which differentially chooses superior and eliminates inferior technological configuration is known as selection. Successfully “selected” technological configuration are adopted and exploited, while inferior ones are abandoned.
- *Retention:* Successful or dominant technological configurations are preserved, copied and imitated within organizations and across industries.

The main conceptual difference between biological evolution of a single species in nature and organizational evolution of a company is the notion of *intended or planned variation* (McCarthy I.P. 2003: 743). While variation in nature is based on random mutations an their combinations, organizations, as complex and adaptive social systems, are able to trigger intended variation processes in anticipation of future events. In nature, random mutation creates variation across and within species. This variation is reduced by the adequateness of fit of these random mutations with the environments (process of natural selection). Although this kind of accidental, blind or unplanned variation also occurs in organizations, the anticipation of changes in the environment can trigger intended, designated or planned variations (McCarthy I.P. 2003: 738). Figure 5-16 summarizes theses ideas on technology strategy as an evolutionary process within an organization.

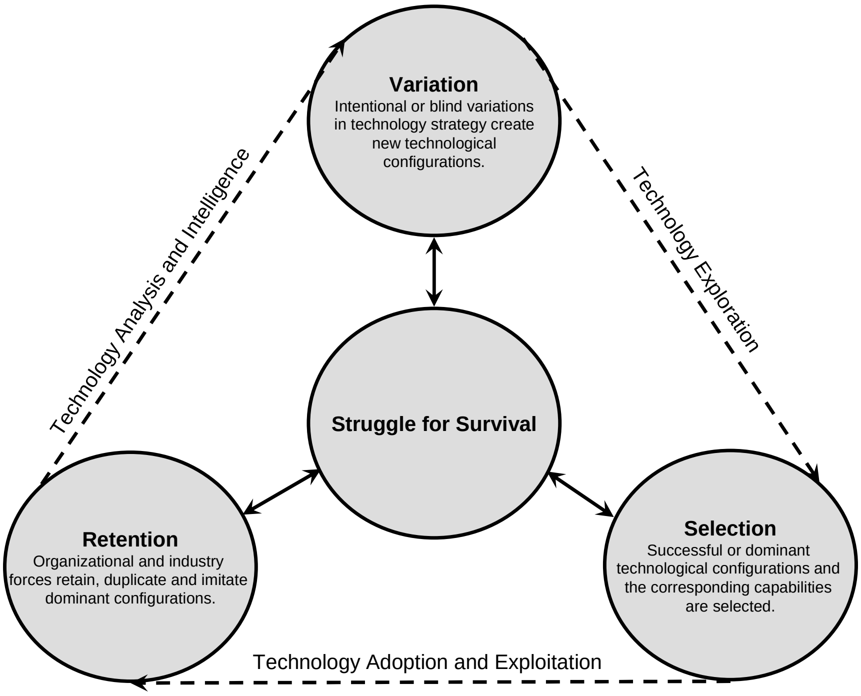


Figure 5-16: Technology strategy as an evolutionary process within an organization (adapted from McCarthy I.P. 2003: 738f).

The cyclical linkage of technology exploration, technology adoption and exploitation and technology analysis and intelligence enables technology strategy as a quasi-evolutionary process within organizations. Quasi-evolutionary, because random mutation and variation is complemented by an intelligent design, which proactively and consciously creates variation for anticipated environmental changes. Technology exploration of new variations in the technology configuration allows adopting and exploiting these configurations. Technology analysis and intelligence enables an organization to initiate intended variations in technology strategy. McCarthy also emphasizes that current fit of a technology strategy with the current technology context is different form the ability or potential for future fitness under different conditions. Future fitness depends on how successful a company explores and achieves future variations of technology configuration by its technology strategy (McCarthy I.P. 2003: 740).

Another but highly related dynamic perspective on technology strategy was offered by Itami and Numagami (Itami H., Numagami T. 1992) and was further developed by Zahra and colleagues (Zahra S.A., Sisodia R.S., Matherne B. 1999). The authors content, that the relationship between technology and strategy has been treated in a too static way. In most market-based approaches, resource-based approaches and adequate combination of both, static strategic fit between current strategy and current technology context seems to be the overall objective of technology strategy (Itami H., Numagami T. 1992: 119ff). Additional to this static, contemporaneous fit and matching between technology and strategy, the authors highlight two dynamic interactions (Itami H., Numagami T. 1992: 120):

- The dynamic interaction between current technology strategy and the future technology context of the firm: Current technology strategy is cultivating a firm's future technology base.
- The dynamic interaction between future technology strategy and the current technology context: The current technology context drives the cognition of a firm's future technology strategy.

The authors propose that exactly these two dynamic linkages between technology and strategy have to be more in focus of technology strategy efforts. Figure 5-17 shows in these three linkages.

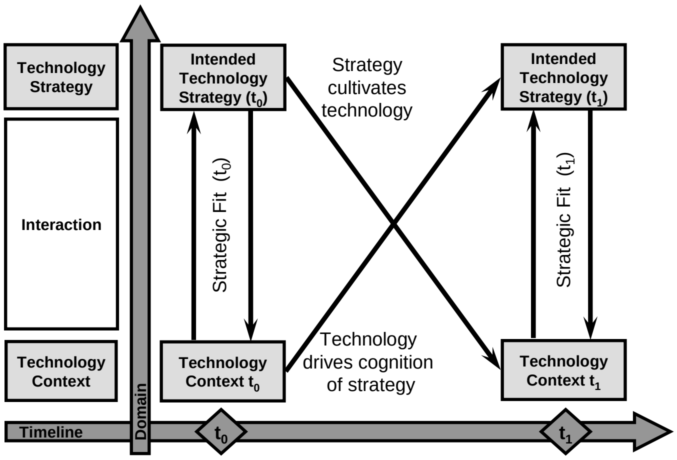


Figure 5-17: Dynamic interaction between strategy and technology (adapted from Itami H., Numagami T. 1992: 131, Zahra S.A., Sisodia R.S., Matherne B. 1999: 193).

Itami and Numagami basically argue that both dynamic perspectives on the strategy and technology linkage demand that current strategy should not be perfectly balanced with the firm's current technology context. They suggest that some technological initiatives of firms should not be targeted at the currently pursued strategic fit. The authors actually propose a certain amount of misfit between the current technology base and a firm's current strategy (Itami H., Numagami T. 1992: 125f). It seems that a holistic technology strategy's goal should be to establish a *dynamic balance* and a trade-off between these different static and dynamic linkages of technology and strategy, and therefore should balance strategic fit and deliberate strategic misfit between a firm's current strategy and its current technological capabilities and resources. The authors conclude that this balance between these perspectives on technology strategy is necessary for a firm's survival over the long haul (Itami H., Numagami T. 1992: 132). It is concluded, that in turbulent business environments, technology strategy and technology context should not be perfectly synchronous with each other, as suggested by the concept of strategic fit (Zahra S.A., Sisodia R.S., Matherne B. 1999: 196).

5.2.3.3 Dynamic Strategic Planning of Technology Strategy

De Neufville and Pirnar propose principles, which enable a company to plan a dynamic technology strategy (De Neufville R., Pirnar A. 1999). They describe it as an effective approach, which allows dealing proactively with risk and uncertainty by anticipation and corresponding build-in flexibility within strategic plans. Dynamic strategic planning explicitly and realistically addresses two major issues related to technology turbulence (De Neufville R. 2000: 231f):

- The future cannot, if at all, be predicted accurately, so that forecasts are typically quite different from what eventually occurs.
- There is no single "right" plan, which can be perfectly planned in advance.

The authors highlight the different relevance of strategic plans in more dynamic environments as planning as learning and emphasize that strategic planning is not a useless exercise in a dynamic and uncertain context. They propose that the goals, content, process and tools of strategic planning should be adapted to these environmental conditions. Dynamic strategic planning is (De Neufville R. 2000: 232):

- *Dynamic* in that it recognizes that in an uncertain and changing world it is important to have flexible plans that can adjust for future conditions, instead of identifying an "optimal plan" in advance that will not hold for any meaningful time.
- *Strategic* in that it properly takes the view that the planed configuration has to perform well not just in the immediate but over the long term.
- *Planning* in that it does indeed develop a coherent set of guidelines for management as to what should be done and when and how it should be done.

Plans under these conditions explicitly involve flexibility and do not minimize it by premature commitment. By development of options, either for exploiting opportunities or for mitigation of threats, flexibility can be created within strategic plans. Buying the right capability to response easily to future events is the key to building an adequate strategy under uncertainty. A planned technology strategy is flexible, when it defines the first steps of action and leaves later steps to be decided on according to the way events develop. A planned strategy, which is interpreted this way, emphasizes not only advantageous strategic positions, as many strategy frameworks do, but also enable strategic moves that permit easy response to the potential range of circumstances (De Neufville R., Pirnar A. 1999: 85). The authors basically propose that some degree of flexibility can build-in into the planned and intended technology strategy.

5.2.3.4 Technology Strategy as a Portfolio and Sequence of Options

In chapter 3 strategic options were defined as the right, but not the obligation to adopt new forms and sources of competitive advantage. The notion of a strategic option was clearly distinguished from financial options, operational options and the real options valuation technique. As one of the first, Hamilton and Mitchell transferred the concept of strategic options to the domain of technology strategy, by proposing a new and dynamic approach to technology strategy, which explicitly takes into account the dynamics of technology and strategy evolution and the uncertainty that is usually involved (Hamilton W.F. 1985, Mitchell G.R. 1985, Mitchell G.R. 1988). Technology strategies change evolutionary with the gradual creation and exercising of strategic options. A strategic option within technology strategy is regarded as the opportunity but not the obligation of a company to increase strategic commitment for a new or additional technology. The authors propose that technology strategy, regarding an identified strategic technology area (STA), is a program portfolio of strategic options which differ along the involved uncertainty and strategic commitment and focus (see Figure 5-18). It is proposed that within an STA, technology strategy shows evolutionary patterns, as a series of strategic options is created and exercised over time (Hamilton W.F. 1990:145f).

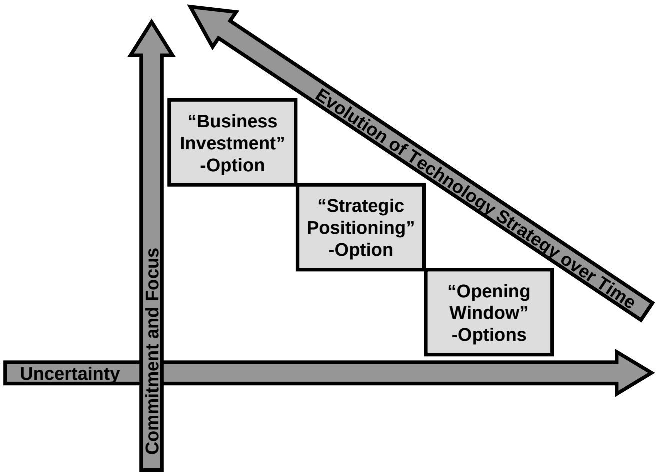


Figure 5-18: ***Evolution of technology strategy over time regarding a strategic technology area (adapted from Mitchell G.R., Hamilton W.F. 1988: 16).***

Opening window options regarding an emerging STA are knowledge building programs. The initial technology strategy of established firms is to identify and monitor leading-edge technologies of potential interest to the firm. Such an approach may involve internal efforts, like limited pre-assessments, feasibility studies or monitoring assignments, and may include external linkages like designated research cooperations and projects with universities and minority equity investments in start-up firms based on emerging technologies. Awareness and understanding of an emerging technology is in focus of these efforts, which typically involve only limited resources.

Strategic positioning options are primarily oriented towards the intended creation of opportunities for a potential future and active participation in the commercial application and exploitation of a technology. This may include internal pre-development and development projects of technologies or products with an already existing focus to a specific technical approach and a roughly defined market. Compared to opening window options a lower level of uncertainty allows for higher commitments and a more designated focus.

Business investment options are options on a continued commitment to a strategic technology investment into already known or related markets and businesses. Business investment options allow for high commitments and specific designation, as the perceived level of uncertainty is lower. Business investment options are strategic technology options that can be described as investments in new but related technologies or technological innovations, designated for already known markets and businesses.

The uncertainty involved in a strategic option is usually related to the familiarity of a company with a technology and the overall newness and maturity of a technology. The level of commitment and focus of a strategic option can be controlled by the level of resource commitments and the adequate organizational mode of internal or external technology exploration. Mitchell and Hamilton also argue that because of their different characteristic and intention, these three forms of strategic options within technology strategy should be treated differently, especially from a valuation point of view (Mitchell G.R., Hamilton W.F. 1988). In 1988 Mitchell first argued that as long as business managers treat strategic option in technology strategy only either as expenses, costs or investments, and not also as options for future opportunities, technology strategy will be static with a short-term bias (Mitchell G.R. 1988: 260). The critical insight is to recognize that a significant amount of expenditures of firms into technology are not so much directed to an direct investment into a business, but to the creation of an opportunity to make a significant commitment at some later date (Mitchell G.R. 1990: 153). Table 5-14 is summarizing Hamilton and Mitchell's approach.

Table 5-14: Technology strategy as strategic options (adapted from Mitchell G.R., Hamilton W.F. 1988: 21, Hamilton W.F. 1985: 208).

	Strategic Options in Technology Strategy		
Attribute	**"Opening Window"-Option**	**"Strategic Positioning"-Option**	**"Business Investment"-Option**
Uncertainty	High	Medium	Low
Commitment and Focus	Low	Medium	High
Involved Activities	Basic and exploratory research, technology awareness, technology intelligence;	Applied research, pre-development and development of technologies and products;	Development and engineering;
Locus	Central R&D unit;	Business development at corporate or business level;	Business unit, product group;
Organizational Mode	Research grant, internal or external R&D project, minority equity investment;	R&D project, minority equity investment, licensing-in, joint venture;	Internal project, R&D contract, license-in, joint venture;
Financial Valuation Approach	No valuation but allocation as overhead cost and expenses.	Qualitative and quantitative methods for option valuation.	Valuation as investment with net present value, discounted cash flow or return on investment methods;

	Strategic Options in Technology Strategy		
Attribute	**"Opening Window"-Option**	**"Strategic Positioning"-Option**	**"Business Investment"-Option**
Market Approach	None.	Total market less specific exclusions.	Specific targeted market or market segment.

5.2.3.5 Concluding Summary

Although there is no dominant concept or integrated approach for a dynamic technology strategy, the reviewed contributions reveal that technology strategy cannot be a static one-way or mutual alignment between the internal and external technology context and a company's strategy. Technology strategy must enable a dynamic interaction between the technology context and a company's strategy over time. This dynamic interaction is mandatory if technology turbulence is directly threatening existing competitive advantage. All reviewed contributions emphasize certain aspects of flexibility in technology strategy. Increased organizational flexibility was highlighted as a successful response strategy regarding threats of technological substitution and obsolescence. An evolutionary perspective on technology strategy emphasizes the necessity of intentional and blind variation from a perfect strategic fit with the current technology context before selection occurs in the market place and adaption becomes necessary. Other authors highlighted strategic options in technology strategy as an adequate mechanism for both, creation of a proactive variation in intended technology strategy and reactive adaption of technology strategy. It is therefore concluded that an explicitly dynamic perspective on technology strategy, which is neglected by most market-based and resource-based approaches, has to be integrated in an a-priori construct of technology strategy.

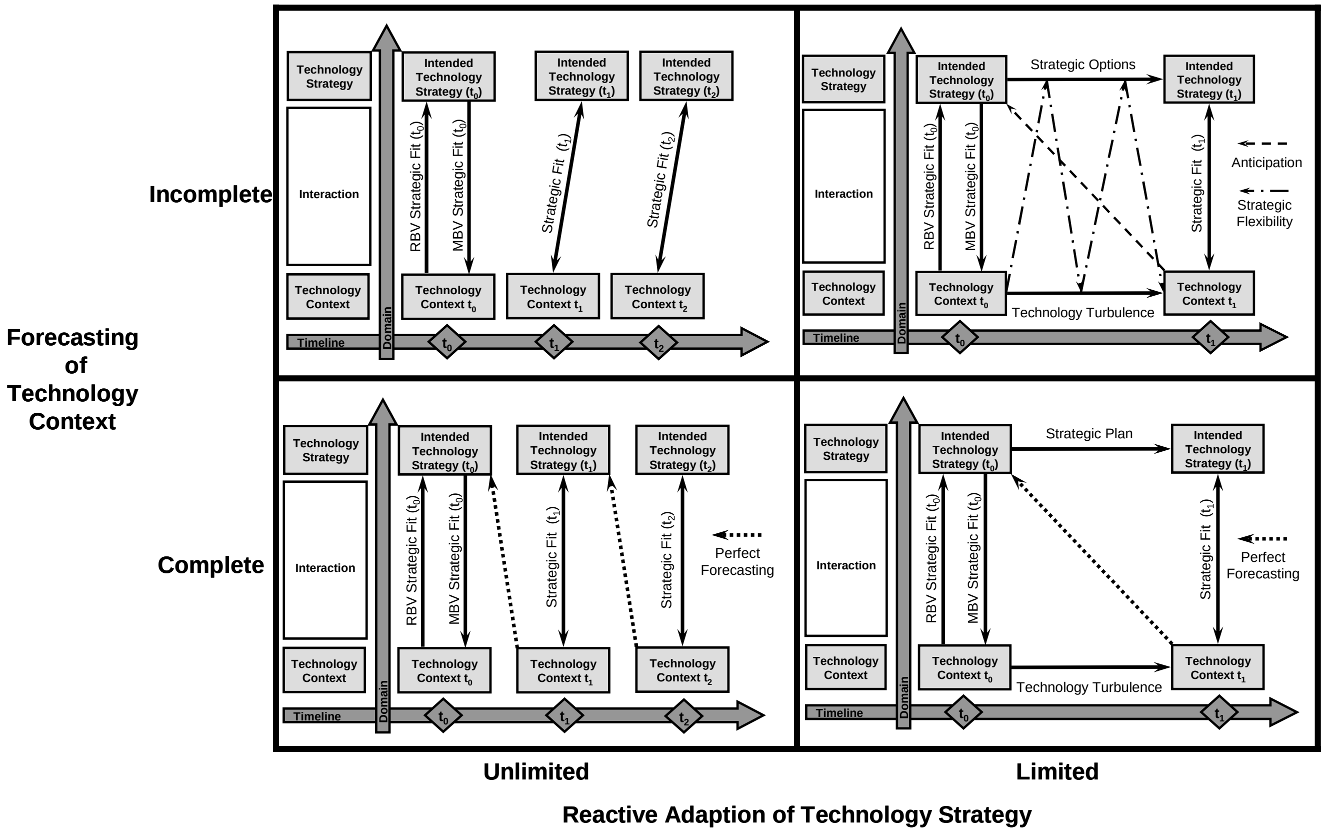


Figure 5-19: Dynamic perspectives on technology strategy under technology turbulence.

Figure 5-19 is summarizing some conclusions on dynamic interactions of technology strategy with the internal and external technology context of a company. If a company is able to perfectly and completely predict technology turbulence and is perfectly able to adapt its strategic fit, its technology strategy will always be perfectly aligned right on-time. If the condition of complete forecasting is not fulfilled, a company can still rely on its ability to reactively align its intended technology strategy with a short delay to the detection of evolving events. Vice versa, if a company’s ability to adapt reactively to changes in technology context is limited but it still has the ability to perfectly forecast technology turbulence, its forecasting ability allows formulating and implementing a perfectly informed strategic plan. Although there may be real cases where a firm is able to perfectly predict and to perfectly adapt to technology turbulence, it is assumed, that in the real-world context of an industrial organization under technology turbulence, both forecasting ability and pure reactive adaptability are limited. In this case a company may only anticipate a fraction of technology turbulence, which can be addressed in an intended technology strategy. The static concept of strategic fit between technology strategy and technology context should be complemented by strategic flexibility to respond to anticipated and unanticipated technology turbulence. It is therefore concluded that Mintzberg’s notions of deliberate and emergent strategies is fully transferable to the domain of technology strategy (see Figure 5-20).

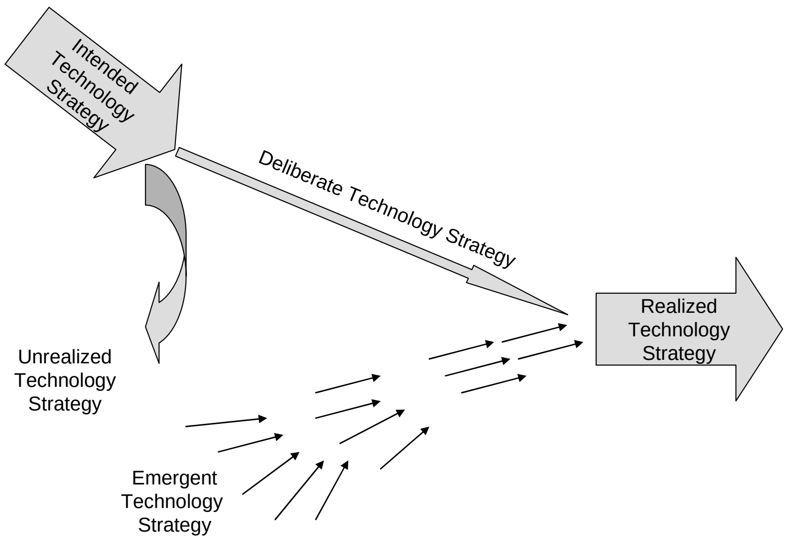


Figure 5-20: ***Mintzberg's dynamic patterns of strategy applied to technology strategy (adapted from Mintzberg H., Waters J.A. 1985: 258).***

5.3 An A-Priori Construct for Technology Strategy in Industrial Organization

Goal of this chapter was to identify and summarize the unit of analysis – technology strategy of industrial organizations – for the conduct of qualitative empirical research. As the overall objective of this research is to identify forms of flexibility in technology strategy under conditions of technology turbulence, most questions in the interview guide are directly addressing the concept of technology strategy within the interviewee's organization. Based on the review and analysis of different existing approaches to technology strategy in the previous subchapters, an a-priori construct for technology strategy is developed. Although there are significant differences between the reviewed prescriptive approaches, some common elements are identified, which are proposed to constitute the concept of technology strategy. The identified elements and dimensions of technology strategy proposed by the various approaches where compared and clustered into five categories:

- *Technology strategy decisions and content*: What is the content of the technology strategy of an industrial organization and which strategically relevant technology decisions are addressed?
- *Technology strategy formulation and methodology*: How is technology strategy formulated in an industrial organizations and which tools, methods and instruments are used to so?
- *Technology strategy organization and infrastructure*: How is technology strategy integrated in the organizational structure, processes, functions and routines of an industrial organization?
- *Technology strategy leadership and culture:* How is technology strategy formation and implementation lead within an industrial organizations and how it is related to the overall culture of this organization?

- *Patterns of technology strategy formation and change*: How has the technology strategy of an industrial organization evolved over time until today and how will it evolve in the future?

While interrelated and not independent, these elements represent different domains within the overall concept of technology strategy, which are explicitly considered in the interview guide for the expert interviews with senior technology managers of industrial organizations.

Technology Strategy Decisions & Content

All reviewed approaches to technology strategy are focusing on certain critical questions and decisions, which should be specifically addressed by technology strategy. The scope of theses strategic questions and decisions, which should be addressed within the domain of technology strategy, constitutes the content of technology strategy. Although the proposed content of technology strategy differs in breadth and depth across the reviewed approaches in this chapter, a list of interrelated technology strategy decisions, which are of expected relevance to industrial organizations, can be compiled:

- *Technology adoption decisions*: The decisions of an industrial organization to adopt an additional or new technology or technological innovation, which include selection and prioritization of technologies, timing of technology adoption and source of adopted technologies.
- *Technology exploration decision*: The decisions of an industrial organization to participate in the exploration of technologies or technological innovations, which include selection, prioritization and intensity of research, development and engineering efforts, and the organizational mode and vehicle of exploration.
- *Technology exploitation decisions*: The decisions of an industrial organization on how, where and when to exploit technologies internally or externally.
- *Technology appropriation decisions*: The decisions of an industrial organization on how to appropriate and protect technologies, technological knowledge or expertise.
- *Technology exit decisions*: The decisions of an industrial organization to leave a technology, including the selection of technology and timing and mode of exit.

Technology Strategy Formulation & Methodology

Most of the reviewed concepts of technology strategy are prescriptive frameworks, which suggest an explicit technology strategy formulation or planning process of different detail and scope. Many frameworks also propose methods or a set of methods, which should support the strategy formulations process. While some of these methods are integral part of one or more steps in the suggested sequence of technology strategy formulation and are analytical in nature, other methods are aimed to summarize results and to provide a platform for communication. In all reviewed cases, suggested formulation processes and methodology are highly integrated.

It is therefore concluded, that in practice methodology and processes for technology formulation cannot be separated and individually addressed. Analog, methods, tools, concepts, and models of technology strategy may cover multiple functions within the formulation process. Although the suggested processes, analytical routines and methods to formulate technology strategy are different in sequence, focus and scope across the reviewed approaches in this chapter, some core elements are identified which are considered in the proposed a-priori construct:

- *Technology strategy formulation process*: The implicit or explicit process of technology strategy formulation within an industrial organization.
- *Methods for technology analysis and forecasting*: The set of methods, tools and routines an industrial organization is employing to analyze already employed or produced technologies and their future technological development and potential.
- *Methods for technology intelligence:* The set of methods, tools and routines an industrial organization is employing to screen, identify, and monitor new and/or additional technologies with potential impact on and beyond the business environment of the organization.
- *Methods for technology assessment and valuation:* The set of methods, tools and routines an industrial organization is employing to qualitatively and quantitatively evaluate the impact a technology or technological innovation has on the overall economy, the business environment, the firm, a specific industry, market, market segment, a market venture or a business proposal.

Technology Strategy Organization & Infrastructure

Technology strategy organization and infrastructure summarizes the aspects on how technology strategy is integrated into the organizational structure and processes within a firm. As most of the prescriptive approaches to technology strategy are highly generic, only few emphasize specifics on how technology strategy formulation and implementation should be integrated into the structure and processes of an existing organization. Although many approaches highlight how critical the organizational implementation and operationalization of technology strategy is to its eventual relevance and success, it is also stated the many different contingency factors on firm, industry and environmental level affect horizontal and vertical embedding of technology strategy in a specific organization. Based on the reviewed approaches to technology strategy, following elements are explicitly considered in the a-priori construct of technology strategy:

- *Technology strategy functions and units:* The organizational functions and units within an industrial organization, which are directly involved in technology strategy formation and realization.
- *Horizontal and vertical organization of technology strategy:* The organization of vertical and horizontal alignment, coordination and communication of technology strategy formation and realization across the structure of an industrial organization.

- *Internal technology strategy implementation routines:* Various relevant routines of the organization to implement technology strategy in relevant and affected domains within the organization.
- *External technology strategy implementation routines:* Various relevant routines of the organization to implement technology strategy in relevant and affected domains beyond the organization's own boundaries.

Technology Strategy Leadership & Culture

Another element of technology strategy in industrial organizations summarizes leadership and cultural aspects and issues of technology strategy. This includes issues of leading and motivating of people regarding technology strategy formation and implementation in an organization, but also the overall organizational policies and norms regarding or affecting technology, technological innovation and change.

- *Technology strategy leadership:* The way and style how people in functions and units, which are directly relevant to technology strategy formation and implementation, are lead, motivated, developed and integrated and how their interests are considered, aligned and negotiated.
- *Technology strategy culture:* The overall organizational culture, policies and norms regarding technology, technological change and new technological ideas and innovations.

Patterns of Technology Strategy Formation & Change

Analog to the discussion of the overall strategy concept under turbulence in chapter 3, and the review of existing dynamic perspectives on technology strategy in this chapter, it is concluded that there is also a dynamic aspect to technology strategy. This is especially important, if it is intended to observe technology strategy ex post and if one intends to identify impact of changes in the business context on technology strategy over time. It is therefore concluded that similar to the framework for patterns of strategy formation by Mintzberg, a distinction in intended, deliberate, realized, non-realized and emergent technology strategies allows for a dynamic view on technology strategy:

- *Intended technology strategy:* The currently valid, pursued and explicitly or implicitly formulated technology strategy of an organization.
- *Deliberate technology strategy:* The fraction of an initially intended technology strategy, which is eventually realized as intended.
- *Non-realized technology strategy:* The fraction of an initially intended technology strategy, which is eventually not realized as intended.
- *Emergent technology strategy:* Strategically relevant decisions, actions and behavior, which, although never intended, change, affect, extend, contradict or substitute the initially intended technology strategy or parts of it.

- *Realized technology strategy:* The eventually realized and ex-post observable technology strategy of an industrial organization.

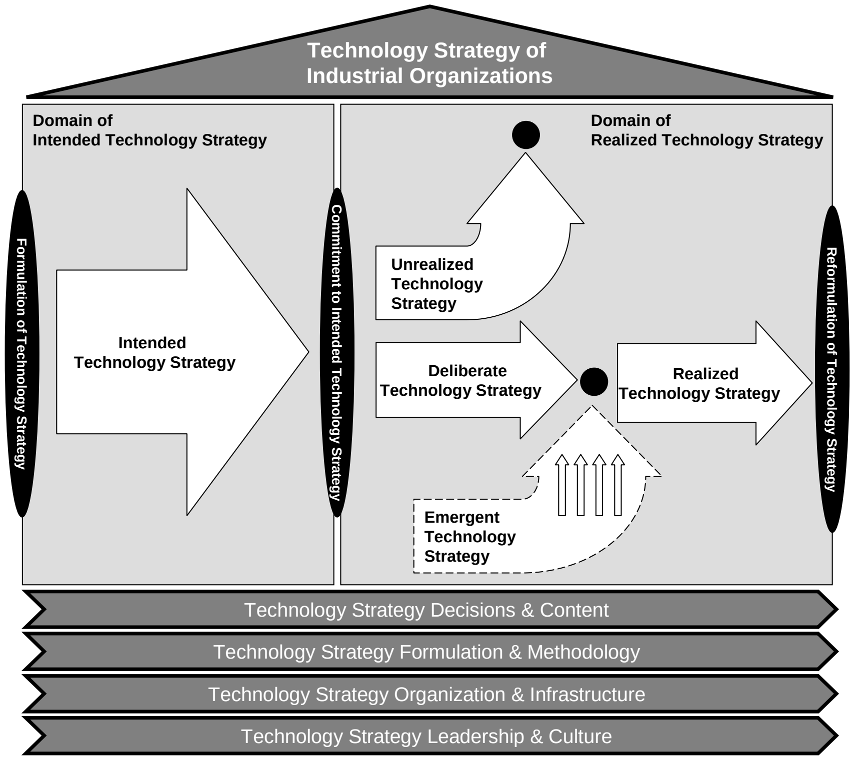


Figure 5-21: A-priori construct of technology strategy of industrial organizations for this research.

Figure 5-21 is summarizing the adopted a-priori construct of technology strategy for this research. This a-priori construct of technology strategy has multiple functions. While it identifies important elements of technology strategy and therefore defines content and topics for the interviews with senior technology managers in industrial organization, it is also expected to be broad, open, and unbiased enough to absorb both expectable and non-expectable characteristics, forms of appearance and manifestation of technology strategy in real-world practice. Table 5-15 shows the explicit consideration of the developed a-priori construct of technology strategy and its elements in the conduct of this research. As in the case of technology turbulence, these explicit considerations in form of pre-formulated questions in the prepared interview guide were complemented by various and context-specific follow-up questions during the course of different interviews.

Table 5-15: Explicit consideration of a-priori construct of technology strategy in conduct of research.

Element	Explicit Consideration in Conduct of Research
Technology Strategy Content & Decisions	Question 2, 18, 23, 31, and 32 in interview guide, Appendix A.

Element	Explicit Consideration in Conduct of Research
Technology Strategy Formulation & Methodology	Question 19, 22, 27, 28, 29, and 30 in interview guide, Appendix A.
Technology Strategy Organization & Infrastructure	Question 1, 20, 21, 24, and 25 in interview guide, Appendix A.
Technology Strategy Leadership & Culture	Question 26 in interview guide, Appendix A.
Patterns of Technology Strategy over Time	Question 9-17 in interview guide, Appendix A.

PART C: EMPIRICAL ANALYSIS AND RESULTS

6 STRATEGIC FLEXIBILITY IN TECHNOLOGY STRATEGY

This chapter presents the first part of the empirical findings, derived from the analysis of the collected interview data, and is focusing on answering research questions 2 and 3.

RQ 2:	*Which forms of technology turbulence do industrial organizations perceive in their business contexts?*
RQ 3:	*Which forms of strategic flexibility can be identified in technology strategies of industrial organizations when facing technology turbulence?*

The results presented in this chapter are based on the analysis of how the interviewed companies perceive and handle reported technology turbulence in their technology strategy. In chapter 4 technology turbulence was described as strategically relevant changes in the technology context of an organization, which constitute the degree of non-sustainability of technology-based competitive advantage. Various elements of technology turbulence were identified and discussed, based on the review of existing literature. To answer research question 2, technology changes, which have a significant impact on the technology-based competitive advantage of the interviewed organizations, have to be identified and analyzed. To answer research question 3, it is necessary to study the changes in technology strategy of industrial organizations when facing identified forms of technology turbulence.

6.1 Conduct of Analysis

Figure 6-1 shows the iterative sequence for the applied inductive analysis of the gathered interview data. The interview guide for the expert interviews on technology strategy under technology turbulence is based on the research questions and the a-priori constructs of technology strategy and technology turbulence (see Appendix A). Basically, the interviewees were asked how their companies perceive or perceived strategically relevant changes in the technology context of their organization and how this perception is or was affecting the technology strategy of their companies. First, the reports on current, recent and historical incidents of technology turbulence, which were reported by the interviewees in the business context of their organizations, are analyzed (see Chapter 6.2). Based on these identified incidents of technology turbulence and the description of the interviewees how their organizations handled or are currently handling the incidents, the impact of these incidents on technology strategy is studied in Chapter 6.3.

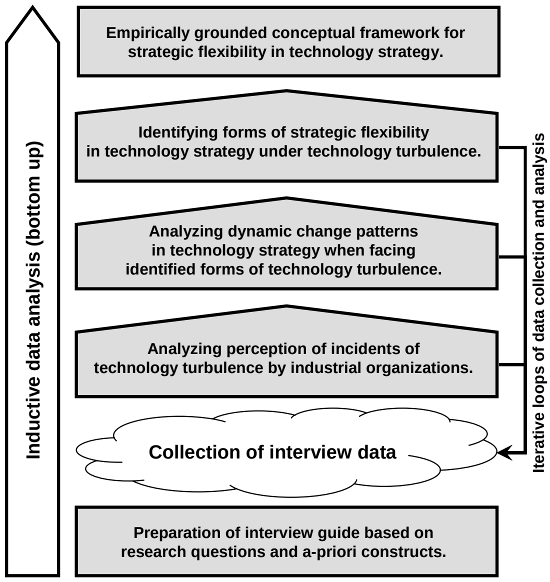


Figure 6-1: ***Conduct of inductive data analysis for research question 2 and 3.***

By applying the preliminary and generic insights on strategic flexibility from the discussion in chapter 3, distinguishable forms of strategic flexibility in technology strategy are identified. Although the analysis of the gathered data is presented as a linear sequence in the following subchapters, the real process of data gathering and inductive data analysis was iterative in multiple loops (see Figure 6-1). As a result of this chapter and based on the inductive analysis of the interview data, an empirically grounded conceptual framework for strategic flexibility in technology strategy is developed in chapter 6.4.

6.2 Perception of Technology Turbulence

A prerequisite for identifying distinguishable types of strategic flexibility in technology strategies of industrial organizations is to identify strategically relevant changes in the technology context, which demand a form of changed behavior and action from the affected organization. As discussed in chapter 4, these strategically relevant changes could be singular and discrete events or continuous and incremental changes, which eventually show significant impact on the technology-based competitive advantage of an organization. These changes may be caused by technological innovation and progress, but may also reflect general trends and changes, which are not causally related to technology but have severe impacts on the technologies a company is using or producing. Figure 6-2 highlights research question 2 in the overall research framework of this dissertation as the causal relationship between technology turbulence in the business context of an organization and its technology strategy. It is basically proposing that the perception of technology turbulence by technology strategists in the business context of their organization is affecting its technology strategy.

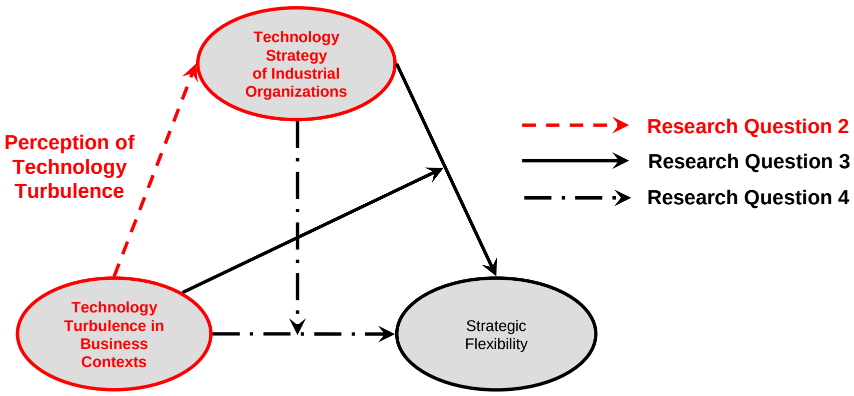


Figure 6-2: ***Research question 2: Perception of technology turbulence.***

In the collected interview data the interviewed experts reported on 116 historical and recent cases of strategically relevant changes in the technology context of their companies (see Appendix C for the complete list and the direct reference to the relevant interview section). Despite significant differences in industry context and the heterogeneity of the involved companies, it was possible to cluster these incidents into generic categories by identifying relevant dimensions. Although there are numerous imaginable dimensions by which a distinction of reported incidents of technology turbulence seems reasonable, this research is interested to identify dimensions, which are relevant to the corresponding patterns of strategic behavior, action and decision making at the moment these incidents became evident to the involved company. Additionally, the categorization should be independent from individual and case specific content to allow for general conclusions. This indicates that the most relevant dimensions for the categorizations of the reported incidents are related to the questions of when and how well the relevant company, represented by the expert interviewee, perceived the incident. By analyzing the 116 incidents and their perception within the companies, three rough categories for incidents of technology turbulence emerged:

- *Known Knowns*: Strategically relevant incidents in the technology context of an organization, which were anticipated by the organization before they actually occurred and which were sufficiently understood by the organization before they showed any impact on the organization.
- *Known Unknowns*: Strategically relevant incidents in the technology context of an organization, which were anticipated by the organization before they actually occurred but initially not sufficiently understood at the moment of anticipation.
- *Unknowns*: Strategically relevant changes in the technology context of the organization, which were not anticipated before their occurrence showed direct impact on the organization.

Figure 6-3 shows the underlying logic of this categorization. While the first dimension distinguishes between anticipated and unanticipated incidents (*timing of initial perception*), the second dimension differentiates the quality of existing knowledge and insights related to the incident and its consequences within the company (*quality or perception*). The first dimension basically separates between incidents, which have or have not been anticipated by the organization before they actually occurred. If an incident was described as surprising, unexpected or unrecognized, it was concluded that the level of anticipation was low. The second dimension distinguishes, if there is or is not existing knowledge within the organization on the incident itself and its consequences at a given time. This dimension reflects the level of ambiguity on the impact, its consequences and necessary response an incident is causing within the organization.

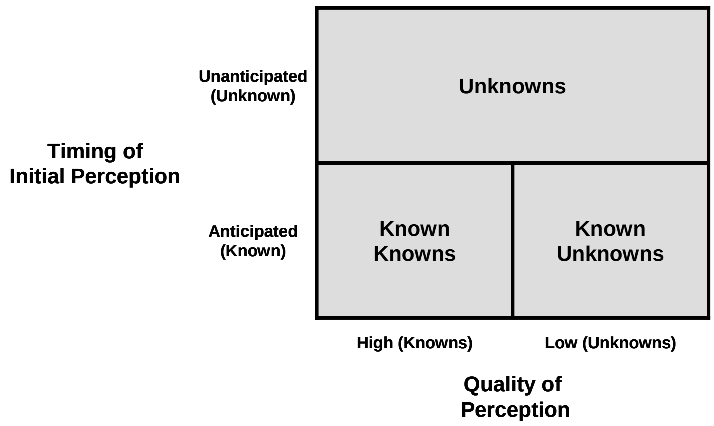


Figure 6-3: ***Rough categorization of identified incidents of technology turbulence regarding timing and quality of perception.***

Among others, this distinction to categorize perceived uncertainty and ambiguity in a context of strategic decision making was recently emphasized by Donald Rumsfeld and has also been used to analyze situations of perceived uncertainty during military conflicts and complex space missions (Furlong R.B. 1984, Maluf D.A., Gawdiak Y.O., Bell D.G. 2005).[3] Figure 6-3 would also suggest a fourth category and a separation of unanticipated incidents in *unknown knowns* and *unknown unknowns*. Although the concept of *unknown knowns* does not seem too far-fetched, the analysis of the empirical interview data did not support this distinction.

This categorization of the 116 reported incidents emerged from the analysis of the qualitative data and eventually all incidents were assigned to one of these categories. Both dimensions in Figure 6-3 are based on the analysis of the anecdotal evidence given by the interviewees and their appraisal: Simply stated, while vertical dimension represents the retrieved timing of initial perception, the horizontal dimension represents the retrieved initial quality of perception by the interviewees. It has to be stated that the distinction of incidents regarding the subjective perception by the interviewed senior technology manager is not regarded as a flaw: This research suggests that different perception of incidents by senior technology managers is inducing different

[3] *"There are known knowns. There are things we know that we know. There are known unknowns. That is to say, there are things that we now know we don't know. But there are also unknown unknowns. There are things we do not know we don't know."* Donald Rumsfeld, former US Defense Secretary, in a press briefing on the Afghanistan campaign on February 12, 2002;

corresponding decisions, actions, and patterns of behavior, which reveal distinctive forms of strategic flexibility in technology strategy. In the following subchapters the categories and sub-categories of incidents of technology turbulence, which emerged from the collected date are described.

6.2.1 Known Knowns

Eventually, 48 of 116 reported incidents of technology turbulence were categorized as *known knowns*. *Known knowns* are incidents of technology turbulence, which were anticipated and sufficiently understood in their relevance, probability of occurrence, impact, timing and causality before they significantly affected the relevant organization. Using the matrix presented in Figure 6-3, the existence and relevance of an incident of technology turbulence was anticipated by the company (*timing of initial perception*) and existing knowledge and expertise on the incident and on adequate responses was available within the company (*quality of perception*). Therefore, it is concluded that in the case *of known knowns*, the company knows that it should act on the anticipated incident and it has already an idea how to adequately act on it. Further analysis of the 48 incidents indicates that within the domain of *known knowns*, a distinction can be made regarding the level of ambiguity on the eventual realization of the anticipated incident.

6.2.1.1 Probable Predictions

An incident of technology turbulence was labeled as a *probable prediction* in this analysis, when it was described as an upcoming incident, whose future occurrence is perceived as highly certain. Additionally, the causality and timing of the incident and its impact on the organization and an adequate response are predicted in sufficient detail by the relevant company. Although the incident is predicted and therefore expected, its eventual realization lies in the future. Therefore some level of uncertainty remains until the predicted incident eventually, gradually or abruptly, occurs as predicted. In the empirical data 32 reported incidents of technology turbulence were interpreted as *probable predictions*. Table 6-1 lists these incidents of technology turbulence by directly referring to relevant interview positions in the collected interview data.

Table 6-1: Reported incidents of technology turbulence labeled as probable predictions.

#	Company	Probable Predictions	Interview positions (min.)
1	Company 1	Environmentalism, energy efficiency and resource sustainability as dominant drivers and enablers of technological innovation.	0:12, 1:16;
2	Company 2	Global upstream consolidation and concentration in raw aluminum mining, production and processing industry.	0:29, 0:48, 1:33;
3	Company 3	Environmentalism and optimization for energy efficiency demand vertically integrated technology expertise of complete value chain.	0:06, 0:51, 1:28
4	Company 4	Usability and simplicity as new drivers of technology development because of changing end-users of produced products.	0:10, 1:19;
5	Company 5	Global commoditization and off-shoring of wafer fabrication for standard CMOS technology of digital applications.	0:13 and 0:02, 1:15;

#	Company	Probable Predictions	Interview positions (min.)
6	Company 5	Convergence of new functionalities, applications and technologies into mobile phones and portable electronic devices.	0:09;
7	Company 5	Increasing availability, demand and use of electronic mobile applications and services for hand-held devices.	0:12, 0:33 and 0:06 0:18, 0:44;
8	Company 6	Insufficiency of current technological core know-how for most probable future drive train scenarios for passenger cars.	0:05, 0:16, 0:23; and 0:11;
9	Company 8	Comfortableness of passenger transportation as increasingly important driver of technology integration and innovation.	0:38;
10	Company 9	Partial substitution of core product technology by alternative and improving process technology.	0:13, 1:08;
11	Company 10	Restrictive legal regulations of acoustic and noise emissions as enabler of technological innovation in core markets.	0:12, 0:48;
12	Company 11	Diffusion of new functionalities, applications and technologies into street and highway infrastructure and vehicles.	0:22;
13	Company 12	Increasing potential, availability and industrialization of carbon-fiber composite materials.	0:22, 0:56;
14	Company 13	Imitation and increasing commoditization of current process and product technologies by Asian competitors.	0:01, 0:11, 0:44;
15	Company 13	Energy efficiency and environmentalism as new dominant drivers of technology development and process innovation.	0:03, 0:16, 0:44;
16	Company 14	Substitution of chipping technology by advancing chipless molding and forming technology.	0:24;
17	Company 14	Increasing potential of alternative drive train concepts enabled by shifting drivers of technological innovation.	0:23;
18	Company 16	Strength and stiffness as additional and new requirements for sintered components additionally to precisions, quality and price.	0:13. 0:20;
19	Company 16	Outsourcing of technological expertise and know-how by main customers.	2:11;
20	Company 16	Increasing successful substitution of sintering by stamping technology in low-end markets.	0:16, 2:09;
21	Company 17	Increasing imitation and commoditization of pure electro-mechanical systems in existing product portfolio.	0:24, 1:17;
22	Company 18	Energy efficiency and sustainability of production process as new drivers for process technology development and innovation.	0:11, 0:16;
23	Company 19	Commoditization of technological core competence in current business portfolio.	0:38, 0:56;
24	Company 19	Outsourcing of technological expertise and know-how by OEM customers.	0:08, 0:23, 1:09;
25	Company 20	Usability and simplicity as new drivers of technology development and innovation because of changing end-users.	0:14, 0:39, 0:47;
26	Company 21	Substitution of pure electro-mechanical systems by electronic and digital technology in fire fighting equipment and vehicles.	0:15;
27	Company 21	Modularization of products and manufacturing processes to fulfill compulsory local content requirements of international markets.	0:10, 0:32;
28	Company 21	Significant substitution of conventional material by carbon-fiber in future aircraft bodies.	1:41;
29	Company 22	Increasing employment of aluminum and composite materials and substitution of steel in the automotive industry.	0:35;

#	Company	Probable Predictions	Interview positions (min.)
30	Company 23	Increasing future potential and demand for electrical and hybrid cars.	0:41;
31	Company 24	Technological know-how and engineering outsourcing of liberalized and privatized national railways organization.	0:24;
32	Company 25	Optimization for energy efficiency of integrated systems as dominant driver of technology development and innovation.	0:34, 0:53, 1:12;

All of these 32 incidents were reported to have impact on sources and forms of technology-based competitive advantage. Although all of these incidents of technology turbulence in Table 6-1 reflect significant changes in the technology context for the involved companies in form of new opportunities and threats, the interviewees reported that their companies anticipated and understood these changes before they showed direct impact on the company. To clarify the understanding of an incident of technology turbulence and its interpretation as a *probable prediction* in this research, three individual cases from the collected data are described in some detail (see Case vignette 6-1, Case vignette 6-2 and Case vignette 6-3).

Case vignette 6-1: #6 Company 5: Convergence of new functionalities, applications and technologies into mobile phones and portable devices.

Company 5 develops and manufactures analog semiconductors and integrated circuits for sensor and power management applications and has its own integrated wafer fabrication facility. One predicted and expected development in an important market Company 5's main customers was the increasing demand of consumers for portable communication and entertainment devices and the convergence of new functionalities and applications into existing handheld devices like cell phones. The convergence of digital cameras, mobile phones, PDAs, MP3 player into a single portable device includes a lot of analog and digital interface and sensor technologies. Although this incident of technology turbulence has massive consequences Company 5's own technology agenda because the company has to integrate new technologies, functionalities and interfaces into its products, this convergence of different analog and digital functionalities in downstream markets of Company 5 was anticipated and understood ahead of time and was addressed by various designated initiatives. This process of convergence of functionalities and applications in one of Company 5's downstream markets leads to increasing technology complexity, as additional and new technologies have to be integrated by the company.

Case vignette 6-2: #10 Company 9: Partial substitution of core product technology by alternative and improving process technology.

One of Company 9's business units is producing precision machinery and automation equipment for tool and mould making. Wire and die-sinking electric discharge machines were initially one of Company 9's core products and are still part of its current product portfolio. The production *process provided by Company 9's technology was basically without alternative for the applications of Company 9's customers. In their very beginning, so-called high-speed or high-performance milling systems were regarded as inferior to the provided electric discharge machines until technological innovations and continuous improvements of this technology enabled the application of high-speed milling for tool and mould making of Company 9's customers. Although high-speed milling and its future potential was regarded as massive threat of obsolescence to one of Company 9's core technology and flagship product, this partial substitution process between competing process technologies was perceived as foreseeable change and was therefore expected and prepared by the company. The partial substitution of one of Company 9's core products by an alternative technology is an increase in technology diversity, as the provided value to the customer is also realized by an alternative technology.*

Case vignette 6-3: #16 Company 14: Substitution of chipping technology by advancing chipless molding and forming technology.

Company 14 is a global developer and manufacturer of engine, transmission and axle components and modules for the automotive industry and its customers are original equipment manufacturers in the automotive industry. The most critical process technologies currently employed in the production of parts, components and modules of automotive drive train systems are various chipping technologies for materials like steel and light metal. Additionally to designing and engineering of innovative products, Company 14's core competence is deeply embedded is the mastery, integration and sequencing of these different chipping technologies at a global scale and dispersed over different plants. The increasing possibilities regarding precision and quality provided by improved and new chipless molding and forming technologies, which make further processing of components by chipping technologies obsolete or at least less critical, is a direct threat to Company 14's strong competitive position in chipping technologies. Although this substitution trend in manufacturing technologies, which somehow reverses the priorities and criticalness of the involved production processes, has a strong impact on the company, it is perceived as an expected change and is addressed in designated technology development programs. The emergence of new and improved technologies, which show high potential to make existing competences obsolete, is regarded as a technology discontinuity.

These three cases represent strategically relevant changes in the technology context of the involved companies and their occurrences were reported as highly probable by the interviewed experts. If ignored, these incidents would negatively affect the competitive positions of the companies. Table 6-2 summarizes and generalizes characteristics of incidents of technology turbulence, which are interpreted and labeled as *probable predictions* in this research. The timing and quality of perception suggests that proactive and planned actions are possible and reasonable. As the quality of perception is high, these possible proactive measures could be very designated and customized to the identified change.

Table 6-2: ***General characteristics of incidents labeled as probable prediction.***

	Probable Predictions		
Company	Company 5	Company 9	Company 14
Incident of Technology Turbulence	Convergence of new functionalities, applications and technologies into mobile phones and portable electronic devices.	Partial substitution of core product technology by alternative and improving process technology.	Substitution of chipping technology by advancing chipless molding and forming technology.
Dominant Element of Technology Turbulence	Increasing technology complexity	Increasing technology diversity	Increasing technology discontinuity
Timing of Initial Perception	Prediction of incident before occurrence of significant impact.		
Quality of Perception	Predicted incident creates a very probable and clear-enough future.		
Resulting Ambiguity for Organization until Realization	Low – Existing insight on causality, realization and timing of incident, its impact on and an adequate response by the organization.		
Proactive Measures before Realization	Diligent formulation of a specific and designated agenda and preparation for eventual full enactment of measures.		

6.2.1.2 Possible Risks

According to the general and common understanding of a risk situation, an incident of technology turbulence is interpreted and labeled as a *possible risk*, if the probability, timing, impact and causality of its occurrence and non-occurrence can be estimated sufficiently by a company. While in the case of *probable predictions* the involved companies usually expect that the predicted incident will eventually occur as predicted, in the case of a risk situation companies assume that both the occurrence and the non-occurrence of an anticipated and understood incident are possible. Although a *possible risk* is anticipated, there is ambiguity about its eventual realization in the future. Directly compared to a *probable prediction*, there is a reduced quality of perception. Table 6-3 lists the incidents of technology turbulence from the collected empirical data which are interpreted as *possible risks*.

Table 6-3: ***Reported incidents of technology turbulence labeled as possible risks.***

#	Company	Possible Risks	Interview positions (min.)
1	Company 1	Increasingly rising world market price for currently employed material resource.	0:40, 1:09;
2	Company 4	Decay of the local glass manufacturing industry for industrial applications.	1:21, 2:11;
3	Company 5	Potentially disruptive downstream innovation in assembly technology (wafer level packaging).	0:37 and 1:21;
4	Company 11	Increasing importance of a technology based on shared intellectual property rights and cross-licensing contracts with a competitor.	1:50;
5	Company 12	Rising importance of sourced complementary technology due to rising technology complexity of engines.	0:13, 0:54;

#	Company	Possible Risks	Interview positions (min.)
6	Company 14	Further performance improvements of increasingly critical but sourced sintering technology.	0:12;
7	Company 14	Rising importance and criticalness of bevel gear and crown wheel manufacturing.	0:15;
8	Company 14	Advanced forging technology for tooth gears of automotive transmissions systems.	0:45;
9	Company 16	Material substitution in engine and transmission components.	1:25, 1:42, 2:26;
10	Company 16	Commoditization and decreasing criticalness of products and technological competence in high volume markets.	1:58;
11	Company 17	Competing international industry standards for radio communication of wireless product technology.	0:18;
12	Company 17	Slow market adoption of new digital product generation.	0:24, 1:36;
13	Company 18	Energetic versus enzymatic technology for bio-fuel production as a by-product of paper production.	1:19;
14	Company 19	Substitution of steel and metal by ceramic material in current core business.	0:13, 0:18, 0:34, 1:00;
15	Company 22	Disintegrated mini mill process technology for high quality and requirement applications.	0:59;
16	Company 23	Competitors' increasing and steady investment in high-alloyed steel grades.	0:33;

All these 16 incidents were perceived as *possible risks*, which are potentially affecting the current technology-related forms and sources of competitive advantage of the involved companies. The main difference to incidents categorized as *probable prediction* is that the eventual realization of the incident depends on some factor, which can be identified and observed, but its future manifestation cannot be predicted. To clarify the interpretation and labeling of an incident of technology turbulence as a *possible risk* in this research, three examples from the collected interview data are described in some detail (see Case vignette 6-4, Case vignette 6-5 and Case vignette 6-6).

Case vignette 6-4: ***#1 Company 1: Rising world market price for currently employed material resource.***

Company 1's core business is the engineering and manufacturing of electro motors and compressors for household applications, predominantly white ware like refrigerators and washing machines. Company 1 delivers integrated components and modules to its OEM customers and basically sources raw materials and commodities from globalized factor markets. In all of Company 1's products significant amounts of copper are processed. Copper is used in the stator/rotor package of each electro motor, which also drives the compressor unit. Technologically, copper is the most suitable material for this function and Company 1's manufacturing processes and product specifications are optimized for copper. As the cooper price was steeply and steadily increasing, the material costs for copper became a substantial fraction of the average total *costs of compressors and electro motor. For a steady trend of a rising commodity price, financial instruments for hedging are useless. When it became obvious to Company 1 that the chances for a further increase of copper price are significant, the exclusive technological focus of Company 1 on copper was regarded as a potential risk. The functional and technological advantage of copper in the manufacturing process and the final product could become obsolete due to the huge cost-disadvantage of the manufacturing process and the final product, which are customized for copper. A further increase in the price of copper includes a critical risk for Company 1, as performance advantages of Company 1's products, like technology leadership and energy efficiency, may become irrelevant compared to the cost/price disadvantage.*

Case vignette 6-5: #2 Company 4: Decay of the local glass manufacturing industry for industrial applications.

Company 4 is a producer of measuring instruments and devices for scientific and industrial applications and has customers in the food, beverage, chemical, medical and pharmaceutical industry. Many of Company 4's core products need key components made of glass for the actual measuring module. Because there was an established local supplier base for these critical glass components near Company 4's own manufacturing facilities, the company sourced these components externally. Due to globalization, commoditization and off-shoring trends within the glass manufacturing industry, the local glass manufacturer increasingly shifted their focus away from price-sensitive industrial applications to art and lifestyle products and end-consumer markets. Because of the relative criticalness of the sourced glass component and high requirements of Company 4 in terms of precision and quality, Company 4 wanted a local source as an innovative, reliable, and flexible partner for its glass components. Company 4 perceived the beginning decay and increasing non-reliability of its local supplier base for the necessary glass component as a possible risk to the company's own future competitiveness.

Case vignette 6-6: #15 Company 22: Disintegrated mini mill process technology for high quality and requirement applications.

Company 22 is a diversified corporation with a dominant core business of steel production and processing. One core process technology of Company 22 is the highly integrated process to produce and process raw steel, based on a vertically integrated raw iron production in a blast furnace section (so-called LD process). As Company 22 is focusing on steel grades of higher quality for industries with above-average requirements (e.g. automotive industry) and is not competing on the commodity market for regular and conventional steel grades, this integrated process, which enables full influence on the overall process and product quality, was without alternative. Volatility in scrap steel and energy prices and the increasing quality of an alternative, more flexible process technology (so-called mini mill technology) created the risk that the used process technology might be inferior to this competing process technology, if certain external condi-

tions, like world market prices, remain at their current level. Under these conditions, this alternative process technology could become superior to the integrated LD process. The improvements of the mini-mill process technology and its potential ability to increasingly fulfill the requirements and demands of Company 22's customer segments combined with its cost advantages under certain conditions, created a possible risk for the organization's current technology-based advantage.

The three reported incidents represent predicted and specific risk situations for the involved organizations and their future occurrence is perceived as possible event. If the anticipated but ignored risk occurs, the competitive positions of the involved companies would be negatively affected. Table 6-4 summarizes and generalizes characteristics of perceived incidents of technology turbulence, which are interpreted and labeled as *possible risks* in this research. Although the incident is anticipated before it shows any direct impact on the organization (*timing of initial perception*), the perception is incomplete and it creates ambiguity for the company in form of a risk situation (*quality of perception*). Therefore, the possible proactive measures may include the preparation of the organization for both risk occurrence and non-occurrence. Although the scope of possible proactive measures is somehow divided into the preparation for risk occurrence and non-occurrence, the overall preparation can be highly designated to the anticipated risk situation.

Table 6-4: Generalized characteristics of incidents labeled as possible risks.

	Possible Risks		
Company	Company 1	Company 4	Company 22
Incident of Technology Turbulence	Steadily rising world market price for currently employed material resource.	Increasing decay of the local glass manufacturing industry for industrial applications.	Disintegrated mini mill process technology for high quality and requirement applications.
Dominant Element of Technology Turbulence	Increasing technology diversity/discontinuity	Increasing technology intensity/complexity	Increasing technology diversity/discontinuity
Timing of Initial Perception	Anticipation of a possible incident before any occurrence of significant impact.		
Quality of Perception	Anticipated incident creates a future risk situation with a possible occurrence and non-occurrence of the risk in the future.		
Resulting Ambiguity for Organization until Realization	Medium – Existing insight on causality, timing, impact, and adequate response.		
Proactive Measures before Realization	Specific preparation for both occurrence and non-occurrence of risk with commitment according to estimated probability of occurrence.		

6.2.2 Known Unknowns

Incidents categorized as *known unknowns* are incidents of technology turbulence, which are anticipated by a company before they occur, but a significant lack of knowledge and understanding on the incident and its eventual consequences for the company limits the quality of insights and creates significant ambiguity for the organization. Following the matrix in Figure 6-3, *known unknowns* are anticipated by companies (*timing of* *initial perception*) but relevant knowledge on the incident itself is missing (*quality of perception*). Therefore, it is concluded that the involved company knows it should act on the anticipated future incident, but it has initially no clear idea on what to do specifically. Again, the analysis and interpretations of the collected data allowed for an additional distinction within the rough domain of *known unknowns*.

6.2.2.1 Imaginable Scenarios

The more explicit subcategory of *known unknowns*, which emerged from the analysis of the collected interview data in this research, is summarized under the notion of *imaginable scenarios*. *Imaginable scenarios* are alternative or additional visions for the company and its business context and are perceived as plausible and consistent pictures of the future by the company. Very often companies perceive scenarios as alternative and occasionally competing versions of the future and sometimes scenarios include a potential extension for the existing landscape of the company's activities. Although scenarios are plausible and consistent visions of the future, they also imply high ambiguity within the company on which and how a scenario will eventually realize, within which time horizons and for which reasons. Usually different and alternative scenarios are perceived as more or less advantageous by a company and therefore there are scenarios are targeted for and scenarios which companies try to avoid. Table 6-5 lists identified incidents of technology turbulence from the collected empirical data, which are interpreted and labeled as *imaginable scenarios*.

Table 6-5: Reported incidents of technology turbulence labeled as imaginable scenarios.

#	Company	Imaginable Scenarios	Interview positions (min.)
1	Company 1	Scenario of "intelligent white goods".	1:20, 1:31;
2	Company 2	"All-aluminum car"-scenario.	0:38, 1:18, 1:25;
3	Company 2	Aluminum as dominating material for railway vehicle bodies.	0:36;
4	Company 4	Potential substitution of core product technology.	0:12, 0:20, 1:44;
5	Company 6	Alternative engine and drive train technology scenarios.	0:32, 0:39;
6	Company 8	Global warming scenario of significant climate change and snow free alps.	0:19;
7	Company 8	Scarcity of parking space in urban centers as enabler for technology transfer from Japan.	0:56;
8	Company 9	Complete substitution of metal by plastic in core business.	0:12;
9	Company 10	Increasingly restrictive legal regulation and sensitivity for energy-efficiency as enabler of technology substitution on adjacent market.	0:47;
10	Company 11	Multiple scenarios for standards and global technological dominant design.	0:03, 0:40;
11	Company 12	Combustion engine vs. electro engines and battery technology.	0:09, 0:12, 0:33;

#	Company	Imaginable Scenarios	Interview positions (min.)
12	Company 13	Rising importance, demand, industrialization and mass-production of fiber-based composite materials.	0:32;
13	Company 14	Potential commoditization of current core product.	0:54;
14	Company 15	Alternative and supplementary scenarios for future engine and drive train scenarios.	0:23;
15	Company 18	Different future technology scenarios for different global locations and facilities.	0:05, 0:36;
16	Company 18	Diverse substitution and obsolescence scenarios for uncoated fine paper.	0:09, 0:12;
17	Company 21	Real-time information system for fire fighting operations enabled by mobile information and communication technology.	0:17, 0:48;
18	Company 21	Substitution of mobile fire fighting by stationary fire fighting facilities enabled by legal requirements and facility modernization.	1:22;
19	Company 21	Frame construction vs. self-supporting body design for fire fighting vehicles.	1:27;
20	Company 22	Alternative scenarios for exploiting unit injection technology.	0:29;
21	Company 23	Enabled hot stamping process technology.	0:13;
22	Company 23	Low-emission and low-energy steel mill scenario	0:20;
23	Company 25	Switching drivers of technology development as innovation enabler.	0:08, 0:18, 0:28;

All of these 23 incidents, which were labeled *as imaginable scenarios,* would have massive impact on currently existing sources and forms of technology-based competitive advantage in the case of their realization. Most *imaginable scenarios* imply multiple opportunities and threats to the relevant organization, but ambiguity on their eventual realization is perceived as high. To clarify the interpretation of these 23 incidents of technology turbulence as *imaginable scenarios* in this research, three examples from the collected interview data are described in more detail (see Case vignette 6-7, Case vignette 6-8 and Case vignette 6-9).

Case vignette 6-7: #9 Company 10: Increasingly restrictive legal regulation and sensitivity for energy-efficiency as enabler of technology substitution in an adjacent industry.

Company 10 is global manufacturer of tools for the professional construction industry. Company 10's technology strategy is focused on its existing customers and customer segments. If requirements, needs and demands of the professional construction industry are changing, Company 10 develops and adopts new technologies to enable or even to drive these changes. Increasingly restrictive regulations of safety issues and acoustic emissions for mining workers and increasing sensitivity for energy efficiency of mining companies, triggered by increasing energy prices, created a new imaginable scenario for Company 10: Certain segments of the mining industry are dominated by very noisy pneumatic hammer drills. Additionally to the significant *acoustic and health issues of these tools, the necessary pneumatic pipes to run this hammer drills are very inefficient in terms of energy loss, which became evident to the mining companies as energy prices were increasing. These anticipated changes in the context of the mining industry created the scenario for Company 10 to enter a completely new industry, where customers are unknown and existing products and technologies of Company 10 have to be adapted for the different conditions and requirements. In this imaginable scenario for Company 10 the company is successfully extending its product and business portfolio and is becoming an equipment supplier in specific segments of the global mining industry. This scenario includes that Company 10 is entering a new market with an adapted product technology, where it substitutes a significant share of the dominant technology of pneumatic hammer drills by its tools powered by electricity. This imaginable scenario implies an increase of technology complexity and diversity for Company 10.*

Case vignette 6-8: #12 Company 13: Rising importance, demand, industrialization and mass-production of fiber-based composite materials.

Company 13 is a manufacturer of pulp and cellulose and plastic fibers. Because its two core products, pulp and viscose fiber became global commodities, Company 13 is increasing its efforts in more advanced cellulose and plastic specialty fibers. Increasing imitation of its current core products by competitors from low-cost countries forces Company 13 to increase product development efforts in more technology and know-how-intensive specialty applications of cellulose and plastic fiber materials. The increasing importance and potential industrialization of the manufacturing of fiber-based composite materials is regarded as one possible future scenario for Company 13. Carbon-fiber composite materials need polyacrylnitrile fibers as quality and function-relevant precursor material. Among others, the aerospace, automotive and sport industries drive the increasing industrialization of carbon-fiber composite materials. Company 13 may become an important supplier of these critical polyacrylnitrile fibers. Although Company 13 does not know the downstream markets and its potential customers in this emerging industry and it has only preliminary expertise on polyacrylnitrile fibers today, the imaginable industrialization of the production of carbon-fiber composite materials creates the scenario for Company 13 to become an important supplier of this emerging industry. This imaginable scenario implies an increase of technology complexity and intensity for Company 13.

Case vignette 6-9: #16 Company 18: Diverse substitution and obsolescence scenarios for uncoated fine paper.

Company 18 is a global manufacturer of uncoated fine paper of different quality. Depending on local conditions, the integrated paper mills of Company 18 use different technologies and resources for its production processes by eventually producing a certain portfolio of homogenous products. The actual production process of paper is considered to be a mature industrial proc-

ess with many incremental improvements but with a very stable dominant design in process and architecture. One imaginable future scenario for Company 18 is the complete substitution of paper by bio-plastic made of renewable organic resources. Plastic extrusion technology could be used to produce paper-like plastic films, which could substitute the entire product by using less energy and creating less environmental emissions over the whole production process. Additionally to the substitution of conventional paper by plastic, another imaginable scenario is the obsoleteness of paper, because of breakthroughs in mobile electronic devices. E-books, flexible displays and improving information and communication technology and infrastructure could eventually realize the long-existing scenario of a "paper-free office". Next to the preferred scenario of incremental developments of the status-quo, Company 18 perceives these two alternative pictures of the future, which would imply massive technology discontinuities in the case of their realization.

The three reported incidents represent future scenarios and their realization is perceived as imaginable by the involved companies. If an ignored scenario eventually realizes, the related opportunities may be unattainable and the implied threats may hit the organization unprepared. Table 6-6 summarizes and generalizes characteristics of perceived incidents of technology turbulence, which are categorized and labeled as *imaginable scenarios*. Although anticipated, different imaginable technology scenarios of the future create significant ambiguity to the relevant company. Possible proactive measure could be an adequate but limited preparation for each scenario, depending on an estimation how probable a future realization may be and the necessary efforts and investments and available resources for this preparation.

Table 6-6: Generalized characteristics of incidents labeled as imaginable scenarios.

	Imaginable Scenarios		
Company	Company 10	Company 13	Company 18
Incident of Technology Turbulence	Increasingly restrictive legal regulation and sensitivity for energy-efficiency as enabler of technology substitution on adjacent market.	Rising importance, demand, industrialization and mass-production of fiber-based composite materials.	Diverse substitution and obsolescence scenarios for uncoated fine paper.
Dominant Element of Technology Turbulence	Increasing technology complexity/diversity	Increasing technology complexity/intensity	Increasing technology discontinuity
Timing of Initial Perception	Anticipation of an imaginable incident before any occurrence of significant impact.		
Quality of Perception	Anticipated incident creates alternative or additional, but distinguishable scenarios for the future.		
Resulting Ambiguity for Organization until Realization	High – Existing but limited insight on causality and impact.		
Proactive Measures before Realization	Preparing for all imaginable scenarios with only limited commitment and scope because of multiple and contradictory requirements for different scenarios.		

6.2.2.2 Weak Signals

Additionally to *imaginable scenarios*, a second subcategory of how incidents of technology turbulence are perceived as *known unknowns* emerged from the interview data. This subcategory was labeled *weak signals* and the main difference to incidents categorized as *imaginable scenarios* is the non-existence of a consistent and plausible picture of the future. The applied and apt notion of *weak signals* was introduced into the context of strategic management by Ansoff (Ansoff H.I. 1975, Ansoff H.I. 1980). The 19 reported incidents share the existence of some prior anticipation as signals, signs or omens for strategically relevant change in the future technology context of an organization, but they also share the low level of insight on relevance, impact and necessary consequences and therefore create a very high degree of ambiguity for the affected organization when noticed. The combination of anticipation before any specific or significant impact on the organization is observable and the low level of insight is exactly what creates this very high level of ambiguity for an organization when perceiving *weak signals*. Table 6-7 lists reported incidents of technology turbulence from the collected empirical data which are categorized as *weak signals*.

Table 6-7: Reported incidents of technology turbulence labeled as weak signals.

#	Company	Weak Signals	Interview positions (min.)
1	Company 1	Alternative cooling technologies in other industries and markets which make compressors and engines obsolete.	0:10;
2	Company 3	Emerging market of bio-fuel and renewable and sustainable energy production.	0:40, 1:07;
3	Company 6	Magnesium as a possible material for modules and components in drive train systems.	1:37 and 0:07;
4	Company 7	Increasing potential of electrical cars and alternative materials in the automotive industry.	0:50;
5	Company 8	New and enabling cable car technology which allows operation under special environmental conditions.	0:09;
6	Company 8	Cornering technology as potential enabler for various additional applications of cable-car technology.	0:41;
7	Company 9	Composite material as a potential material for auto body and chassis parts.	0:14, 0:19, 1:03;
8	Company 11	Increasing convergence of functionalities and applications into mobile phones and mobile digital devices.	1:52;
9	Company 14	Increasing relevance and technological complexity of main transmission systems.	0:37;
10	Company 14	Magnesium as a possible material for modules and components in drive train systems.	0:59;
11	Company 15	Composite materials for auto body applications.	0:46 and 1:15;
12	Company 15	Enabled car to car and car to infrastructure communication.	0:31;
13	Company 16	Substitution of conventional internal combustion engines by alternative engine systems.	0:16, 0:23, 1:08;
14	Company 17	Possibilities for wire-less and decentralized energy supply in buildings by fuel cell technology.	1:24;

#	Company	Weak Signals	Interview positions (min.)
15	Company 18	Complete virtualization and digitalization of information.	0:09;
16	Company 20	Convergence of new functionalities and applications into existing diagnostic products suggested by clinical medical research.	0:06, 0:12, 0:33;
17	Company 21	Development, mass production and application of sophisticated sensor technology in adjacent industry.	0:58;
18	Company 23	Future potential of thin sheet casting process technology.	0:21;
19	Company 25	Potential of carbon fiber and composite materials in all business units.	0:56, 0:59, 1:54;

All these reported incidents, which are categorized as *weak signals*, were perceived as diffuse indicators for some form of future and strategically relevant change, which is currently beyond the organizations grasp and understanding. Although no explicit opportunity and threat can be identified, incidents perceived as *weak signals* are somehow related to a so-called "gut feeling" or some form of management intuition for an upcoming opportunity or threat for the organization. To clarify the perception of an incident of technology turbulence as *weak signal* in this research, three examples from the collected interview data are described in more detail (see Case vignette 6-10, Case vignette 6-11 and Case vignette 6-12).

Case vignette 6-10: #1 Company 7: Increasing potential alternative materials in the automotive industry.

Company 7's dominating business is the development and production of tool steel of high quality. A significant share of Company 7's tool steel is employed in all segments of the automotive industry to process various kinds of steel, light metal and other materials. As most of the automotive value chain is dominated either by the equipment for or the actual process of processing steel and metal, Company 7 is highly sensitive to signals, which indicate a change in the current status-quo in the manufacturing technologies and employed materials. Signals that indicate increasing and significant success of electrical cars without combustion engines or the increasing application of various plastic and composite materials are interpreted by a designated "Automotive Future Trend Group", as these signals may indicate a significant change in one current core business of Company 7. These indicative signals imply a possible incident of technology turbulence for Company 7, although its impact and consequences and the opportunities and threats it may generate are not understood. These weak signals from Company 7's downstream markets indicate potential technology discontinuities.

Case vignette 6-11: #8 Company 11: Increasing convergence of functionalities and applications into mobile phones and mobile digital devices.

One dominant business field of Company 11 is related to building and maintaining automated tolling systems for highway and street infrastructure. Due to increasingly restrictive national and international regulation of traffic safety and exhaust emissions the business is growing and the company is expanding globally. Although there are competing technological concepts and standards for automated tolling system, most of the existing solutions are based on a similar system architecture. A potential threat, which may not only substitute the technology, but the complete system architecture and the related business model, is indicated by the increasing convergence of various functionalities and mobile applications into handheld mobile device like cell phones and personal digital assistants (PDAs). As GPS and other wireless communication functions, standards and interfaces (GSM, UMTS, GPRS, EDGE, WLAN etc.) are integrated into mobile devices, Company 11 has installed a dedicated technology intelligence activity, which is monitoring the market, business, services and technologies for portable devices of wireless communications. This convergence of different functionalities and applications into portable electronic communication devices is interpreted as a signal, which indicates a possible future technology discontinuity. These mobile devices may create the potential to make a designated tolling system infrastructure obsolete. Although Company 11 has currently no specific insights on specific opportunities and threats which may result from this signal, they carefully observe and track these developments.

Case vignette 6-12: #13 Company 16: Substitution of conventional internal combustion engines by alternative engine systems.

A business unit of Company 16 is a supplier of sintered components and parts for the automotive industry. Most of these parts and components are for combustion engines and complementary transmission and gears systems of automotive drive trains. Signals indicate that there may be a future threat to Company 16's most prominent technological competence of precision sintering. Although these signals do not suggest that sintering will be substituted by a competing process technology, they indicate that sintering technology in general may become less important or obsolete, as future cars will not have a conventional combustion engine anymore. If future cars are powered by electro motors, the current demand for sintered engine and transmission components may erode significantly. On the other hand, there may be new and unexpected opportunities for sintering technology related to these weak signals, which are currently not obvious to Company 16. This signal for the possible obsoleteness of conventional combustion engines in downstream markets of Company 16 represent an incident of technology turbulence for the company, although opportunities and threats it may generate are not fully understood.

These three reported cases represent the perception of technology turbulence as *weak signals* for some form of strategically relevant change in the technology context of an organization. If reoccurring signals are ignored, an incident of technology turbulence may occur without any or only late preparation. Table 6-8 summarizes and generalizes characteristics of incidents of technology turbulence which are labeled as *weak signals*. Because they are perceived before they occur but the quality of this perception is very low, incidents first perceived as *weak signals* imply a high level of ambiguity for the relevant organization and do not allow for specific and designated proactive measures before increasing insights allow for a reduction of this ambiguity.

Table 6-8: Generalized characteristics of incidents labeled as weak signals.

	Weak Signals		
Company	Company 7	Company 11	Company 16
Incident of Technology Turbulence	Increasing potential of electrical cars and alternative materials in the automotive industry.	Increasing convergence of functionalities and applications into mobile phones and mobile digital devices.	Substitution of conventional internal combustion engines by alternative engine systems.
Dominant Element of Technology Turbulence	Increasing technology discontinuity	Increasing technology discontinuity	Increasing technology discontinuity
Timing of Initial Perception	Anticipation of an indicated incident before any occurrence of significant impact.		
Quality of Perception	Anticipation of an incident as obscure and diffuse signal for some future change.		
Resulting Ambiguity for Organization until Realization	Very high – Only limited insight on causality ("emitter" of signal).		
Proactive Measures before Realization	Identification and designated monitoring of the emitting source of signals with broad monitoring assignments and low resource commitments.		

6.2.3 Unknowns

Until now all of the reported incidents were somehow anticipated before they showed any direct impact on the involved organization. But the interviewed companies also reported incidents, which they perceived as unanticipated and were only recognized when they really occurred. These incidents of technology turbulence, which were not anticipated by a company and were instantly or gradually perceived by the company at the time they occurred, are labeled *unknowns*. While there is no empirical evidence in the collected interview data that suggests a distinction between incidents perceived as *unknown knowns* and *unknown unknowns*, an alternative differentiation emerged from the analysis and interpretation of the field data. Following the matrix in Figure 6-3, *unknowns* are perceived in the moment of their actual occurrence (*timing of initial perception*), and the *quality of perception* switches from an initially complete unawareness to a sufficient understanding, either by a prompt or gradual process of detection of their occurrence.

6.2.3.1 Sudden Emergencies

The label *sudden emergency* is used for an unanticipated incident of technology turbulence, which is perceived as a prompt and unexpected realization of a strategically relevant change. The notion *emergency* is used to emphasize the unpreparedness of the organization for the specific incident, but also the obviousness of its occurrence to the organization. The detection of an incident labeled as *sudden emergency* by a company happens as a discrete event parallel to it occurrence. These incidents are perceived as *sudden emergencies* because of their sudden and unanticipated occurrence and because they were usually not significantly or directly addressed in any strategic agenda before they have eventually impacted the relevant organization. Despite, or maybe because of their surprising occurrence without any warning, the detection of *sudden emergencies* is easy and the necessity to react becomes immediately obvious to the affected company. Table 6-9 lists 12 reported incidents of technology turbulence from the collected empirical data, which are perceived as *sudden emergencies* by the company involved.

Table 6-9: Reported incidents of technology turbulence labeled as sudden emergencies.

#	Company	Sudden Emergencies	Interview positions (min.)
1	Company 2	Unexpected massive substitution of aluminum in the aerospace industry by fiber-based composite materials.	0:43, 0:50, 1:26;
2	Company 3	Unanticipated breakthrough of substitutive product technology.	1:12;
3	Company 4	Unanticipated technological product innovation of competitor.	2:31;
4	Company 6	Unexpected quasi-standardization of particle filter as mandatory add-on technology for diesel engines.	0:34;
5	Company 8	Unexpected applications for ropeway technology for special conveyor applications.	0:14;
6	Company 8	Unexpected introduction of planetary gear set into ropeway systems by competitor.	1:02;
7	Company 9	Unexpected applications of existing technological competence in emerging and fast growing business of life science.	0:03, 0:17, 0:21, 0:59, 1:06;
8	Company 11	Unexpected breakthrough in potential complementary technology of video surveillance technology and algorithms.	2:00;
9	Company 12	Unexpected introduction of substitutive product technology by main competitor.	0:25;
10	Company 15	Unexpected success of hybrid engine technology of main customers' competitors.	0:26 and 0:29;
11	Company 21	Unexpected application of product technology in adjacent businesses.	1:20;
12	Company 24	Significant and IP protected product technology of competitor as potential dominant design.	1:16;

All of these 12 incidents, which were labeled as *sudden emergencies,* turned out as highly relevant to the technology-based competitive advantage of the relevant organization and were reported as unanticipated before any occurrence of a direct impact on the organization. While these incidents were reported as unexpected, the detection and interpretation of implied opportunities and threats by the organization were reported as immediate. To clarify the interpretation of unanticipated incidents of technology turbulence as *sudden emergencies* in this research, three examples from the collected interview data are described in more detail (see Case vignette 6-13, Case vignette 6-14 and Case vignette 6-15).

Case vignette 6-13: #1 Company 2: Unexpected massive substitution of aluminum in the aerospace industry by fiber-based composite materials.

One of Company 2's core business units is the production and processing of aluminum parts for commercial passenger aircrafts of all sizes. Aluminum is one dominating material in most systems and modules of aircraft bodies. Although fiber-based composite materials were always regarded as an expensive substitute for aluminum in market niches (e.g. ultra-light and military aircrafts) and a complementary material to aluminum for certain applications, it was not expected that a significant share of the aircraft body will be made of composite materials. The announcement of both key accounts in the aircraft manufacturing industry of commercial aircrafts, Boeing and Airbus, that the next generation of their products (e.g. B787-Dreamliner, A350) will be dominated by composite materials and not by aluminum and other light metal alloys was perceived as an unexpected material substitution in core businesses of the company. Although a material substitution in this magnitude was reported as unanticipated, the detection and interpretation as a threat to the company was immediate. This material substitution in Company 2's core business is an increase in technology diversity.

Case vignette 6-14: #2 Company 3: Unanticipated breakthrough of substitutive product technology.

A business unit of Company 3 is providing metal and steel processing facilities to their customers. One of the core products and technological know-how of this business unit are galvanization facilities to process steel for high-quality demands of the automotive industry. The galvanization technology by electrolytic zinc coating, provided by Company 3, was considered to be the most reliable process, which was able to fulfill the highest quality requirements. An alternative galvanization process, hot dip galvanization, which allows for lower investment and operation costs, was inferior in quality to the process technology provided by Company 3 and was initially not used for any high quality application of Company 3's customers. Process innovations made the hot dip technology, which was always considered to be inferior to the state of the art in more demanding industries, a reasonable and cheap but unexpected alternative also in segments with higher requirements. Without anticipation, Company 3 was confronted with technological improvements of this substitutive technology in the market place and interpreted it as an unexpected and massive threat to one of its core businesses. Additionally to the cost advantages in investment and operations, it was recognized that there was also a potential for further technological improvements. Although unanticipated, this incident was relatively easy to detect and to interpret as a threat by Company 3. This breakthrough of an alternative process technology increased technology diversity for Company 3.

Case vignette 6-15: #9 Company 12: Unexpected introduction of substitutive product technology by main competitor.

Company 12's traditional core products are off-road and enduro motorbikes for the competitive motorsport segments. The dominant engine concept in these segments were 2-stroke gasoline combustion engines because of their obvious advantages compared to 4-stroke engines in terms response characteristics, power-to-weight ratio, power-per-liter ratio, simplicity and robustness. Other criteria, as low fuel and oil consumption and low emission were irrelevant for competitive applications and because of the insignificant share of the vehicles compared to other mainstream segments. Japanese competitors unexpectedly introduced 4-stroke engines into these segments, which were instantly adopted by racing organizations and regulating bodies. Regulators adopted the view of Japanese companies that the racing competition must serve as an innovation and technology development platform for later adoption in mass and series production. At a time when Company 12 had no significant internal expertise on 4-stroke gasoline engines and the intended technology strategy and projected product portfolio did not include any 4-stroke concept or product, 4 stroke engines unanticipated became a new standard. The introduction of 4-stroke engines by competitor into Company 12's core market was perceived as a sudden emergency. Although unexpected, the occurrence of this incident was immediately detected and interpreted as a threat to Company 12. The introduction of 4-stroke engines was perceived as a discontinuity, which eventually increased technology complexity, diversity and intensity of the overall industry.

These three reported cases were perceived as *sudden emergencies* by the involved organization. They became obvious to the affected companies because they immediately affected their competitive positions. Table 6-9 summarizes and generalizes characteristics of incidents of technology turbulence, which are perceived as *sudden emergencies*. As these incidents were not anticipated, the period before they occurred was not affected by ambiguity but by some form of delusive unawareness. Their detection and the interpretation of their impact happened parallel to their sudden occurrence. The proactive measures for incidents like this are limited to a general preparation of the organization for the reaction to sudden, unanticipated, but strategically relevant changes in the technology contexts without any designated scope for a specific incident. Although a company may not anticipate any specific incident, it may consider the general chance that incidents like *sudden emergencies* may happen in the future.

Table 6-10: Generalized characteristics of incidents labeled as sudden emergencies.

	Sudden Emergencies		
Company	Company 2	Company 3	Company 12
Incident of Technology Turbulence	Unexpected massive substitution of aluminum in the aerospace industry by fiber-based composite materials.	Unanticipated breakthrough of substitutive product technology.	Unexpected introduction of substitutive product technology by main competitor.
Dominant Element of Technology Turbulence	Increasing technology diversity/discontinuity	Increasing technology diversity/discontinuity	Increasing technology complexity/intensity
Timing of Initial Perception	Parallel to the obvious occurrence of significant impact.		
Quality of Perception	Unawareness before occurrence, prompt and discrete detection and interpretation during occurrence.		
Resulting Ambiguity for Organization until Realization	None – Unawareness.		
Proactive Measures before Realization	General and unspecific preparation of the overall organization for the reaction to unexpected and fast-occurring incidents.		

6.2.3.2 Converging Evolutions

The second sub-category of *unknowns*, which was identified in the interview data, was labeled *converging evolutions*. *Converging evolutions* represent unanticipated but more gradual and less obvious occurrences of incidents of technology turbulence. They do not occur as a singular disruptive event, but emerge gradually in different stages, which are often initially perceived as unrelated by the affected companies. Therefore, their occurrence and the necessity to act are not immediately apparent to the company. The notion *converging evolutions* emphasizes that initially unrelated and incremental developments within and beyond the current boundaries of the organization converge into a strategically relevant incident. Although both *sudden emergencies* and *converging evolutions* are unanticipated, in the case of a *sudden emergency* the detection of its occurrence and its interpretation is an immediate and discrete event parallel to its occurrence. *Converging evolutions* are detected and interpreted gradually by some form of exploratory, non-directed and distributed learning processes within the organization. Table 6-11 list 14 identified incidents of technology turbulence from the collected empirical data, which are interpreted as *converging evolutions*.

Table 6-11: Reported incidents of technology turbulence categorized as converging evolutions.

#	Company	Converging Evolutions	Interview positions (min.)
1	Company 1	Unexpected possibilities for material substitution in electro motors and compressors.	1:09;
2	Company 3	Unexpected exploitation opportunities for dewatering and drying technologies of paper and pulp production.	0:10, 0:43, 1:03;
3	Company 4	Unexpected external exploitation of technological competence in sophisticated manufacturing technologies.	1:23, 1:30, 2:23;
4	Company 6	Technology exploitation from niche product development of large-scale and single-unit diesel engines.	0:25;

#	Company	Converging Evolutions	Interview positions (min.)
5	Company 6	Unexpected exploitation opportunity of unsuccessful and pre-mature technology development in completely different context.	0:39 and 0:11;
6	Company 8	Unexpected technology transfer from unsuccessful new market venture in non-core market into core market.	0:06;
7	Company 9	Unexpected application for laser technology in existing business units.	0:07, 0:10, 0:36.
8	Company 10	Unexpected transfer and application of laser technology into new application context.	0:39;
9	Company 12	Unexpected opportunity for technology exploitation of unsuccessful technology and product development project.	0:25, 0:31 0:50;
10	Company 13	External exploitation of internal technological know-how and integrated process optimization competence.	0:28;
11	Company 14	Unexpected application of rotary swaging technology for automotive applications.	1:08 and 0:10;
12	Company 15	Unexpected exploitation of aerospace cryogenic technology for automotive applications.	1:01 and 0:27;
13	Company 21	Unintended potential and possibilities of modular product architecture.	0:32;
14	Company 24	Unexpected technology transfer of friction stir welding technology for railway application.	1:24;

All these 14 incidents, listed in Table 6-11, turned out to be highly relevant to technology-based competitive advantage of the involved companies. None of these ex-post highly relevant incidents were anticipated or were initially part of any designated strategic agenda, but were gradually detected, as unrelated developments within and beyond the organization converged into relevant change. To clarify the interpretation of unanticipated incident of technology turbulence as *converging evolution* in this research, three examples from the collected interview data are described in more detail (see Case vignette 6-16, Case vignette 6-17 and Case vignette 6-18).

Case vignette 6-16: #4 Company 6: Technology transfer from product development projects of large-scale and single-unit diesel engines into core business.

Company 6's core business is to engineer innovative engine and complete drive train systems for later series-production vehicles of original equipment manufacturers in the automotive industry. To reduce its dependency on key accounts in the automotive industry, Company 6 increased its efforts to diversify its technological know-how and expertise into engines of heavy duty vehicles, stationary engines and other large diesel engines like for ships. Although the necessary technological know-how is similar, the size of the engines is by far bigger and the amount of produced units is by far lower, sometimes only a single special-purpose engine is eventually produced. Because only limited or no prototyping at all is possible in these contexts, the design and engineering process was continuously complemented with IT-based simulation and virtual engineering technologies to avoid expensive and sometimes impossible prototyping phases in the development process. As advantages and success of this highly "front loaded" design and engineering process became evident in these new non-core markets, engineers of Company 6 recognized *the possibilities and potential, if these new ideas are transferred into the core business of Company 6. The pioneering of simulation, optimization and virtual design technology for large-scale and single-unit engines was so successful, that, additionally to the transfer into the Company 6's core business, the software is externally exploited as a third independent business unit. Company 6's engagement into engineering projects beyond its initial scope, which was based on the business logic of simple risk diversification, incrementally converged into a new form of technology-based competitive advantage realized in a completely new business unit.*

Case vignette 6-17: #6 Company 8: Unexpected technology transfer from unsuccessful new market venture in non-core market into core market.

The traditional core business of Company 8 is engineering and building of rope-way and chair-lift systems of all kinds for alpine ski resorts. To become more independent from this core business, it was intended to transfer the technological core competence of rope-based transportation systems into other industries and markets. One of the unsuccessful efforts was to design a passenger elevator system for a specific attraction in a water park. The concept proposed by the involved engineering team of Company 8 suggested to design an innovative elevation system as a reversed scoop or water wheel, which can be compared to a giant wheel attraction in a theme park where people can exit the giant wheel at a platform on the very top. The concept turned out to be too complex and expensive for the water park and the initiative to diversify into another market was unsuccessful because the project was eventually lost. In a later and unrelated project for a ski resort and key account customer in the core market of Company 8, involved engineers from the unsuccessful project recognized similar requirements in the different context and adapted the initial "giant wheel"-design idea for this core market application. The "giant wheel" project was a huge success and turned out to be a flagship project and a reference for multiple innovations in the industry. Although initially no success, Company 8's decision to exploit its rope-way competence in the theme park industry incrementally converged into a new source of competitive advantage in its core business.

Case vignette 6-18: #14 Company 24: Unexpected technology transfer of alternative welding technology for railway turnout applications.

Company 24 is developing, engineering, manufacturing, installing and maintaining complete turnout systems for most railway applications. Because of different steel grades of turnout systems and conventional rails, a sophisticated and patented welding technology is necessary for installation (so-called flash-butt welding technology). The corporate owner of Company 24 is a highly diversified corporation. To promote informal contacts between employees from different parts of the corporation, a bi-annual internal conference session is organized by the corporation. All participating R&D&E departments present their current projects. Although highly knowledgeable about welding technologies for relevant steel grades, the head of R&D&E of

Company 24 learned about a relatively new solid-state welding technology, which is used to weld aluminum profiles of window frames. Initiated by this first contact at the internal conference session, it became gradually obvious that this friction stir welding process may be applicable for turnout systems and can potentially substitute the conventional technologies in use. Because friction stir welding does not need an austenitic intermediate piece, which connects the turnout system with the conventional rails, there are three big potential advantages: First, the number of welding seams for each turnout system could be halved. Second, the austenitic material could be saved, and third, the low hardness of the austenitic intermediate piece does not negatively affect the durability of the complete turnout system. Although never part of any intended technology agenda of Company 24, a successful application of friction stir welding for installing turnout systems is rated as on of the biggest technological innovation in the industry.

These three reported cases were perceived as *converging evolutions* by the interviewed organizations. Only after the convergence of initially unrelated developments was gradually detected by the organizations, it became obvious that these developments are somehow affecting their competitive positions. Table 6-12 summarizes and generalizes characteristics of incidents of technology turbulence, which are perceived *converging evolutions*. As these incidents are not anticipated, the period before they gradually occur is not affected by ambiguity but by unawareness. Usually the first decisions, which initiated the first developments of these incidents, were unrelated and based on different rationales. The initial and complete unawareness for related opportunities and threats is reduced by a gradual detection and interpretation of a *converging evolution*. Possible proactive measures for successfully detecting and seizing *converging evolutions* are limited to stimulating, enabling and initiating the emergence and consolidation of learning processes across the complete organization. All possible proactive efforts are only legitimated by the unspecific assumption that *converging evolutions* may occur by chance.

Table 6-12: Generalized characteristics of incidents labeled as converging evolutions.

	Converging Evolutions		
Company	Company 6	Company 8	Company 24
Incident of Technology Turbulence	Technology transfer from product development projects of large-scale and single-unit diesel engines into core business.	Unexpected technology transfer from unsuccessful new market venture in non-core market into core market.	Unexpected technology transfer of alternative welding technology for railway turnout applications.
Dominant Element of Technology Turbulence	Increasing technology complexity/intensity	Increasing technology complexity	Increasing technology diversity
Timing of Initial Perception	Parallel to the unanticipated emergence of an incident.		
Quality of Perception	Unawareness before occurrence, gradual detection and interpretation parallel to the emergence of opportunities and threats.		
Resulting Ambiguity for Organization until Realization	None – Unawareness.		
Proactive Measures before Realization	General and unspecific efforts to stimulate and enable the emergence and consolidation of learning processes.		

6.2.4 Concluding Summary

One important insight of the analysis of the interview data reveals that industrial organizations perceive technology turbulence in their business context as specific incidents and not as a cumulated or aggregated form or frequency of technological change. The identified 116 reported incidents of technology turbulence, which imply strategically relevant change in the business context of an organization, show that the perception of technology turbulence by affected organizations at a specific time can be categorized by two dimensions: The first dimension reflects the *timing of initial perception* regarding the eventual impact of an incident on the organization. It basically distinguishes between anticipated (*known*) and unanticipated (*unknown*) events. The second dimension reflects the *quality of the perception*, which includes the quality of anticipation, interpretation and detection of occurrence when noticed. It distinguishes how well the incident is understood when noticed and how much ambiguity it creates for the organization. Using these dimensions, three rough categories of incidents with two sub-categories each were identified (see Table 6-13).

A first basic conclusion is that, regarding the perception by the affected organizations, strategically relevant changes in the technology context can be distinguished into incidents, which have been anticipated before they actually occurred or not. Anticipated events can be distinguished by how complete this perception is.

Table 6-13: Identified categorization for incidents of technology turbulence.

	Incidents of Technology Turbulence	Timing of Initial Perception	Quality of Perception	Resulting Ambiguity	Commitment and Specificity of Proactive Measures
Known Knowns	**Probable Predictions**	Before occurrence	High	Low	Very High
	Possible Risks	Before occurrence	Medium	Medium	High
Known Unknowns	**Imaginable Scenarios**	Before occurrence	Low	High	Medium
	Weak Signals	Before occurrence	Very low	Very high	Low
Unknowns	**Sudden Emergencies**	During / after occurrence	Prompt detection	None – Unawareness	Low / None
	Converging Evolutions	During / after occurrence	Gradual detection	None – Unawareness	Low / None

The *timing of initial perception* depends on the more or less explicit point in time when an incident is perceived by an organization for the first time and when the incident is eventually occurring and affecting the organization. The second dimension, *quality of perception*, is itself a function of time and is usually increasing as more information on an incident is available over time.

Conclusion RQ 2: Industrial organizations perceive technology turbulence as specific incidents of strategically relevant changes in their technology context, whose occurrences are affecting technology-based forms and sources of competitive advantage. Six generic categories for these incidents of technology turbulence have be identified, which distinguish the incidents of technology turbulence a company is facing at a certain point of time by timing of initial perception and quality of perception (see Table 6-13).

6.3 Dynamic Change Patterns in Technology Strategy under Technology Turbulence

While the previous subchapter identified various forms of how industrial organization do perceive incidents of technology turbulence, this chapters is presenting the analysis how this perception is affecting technology strategies of involved companies. This chapter is based on the analysis of the interview sections on how the interviewed senior technology managers and their companies addressed or are addressing the perceived incidents of technology turbulence in the technology strategy and is designated to answer research question 3.

RQ 3: Which forms of strategic flexibility can be identified in technology strategies of industrial organizations when facing technology turbulence?

Figure 6-4 shows, how research question 3 is integrating the research constructs in the overall research framework. It is proposed that forms of strategic flexibility in technology strategies of organizations can be identified by analyzing patterns of technology strategy formation and change of organizations that face incidents of technology turbulence. The form of strategic flexibility, which is realized in technology strategy, is influenced by a moderating effect of technology turbulence: The characteristics of an incident of technology turbulence will influence the form of strategic flexibility in technology strategies of industrial organizations.

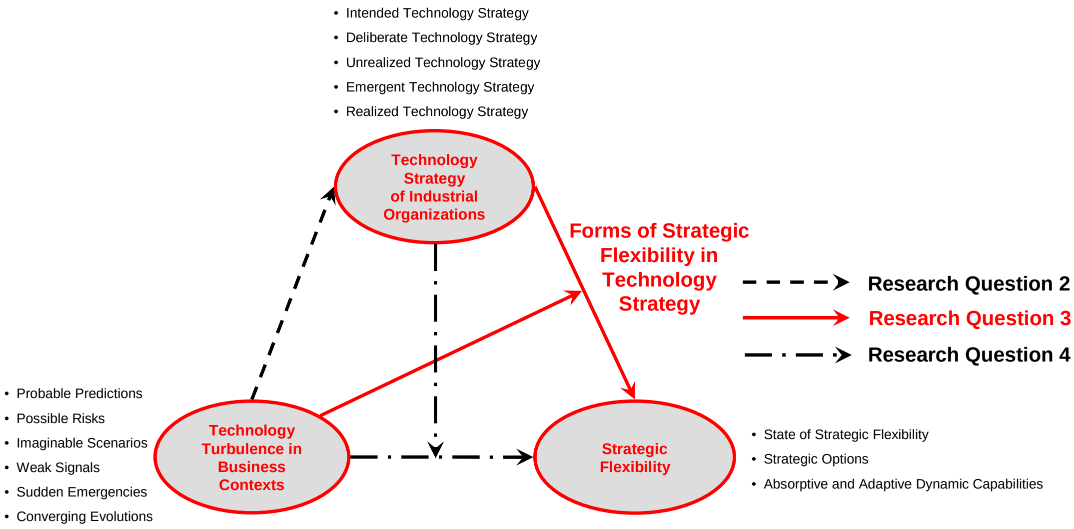


Figure 6-4: Forms of strategic flexibility in technology strategy.

In the previous subchapters incidents of technology turbulence, which affect technology-based competitive advantage, were identified and categorized. As incidents of technology turbulence reflect strategically relevant changes, these changes are supposed to impact the intended and realized technology strategy of a company over time, depending when and how well perceived. Taking into account the results on research question 2 from the previous section, it is expected that the strategic flexibility in technology strategy for *probable predictions* must be different from strategic flexibility for incidents perceived as *sudden emergencies*. Figure 6-5 summarizes this proposition. The a-priori construct of technology strategy, which was developed in chapter 5, adopted Mintzberg's patterns of strategy for the technology strategy context. As Figure 6-5 proposes, it is expected that the identified incidents of technology turbulence have impact on the patterns of technology strategy formation and change of the affected organization. Depending on how the involved companies are managing the identified incidents of technology turbulence, it is analyzed how the incidents affect the initially intended and the eventually realized technology strategies of these companies. Following the findings of the previous subchapter, the reported measures and decisions by the affected companies were analyzed within and across the identified categories of technology turbulence from the previous subchapter.

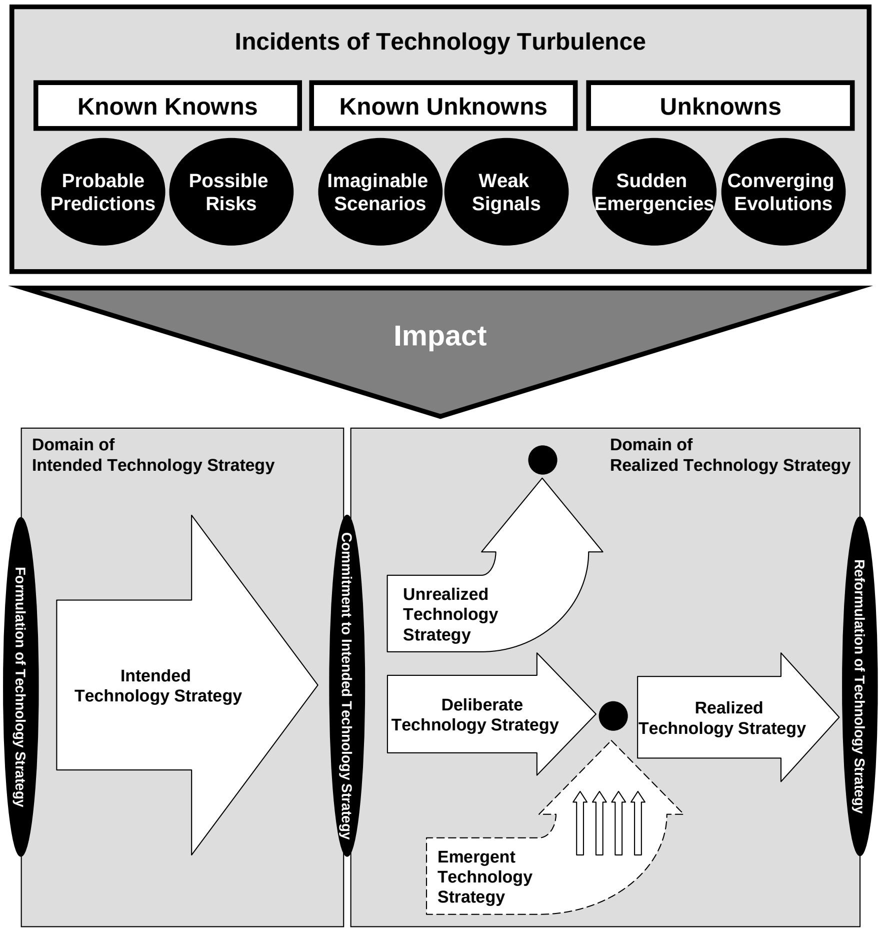


Figure 6-5: ***Analyzing dynamic patterns of technology strategy formation and change in industrial organizations when facing different categories of technology turbulence.***

By analyzing the interview reports on how companies manage incidents of technology turbulence, it was concluded that the perceptions of technology turbulence by senior technology managers triggers dynamic strategic decisions. The notion dynamic implies two phenomena: First, these patterns evolve and change over time and are not discrete events at a certain point of time, and second, the patterns have a cumulative and path-dependent character of commitment and take into account additional or changing insights and assumptions. Depending on timing and quality of perception, three general dynamic change patterns in technology strategy were identified by analyzing the collected data. Figure 6-6 applies the same distinction as introduced in Figure 6-3 and shows these dynamic change patterns depending on timing and quality of perception of a reported incident.

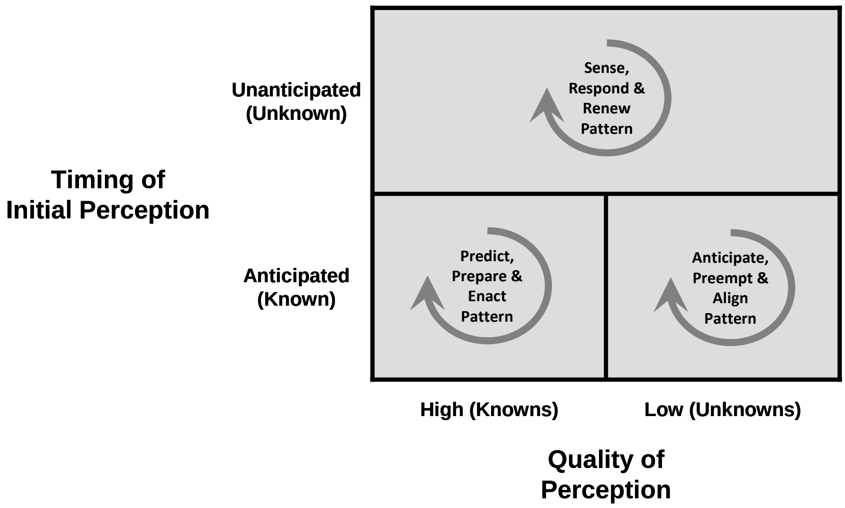


Figure 6-6: ***Dynamic change patterns in technology strategy depending on timing and quality of perception of an incident of technology turbulence.***

If a future incident is perceived as a *known known*, a *predict, prepare & enact pattern* was identified in the technology strategy of the involved company. If an incident is anticipated but there is a significant residual ambiguity on the incident and its consequences for the company (*known unknowns*), the involved organization shows decision patterns in their technology strategy, which can be interpreted as *anticipate, preempt & align pattern*. If the incident is not anticipated at all (*unknowns*), a purely reactive *sense, respond & renew pattern* in technology strategy of studied industrial organizations was identified.

The analysis of the interview data identified these three basic different dynamic patterns of how the interviewed senior technology managers addressed or intend to address incidents of technology turbulence. In most cases the paraphrased data on the identified incidents and the companies' actions on these incidents is exclusively based on the interview data. In some cases additional internal or publicly available material like reports, presentations, charts or financial and business reports were used to complement these information. In few cases the work of on-site graduate students and additional on-site visits of the author provided further insights on a specific incident or the overall technology strategy of the company (see Appendix B for an overview on the studied organization and Appendix D for the paraphrased interview data). The following subchapters will describe and discuss each of the three categories and their subcategories individually by directly referring to reported incidents form the interview data.

6.3.1 Predict, Prepare & Enact Pattern for Known Knowns

The identified dynamic pattern in technology strategy when organizations are facing incidents of technology turbulence, which are predictable and sufficiently understood as *known knows*, can be described in three rough phases (see Figure 6-7):

- *Predicting* the future incident of technology turbulence, its impact on the organization and an adequate response by the organization.

- *Preparing* for the future realization of the incident by designated initiatives as integrated part of the intended technology strategy.
- *Enacting* of prepared measures and relevant elements of the intended technology strategy, if the incident occurs as predicted. If the incident does not occur as predicted because of wrong initial assumptions or changing circumstances, the recurrence to the initially intended technology strategy serves as a fallback position.

This basic dynamic pattern in technology strategy was identified whether the incident was perceived as highly probable (*probable prediction*) or just as possible (*possible risk*).

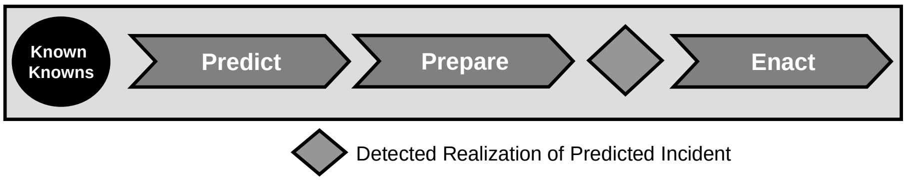


Figure 6-7: ***Identified dynamic change pattern in technology strategy of organizations when facing known knowns.***

6.3.1.1 Strategic Options for Probable Predictions

Figure 6-8 is using paraphrased and interpreted data form the interviews to document the emergence of the *predict, prepare & enact pattern* from the qualitative data in the cases that were already introduced in chapter 6.2. The paraphrased data of all 32 incidents interpreted as *probable predictions* with direct reference to the sections in the expert interviews can be found in Appendix D.

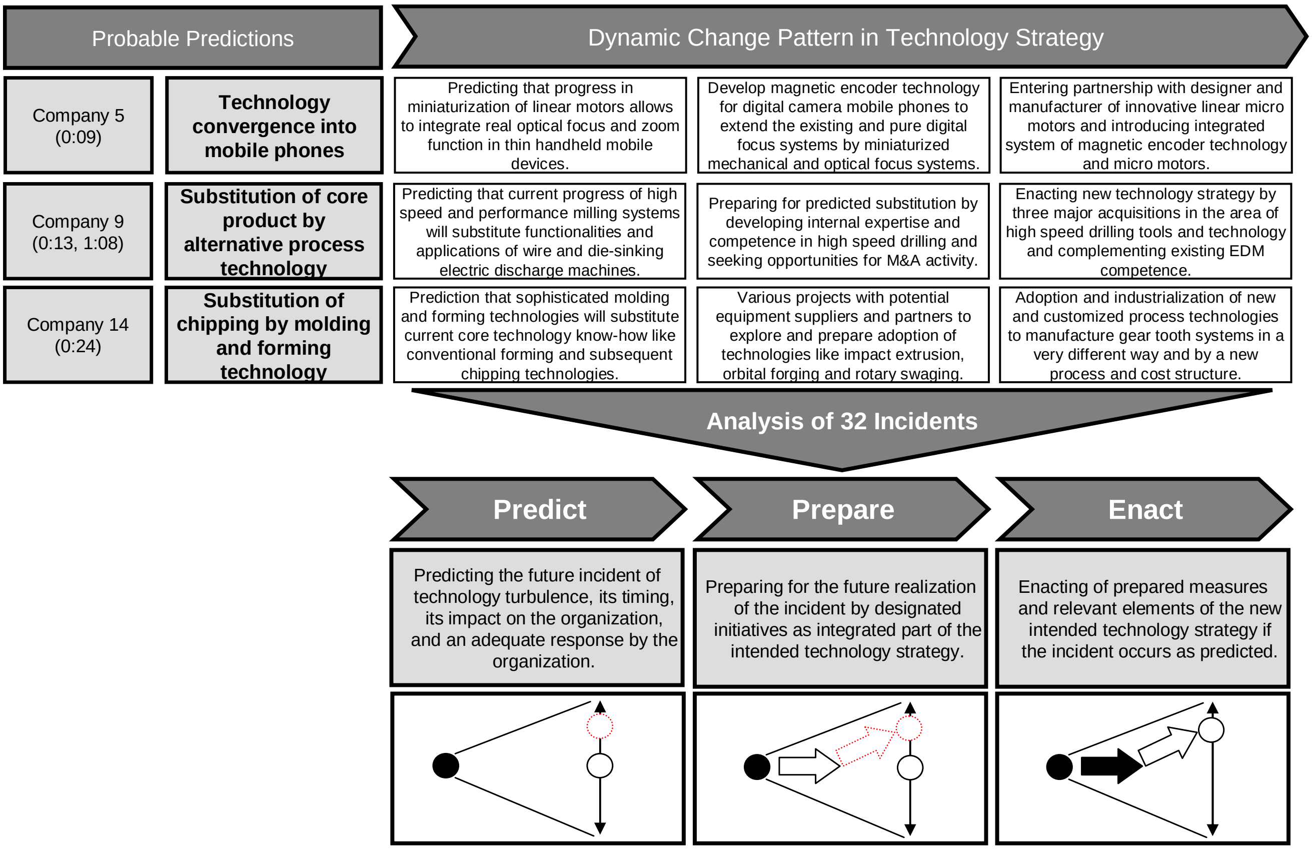


Figure 6-8: ***Predict, prepare & enact pattern in technology strategy of organizations when facing probable predictions.***

By analyzing the 32 incidents of technology turbulence, which were perceived as *probable prediction*, the *predict, prepare & enact pattern* emerged as a dominant sequence in technology strategy formation. In all three cases presented in Figure 6-8, the involved company was completely aware of the future technology turbulence. The impact, timing and the underlying causality of the incident was sufficiently understood by involved decision makers. As the eventual occurrence of the predicted incident and the realization of the consequences for the company were regarded as highly probable, the company prepared by formulating an intended technology strategy, which took into account the predicted incident. Although the eventual efforts of preparation are highly related to the specific context, all efforts are highly designated and committed to the anticipated incident. Company 5 included the development of a complementary and enabling technology in its R&D agenda, to be prepared to absorb the new functionalities and applications which were predicted. Company 9 was initiating merger and acquisition activities to get adequate access to intellectual property and know-how in the emerging substitution technology, which was threatening one of the company’s products. Company 14 emphasized efforts to establish a new equipment supplier base, to face the predicted shift in manufacturing technologies.

Although these incidents were perceived as highly probable and strategically relevant changes, their eventual or complete realization in the future creates a residual uncertainty, whether the prediction turns out right. The complete commitment in form of full enactment and adoption of the prepared measures takes place, if the *probable prediction* is realizing. Company 5 entered an exclusive partnership with a provider of a complementary technology when the company was fully convinced the predicted trend was becoming reality. Company 9 enacted a full commitment to the intended technology strategy by major acquisitions in the competing technology, when they were completely confident it is necessary. Company 14 is eventually adopting new technologies in its core manufacturing processes in adequate stages of substitution. Another case where the response to an incident of technology turbulence, which was perceived as a *probable prediction*, followed a *predict, prepare & enact pattern* is reported in Case vignette 6-19.

Case vignette 6-19: #12 Company 11: Diffusion of new functionalities, applications and technologies into street and highway infrastructure and vehicles.

An example how a probable prediction has impact on the intended technology strategy is Company 11's response to the very probable development of so-called "intelligent" street and highway infrastructure in the western core markets of Company 11. The development of street and highway infrastructure, which provides vehicles, its drivers and the operator of the infrastructure with necessary and valuable real-time data and analysis on weather, emission, traffic conditions, and information about the vehicles that are currently using the infrastructure, is an increase in technology complexity and intensity for a manufacturer and provider of automatic highway tolling systems and devices like Company 11. Due the increase deployment of sensor and communication technology in cars and commercial vehicles and the emergence of new and more restrictive traffic safety and emission legislation, a direct communication between vehicles and the street and highway infrastructure becomes probable in the near future. Information on and enforcement of speed limits because of changing weather or emission conditions or information about traffic congestion and real-time updates of navigation systems can be communicated to the car and its driver by information on the cockpit display or system updates. Although Company 11 already masters technologies, which are necessary to identify and track vehicles and to communicate between a special portable tolling device in vehicles and the gate infrastructure along the highway, further development of technologies and standardized sensors and interfaces to measure emissions or all kind environmental conditions along the highway and to communicate with the vehicle's on-board systems directly are necessary. This concept of "intelligent streets" seems to be the dominant future scenario in most of Company 11's core markets and is reflected in its new strategic agenda. As this convergence and diffusion of technologies into Company 11's current main markets appears to be only a question of time, Company 11 prepares itself by increasing R&D commitment in various forms of sensor, measurement and communication technology. Although a relevant and successful player in the industry, high stakes and commitments in the technology of conventional tolling systems and a good industry position in this business, Company 11 is exploring completely new technologies to prepare strategic options for "intelligent streets". This response to a predicted and probable incident of technology turbulence in Company 11's technology strategy is following a dynamic predict, prepare & enact pattern.

In all the reviewed cases on how companies handled and intend to handle *probable predictions* by their technology strategy, it became clear that, although the strategically relevant change in the technology context was expected to occur in the future, all companies sustained or are sustaining the option to keep or return to their initial technology strategy as long as reasonably possible. Until predictions are eventually confirmed by reality, companies maintain a certain degree of reversibility in their technology strategy change. The analysis of how companies are preparing for and handling predicted and highly probable technology changes showed that the relevant companies are generating strategic options, which create a state of immunity for these predicted changes. Table 6-14 summarizes the identified examples of anecdotal evidence for strategic options against incidents perceived as *probable predictions*.

Table 6-14: Strategic options to create immunity for probable predictions.

	Strategic Options for Probable Predictions		
Company	Company 5	Company 9	Company 14
Probable Prediction	Convergence of new functionalities, applications and technologies into mobile phones and portable electronic devices.	Partial substitution of core product technology by alternative and improving process technology.	Substitution of chipping technology by advancing chipless molding and forming technology.
Timing of Initial Perception	Before occurrence.		
Quality of Perception	High.		
Goal of Strategic Option	Immunity of the organization for the probable prediction by its intended technology strategy.		
Creation of Strategic Option	Develop magnetic encoder technology for digital camera phones to extend the existing and purely digital focus systems by miniaturized mechanical and optical focus systems.	Preparing for predicted substitution by developing internal expertise and competence in high speed drilling and seeking opportunities for M&A activity.	Various projects with potential suppliers and partners to explore and prepare adoption of technologies like impact extrusion, orbital forging or rotary swaging.
Scope of Strategic Option	Specific and designated option for a highly probable and predicted incident.		
Exercise of Strategic Option	Entering exclusive partnership with designer and manufacturer of innovative linear micro motors and introducing integrated system of magnetic encoder technology and micro motors.	Enacting new technology strategy by three major acquisitions in the area of high speed drilling tools and technology and complementing existing EDM competence.	Adoption and industrialization of new and customized process technologies to manufacture gear tooth systems in a different way and by a new process and cost structure.
Linkage between Creation and Exercise	Specific but deferred and partly reversible commitment decision integrated in strategic agenda of intended technology strategy.		
Exercising Trigger	Commoditization of digital zoom and beginning demand for advanced optical systems in downstream markets.	Increasing level of technology substitution by existing and potential customers.	Verification of an advantageous cost structure combined with adequate or better performance.
Ex ante Determinability and Traceability of Trigger	Easy – Indicators and conditions for exercising strategic options are known ex ante and easily observable.		
Impact on Intended Technology Strategy	Committed – Exercising of strategic option is an expected element of strategic agenda.		
General Characteristic of Created Flexibility	Committed to the existing overall goals and strategies of an organization and specific to a predicted change with only limited direct use, if the change does not occur as predicted.		

In all three cases reported in Table 6-14, the companies *immunized* themselves for the predicted change by specific creation of designated strategic options as an element of their intended technology strategy. Company 5 created a strategic option to be *immunized* for the predicted demand for technologically more sophisticated camera phones, while Company 9 and Company 14 prepared for the probable future obsoleteness of current technological competences by strategic options on competing technologies. The eventual and full commitment to the new technology strategy is realized by exercising these created strategic options. This execution of strategic options is triggered by the observation that the incidents seem to occur as predicted. The alternative choice to the execution of the strategic option is the status-quo of the initially pursued technology strategy. This reversibility of technology strategy change by maintaining the possibility to switch back is necessary, if the incident does not occur as predicted. The characteristic of the flexibility, which is created by this *immunity option,* is specific to a predicted incident.

6.3.1.2 Strategic Options for Possible Risks

Figure 6-9 is applying the same concept to incidents that were characterized as *possible risks*. Although the content differs, as the quality of perception is changing, the analysis of all 16 incidents confirms the basic *predict, prepare & enact pattern*. The paraphrasing and interpretation of all 16 incidents interpreted as *possible risk* can be found in the attachment (see Appendix D).

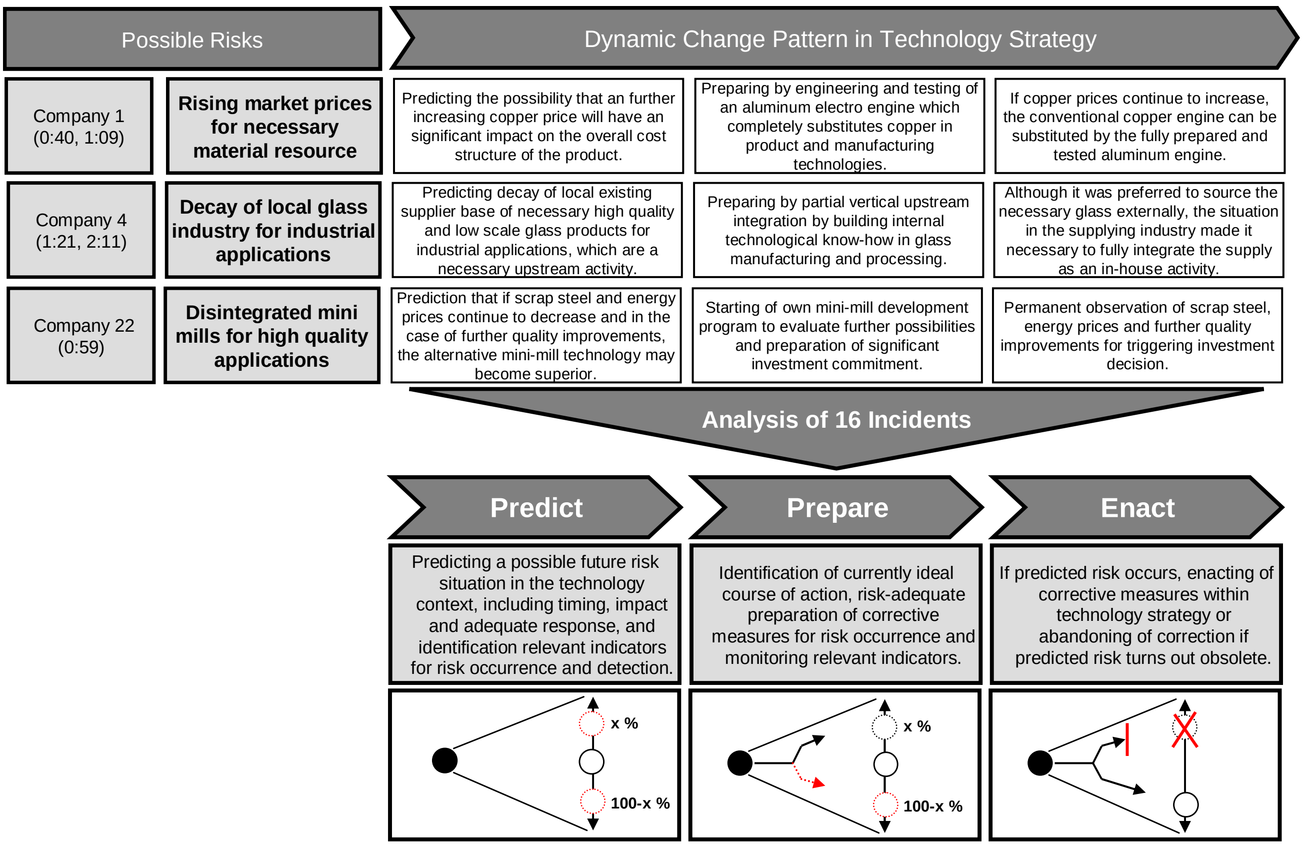


Figure 6-9: ***Predict, prepare & enact pattern in technology strategy of organizations when facing possible risks.***

In all three case presented in Figure 6-9, the involved company predicts a future risk situation related to technology turbulence. The companies are highly aware of the impact, timing and causality of the underlying incident and can identify reliable indicators, which allow the detection of the eventual occurrence or non-occurrence of the risk. As there is ambiguity if the risk eventually occurs or not, the companies perceiving *possible risks* are preparing for both possibilities: Company 1 is preparing the product and manufacturing technologies to substitute copper by aluminum and is monitoring global market price for copper and the cost structure of its products, while Company 4 is creating its own in-house competence in glass manufacturing and is watching the developments in its current supplier base. Company 22 is preparing for the possibility of a major investment in mini-mill technology, while watching the scrap steel and energy prices. As the ambiguity of the risk situation does not allow for a pre-mature commitment, companies are waiting with the final enactment of a strategy until residual ambiguity is resolved. Compared to strategic options for *probable predictions*, where companies expect and plan the occurrence of an incident but maintain the option of reversibility to return to their initial strategy, strategic options for *possible risks* expect and plan that the risk does not occur, but create and maintain an option, if the risk does eventually occur. This distinction in behavior reflects the different perception of an anticipated incident as a *probable predictions* or *possible risks*.

Company 1 eventually shelved the substitution of copper by aluminum in its products, as the economic downturn of 2008 reduced the price of copper and the predicted risk situation disappeared. Company 4 eventually exercised its strategic option, which was created by the creation of an own internal competence, by completely in-sourcing glass manufacturing and backwards integration of this technological competence, because the predicted risk of the decay of the local supplier base realized. The Company 22 also shelved its mini-mill project as scrap-steel and energy prices increased dramatically due to increasing Chinese demand for steel and the limited potential for further quality and performance improvements of mini-mill technology. It is important to state that in most identified cases of non-occurrence of *possible risks*, the prepared contingency plans are not completely abandoned but usually shelved and remembered within the organization, as the same or similar risk situations may emerge in the future. Another paraphrased case from the collected interview data where the response to a *possible risk* followed a *predict, prepare & enact pattern* is reported in Case vignette 6-20.

Case vignette 6-20: #13 Company 18: Energetic versus enzymatic technology for bio-fuel production as a by-product of paper production.

Company 18 follows a clearly formulated technology strategy, which is focused on the mastering of all technologies along the complete value chain from wood and resource production to the final consumer of business paper products. This includes the exploitation of by-products of the whole value adding process. Bio fuel production and building the capabilities to do so therefore became part of the intended technology strategy of Company 18. Company 18 insured this commitment to enter bio fuel production and to integrate this complementary process to its plants and mills by R&D investments in two competing process technologies to produce bio fuel as a byproduct of the paper manufacturing process. Although the decision to enter the emerging bio *fuel industry was made, it was unclear if either energetic or enzymatic-based technologies will be better for Company 18 and which technology will emerge as a dominant standard. While there were rational preferences and tendencies towards one technology, the decision seemed too important but also too risky for a single bet on one technology. The first best decision was therefore hedged by a parallel initiative to allow for a later correction if necessary. Company 18 predicted the possible risk situation of adopting the wrong technology when entering bio fuel production. It prepared itself by a parallel project on an alternative technology and is waiting with the final commitment until the risk situation is resolved. The technology strategy of Company 18 regarding this possible risk is following a predict, prepare & enact pattern.*

When incidents of technology turbulence create a possible future risk situation for a company, the companies generate strategic options, which have the character of designated insurances for these risks. If the risk occurs, the execution of this strategic option allows a correction of the initial and insured decisions by a second alternative. Table 6-15 is using the already introduced three cases to derive some general attributes of strategic options for *possible risk*.

Table 6-15: Strategic options to create insurance for possible risks.

	Strategic Options for Possible Risks		
Company	Company 1	Company 4	Company 22
Possible Risk	Risk of rising world market price for currently employed material resource.	Risk of the decay of the local glass manufacturing industry for industrial applications.	Risk of disintegrated mini mill process technology for high quality and requirement applications.
Timing of Initial Perception	Before occurrence.		
Quality of Perception	Medium.		
Goal of Strategic Option	Insurance of the organization for a possible risk occurrence by its intended technology strategy.		
Creation of Strategic Option	Preparing by engineering and testing of an aluminum electro engine which completely substitutes copper.	Preparing by partial vertical upstream integration by building internal technological know-how in glass and quartz manufacturing and processing.	Starting of own mini-mill development program to evaluate further possibilities and preparation of investment commitment.
Scope of Strategic Option	Designated contingency option, if identified and specific risk is occurring.		
Exercise of Strategic Option	If copper prices continue to increase the conventional copper engine can be substituted by the fully prepared and tested aluminum engine.	Although it was preferred to source the necessary glass externally, the situation in the supplying industry made it necessary to fully integrate the supply as an in-house activity.	If indicated by scrap steel prices and energy prices and improving performance of mini-mill technology, realization of prepared investment program
Linkage between Creation and Exercise	Specific but deferred and partly reversible commitment decision integrated into strategic agenda of intended technology strategy.		
Exercising Trigger	Copper and aluminum prices.	Product quality and reliability of supplier base.	Scrap steel and energy prices and performance of mini-mill technology.

	Strategic Options for Possible Risks
Ex ante Determinability and Traceability of Trigger	Easy – Indicators and conditions for exercising strategic options are known ex ante and easily observable.
Impact on Intended Technology Strategy	Protecting – Exercising allows changing an element of the intended technology strategy to protect the overall intended technology strategy when anticipated risks occur.
General Characteristic of Created Flexibility	Committed to the existing overall goals and strategies of an organization and specific to an identified risk situation with only limited direct use if the risk does not occur.

In all three cases the companies decided to insure their overall intended technology strategy for an identified future risk situation by a designated strategic option. Company 1 is preparing the technological feasibility to substitute copper as a necessary material in its products by aluminum. If the copper price is continuing to increase, this *insurance* allows switching to aluminum. Company 4 creates an internal glass manufacturing competence as *insurance* for the case that the existing supplier base becomes unreliable. Company 22 insures its intended technology strategy for the risk of a necessary substitution of one of its technological core processes. The goal of these strategic options is to have an adequate *insurance*, if the identified risks occur. Like a real insurance, these strategic options are specific for a certain identified risk. For example, fire insurance for a residence won't help in the case of a sports injury of the owner of the residence. The necessity when to exercise one of these strategic options is usually quite obvious. Company 1 can track the copper price on the world market, as Company 4 can track the condition of its supplier base. The flexibility created by *insurance options* is also committed to the current goals and intended strategies of the organization and specific to an anticipated risk situation which threatens them.

6.3.2 Anticipate, Preempt & Align Pattern for Known Unknowns

The identified dynamic pattern, which is observable in technology strategies of organizations when they are facing *known unknowns*, can be described in three rough phases:

- *Anticipating* a future incident of technology turbulence without full insight on its potential impact and an adequate response by the organization.
- *Preempting* the incident of technology turbulence to create additional insight by actively or passively following its further development in the intended technology strategy.
- *Aligning* of the preempting activities within the intended technology strategy, if resolving ambiguity allows more specific commitments.

This dynamic pattern was identified in analyzing responses in technology strategy of organizations when facing *known unknowns*, either *imaginable scenarios* or *weak signals*.

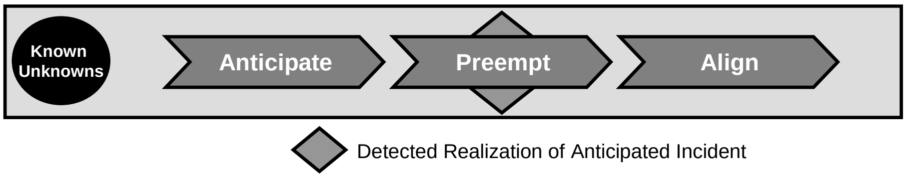


Figure 6-10: ***Identified dynamic pattern in technology strategy when facing known unknowns.***

6.3.2.1 Strategic Options for Imaginable Scenarios

Figure 6-11 is using paraphrased and interpreted data form the interviews to document the emergence of the *anticipate, preempt & align pattern* from the qualitative data for the cases that were already introduced in chapter 6.2. The paraphrasing and interpretation of all 23 incidents interpreted as *imaginable scenarios* can be found in the attachment (see Appendix D).

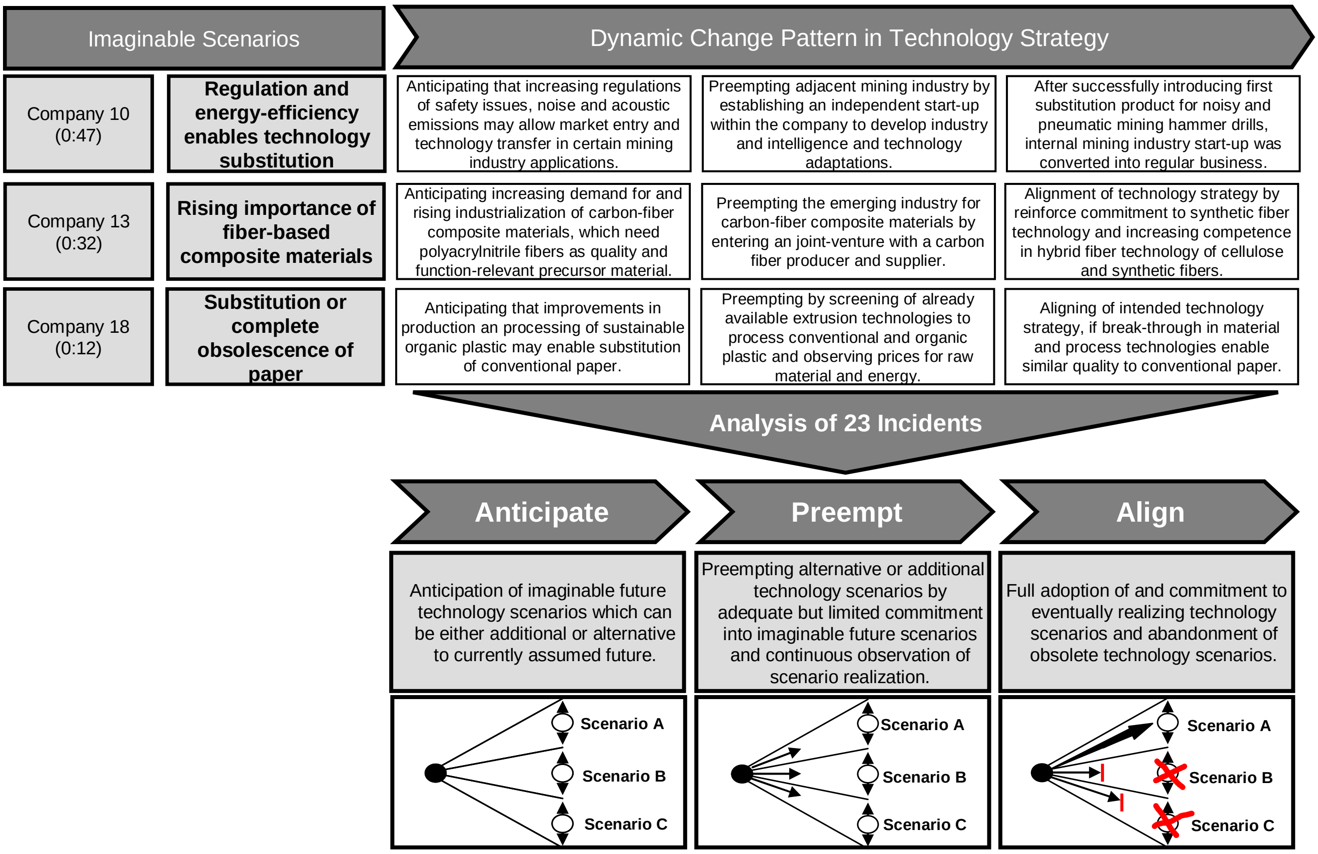


Figure 6-11: ***Anticipate, preempt & align pattern in technology strategy of organizations when facing imaginable scenarios.***

By analyzing the reported behaviors of companies triggered by 23 incidents that were interpreted *as imaginable scenarios*, the *anticipate, preempt & align pattern* was identified. In these cases technology turbulence is perceived as either alternative or additional technology scenario for the future. Although anticipated, it creates ambiguity for the organization, because different versions of the future are imaginable. For Company 10 the successful establishing as a tool supplier for the mining industry was an additional vision for the future. Company 13 could imagine itself as a future supplier for the emerging and fast growing carbon-fiber composite material industry, while Company 18 could imagine its own future obsolescence, as its product may become substituted. Although a scenario is a consistent and plausible picture of the future, the ambiguity on if, how, when and why a scenario realizes, keeps these companies from full commitments. Instead, the studied companies preempted the *imaginable scenarios* with parallel initiatives of limited commitment. While Company 10 established an internal start-up organization with limited resources to pursue and prepare a market entry and to adapt its existing technology for this new industry, Company 13 entered a joint-venture to establish a position in the constituting carbon-fiber industry. Company 18 prepares a specific involvement into sustainable organic resources and the necessary process technologies. While all these steps initiate an involvement into these i*maginable scenarios*, which somehow correlates with perceived probabilities and level of urgencies related to these scenarios, these involvements are of limited commitment and specificity. If an imaginable scenario is realizing, the preemptive actions allow involved companies to align their technology strategies by gradually changing the intensity and specificity of their commitments. After first businesses signaled a possible technology substitution of product technology in the mining industry, the internal start-up organization was converted into a regular business of Company 10 with the full commitment of the overall organization. Company 13 and Company 18 are both able to align their preemptive initiatives, if the imaginable scenarios become obsolete or more realistic. Case vignette 6-21 is reviewing another case from the interview data, how a company is handling an *imaginable scenario*.

Case vignette 6-21: #4 Company 4: Potential substitution of core product technology.

Company 4's success is partially based on the mastering of a specific methodology (oscillating U-tube) to measure density of liquids and gases and the integration of this methodology in the manufactured laboratory and industrial equipment. The technology for this measurement process was innovated and industrialized by Company 4 for specific industrial applications and is still implemented in many of its existing core product. Company 4 anticipated that increasing technological progress, miniaturization, simplification and commoditization of other and more recent measuring techniques may be able to substitute the functionality of the oscillating U-tube technique. Although Company 4 had no internal competence, near-infrared spectroscopy (NIR spectroscopy) was perceived as technology, which allows a more comprehensive analysis of liquids and gases based on different scientific principles. The anticipation of the imaginable scenario that Company 4's core technology may become substituted by a different technology triggered a reaction within its intended technology strategy. Company 4 preempted this imaginable scenario by investing in high-end NIR spectroscopy equipment to explore the overall feasibility and specific enabling or disabling factors for the application in Company 4's markets and products. Although the bulk NIR spectroscopy equipment was initially far away from industrialization in Company 4's products in terms of size and costs, Company 4's preemptive initiatives embraced the technology and began to push its further development. The anticipation and preemption of a threatening scenario enabled Company 4 to turn a potential substitution technology *into complement for Company 4's existing core technology. Eventually the preemption of NIR spectroscopy by a significant but limited first investment has lead to an alignment of Company 4's technology strategy over time. The technology strategy of Company 4 after anticipating an imaginable scenario showed a dynamic anticipate, preempt & align pattern.*

When incidents of technology turbulence are anticipated as *imaginable scenarios*, companies use strategic options to preserve the right to be part of this scenario, if it eventually realizes. These strategic options create adequate levels of *involvement* in each scenario. This adequate involvement is usually determined by preference, pragmatic appraisal and available resources. Table 6-16 is characterizing strategic options for the already introduced cases of *imaginable scenarios*.

Table 6-16: Strategic options to create involvement for imaginable scenarios.

	Strategic Options for Imaginable Scenarios		
Company	Company 10	Company 13	Company 18
Imaginable Scenario	Increasingly restrictive legal regulation and sensitivity for energy-efficiency as enabler of technology substitution on adjacent market.	Rising importance, demand, industrialization and mass-production of fiber-based composite materials.	Diverse substitution and obsolescence scenarios for uncoated fine paper.
Timing of Initial Perception	Before occurrence.		
Quality of Perception	Low		
Goal of Strategic Option	Adequate involvement of an organizing in imaginable scenarios by its intended technology strategy.		
Creation of Strategic Option	Preempting unknown but adjacent mining industry by establishing an independent start-up within the company to develop industry and intelligence and technology adaptations.	Preempting the emerging industry for carbon-fiber composite materials by entering a joint-venture with a carbon fiber producer and supplier.	Preempting by screening of already available extrusion technologies to process conventional and organic plastic and observing prices for raw material and energy.
Scope of Strategic Option	Designated but broad initiatives for a scenario with specifying scope parallel to increasing insight.		
Exercise of Strategic Option	After successfully introducing first substitution product for noisy and pneumatic mining hammer drills, internal mining industry start-up was converted into regular business.	Alignment of technology strategy by reinforcing commitment to synthetic fiber technology and increasing competence in hybrid fiber technology of cellulose and synthetic fibers.	Aligning of intended technology strategy, if break-through in material and process technologies enable similar quality to conventional paper.
Linkage between Creation and Exercise	Cumulative and path-dependent decisions based on additional insight and only generally specified in the intended technology strategy.		
Exercising Trigger	First successful businesses of internal start-up in mining industry.	Take-off and industrialization of carbon-fiber industry.	Starting of significant substitution process of conventional paper.
Ex ante Determinability and Traceability of Trigger	Difficult – Indicators and conditions for exercising strategic options are not exactly known ex ante and are often difficult to recognize.		
Impact on Intended Technology Strategy	Refining – Exercising of strategic option refines the intended technology strategy in areas of low initial expertise and specificity.		

	Strategic Options for Imaginable Scenarios
General Characteristic of Created Flexibility	Committed to the existing overall goals and strategies of an organization and specific to the anticipated scenarios with only limited direct use if the scenario does not realize.

Company 10 regarded the limited commitment of an internal start-up organization as an adequate *involvement option* for the imaginable entry into the unknown mining industry. Company 13 is employing the limited commitment of a joint venture organization as an *involvement option* on the participation in the emerging carbon-fiber industry. Company 18 uses limited resources in research projects and partnerships as an adequate involvement in the imaginable substitution of paper by new materials. These companies regard limited commitments as *involvement options* in *imaginable scenarios*. As *imaginable scenarios* become more dominant or obsolete over time, the relevant companies adapt their level of involvement continuously. Some *involvement options* are downsized, suspended or abandoned, and some are intensified or exercised. As the increasing dominance or obsoleteness of an anticipated scenario is very often a gradual process and not a discrete event, the continuous adaption of *involvement options* allows a gradual alignment of the pursued technology strategy. While the generated *involvement option* may be specific and designated to a certain future scenario, there may be strategic initiatives, which allow an involvement in two or more scenarios. These *no-regret-moves*, which are adequate for different scenarios, allow an increased and more general scope of *involvement options*. The recognition, if an *involvement option* should be exercised, is usually more difficult and not limited to just watching one critical indicator in the organizations business environment. As imaginable scenarios are usually constituted by a complex combination of various conditions, the realization or obsoleteness of a scenario may be difficult to observe.

6.3.2.2 Strategic Options for Weak Signals

Figure 6-12 is applying the same concept to incidents, which were characterized as *weak signals*. Although the content differs as the quality of perceptions is changing, the analysis of all 19 incidents confirms the *anticipate, preempt, & align pattern* for *known unknowns* in technology strategy. The paraphrasing and interpretation of all 19 incidents interpreted as *weak si*gnals can be found in the attachment (see Appendix D).

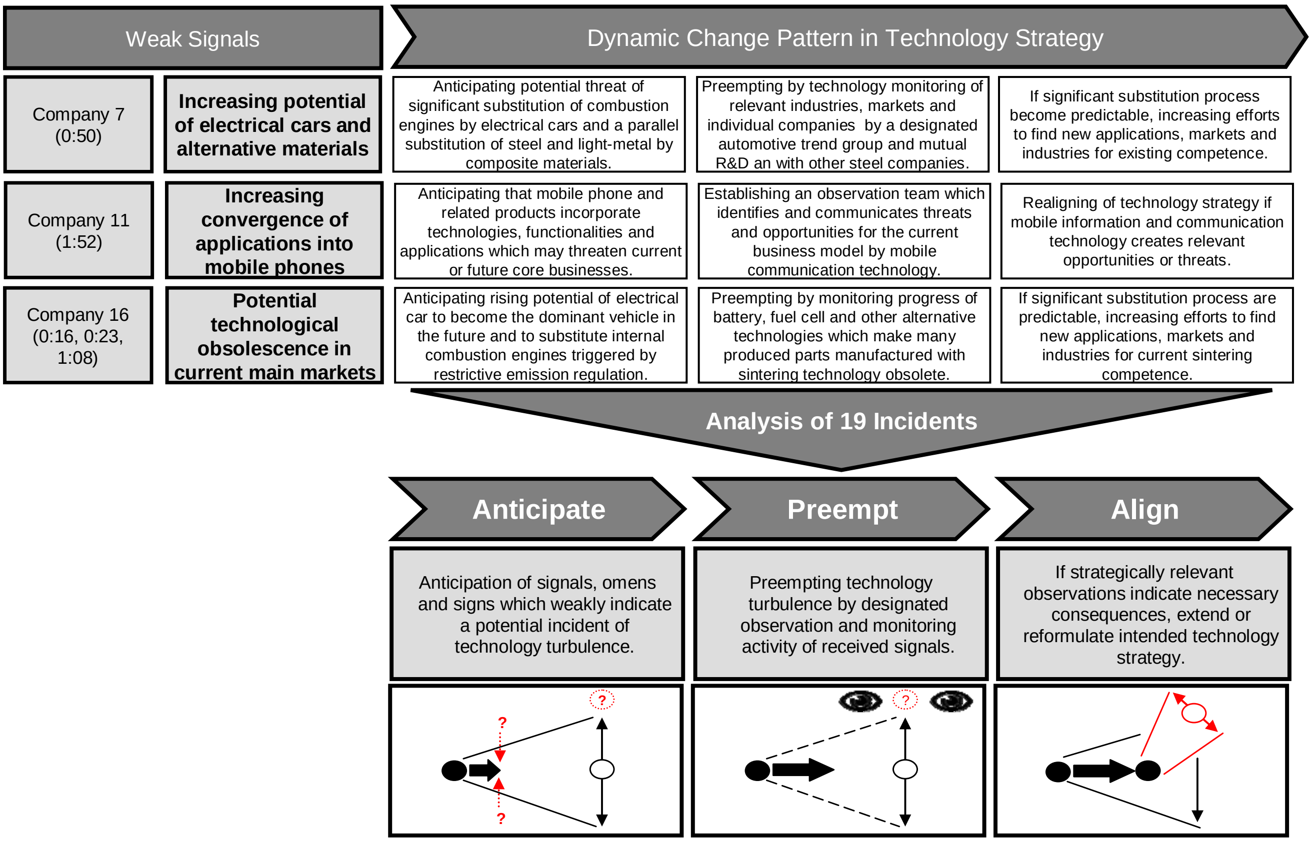


Figure 6-12: ***Anticipate, preempt & align pattern in technology strategy of organizations when facing weak signals.***

All three cases in Figure 6-12 were interpreted as a *weak signal*. The involved companies anticipated signals, signs or omens, which indicate potential sources of technology turbulence. Although the incident is anticipated by the company before its occurrence, the level of ambiguity within the company is very high. The *weak signal* only indicates a potential source of future technology turbulence without any specific details on its relevance for the involved organization. Company 7 and Company 16 receive *weak signals* from downstream markets that their product technologies might be threatened and Company 11 is alerted by a *weak signal* from the consumer markets of mobile electronic devices. Similar to *imaginable scenarios*, the high level of ambiguity does not allow that the involved companies commit to an immediate pursuit of *weak signals* in their currently intended technology strategy. But the potential future threats or opportunities indicated by *weak signals* justifies the preemption by either more active or passive forms of observation of the emitting source of the perceived signals. Company 7 has created a trend observation team for one significant downstream market from which they perceive weak signals for technology and material substitution. Company 11 installed designated monitoring activities for the consumer markets of portable digital devices and their technological and functional development. Company 16 installed a technology intelligence function with the assignment to monitor development and break-troughs in battery and fuel cell technology. If these observation activities reduce the ambiguity on the weak signals over time, the relevant companies can align or reformulate their intended technology strategies. If *weak signals* disappear, the preemptive activity can be suspended or abandoned. If a decrease in ambiguity indicates the occurrence of technology turbulence, the intended technology strategy will be aligned accordingly.

Case vignette 6-22: #14 Company 17: Possibilities for wire-less and decentralized energy supply in buildings by fuel cell technology.

Company 17 is manufacturing electric and electronic installation equipment for industrial and private home applications (e.g. switchgears, boxes, boards and circuit breakers). Enabled by digitalization, miniaturization and technological progress in communication and sensor technologies, the company is confronted with the convergence of various and formerly independent functions, applications and technologies in functional and private buildings. There are multiple, possible applications in private households or in the refurbishment of existing buildings by the integration of alarm, air condition, heating, shading, multi media, kitchen, gardening, power supply, communication, internet, surveillance and lighting functions in one control system. Company 17 realigned its strategy and entered necessary technology fields to prepare for this convergence and diffusion of new technologies into conventional households. While business development is in process, first elements of the new strategy are already successfully adopted and realized, like wireless light switches. This wireless technology allows to position or reposition the light switch easily and more flexible. Although the activation of light by wireless switches reduces the necessity for some wire and cable installation, the energy supply itself is distributed by a fixed cable installation. Company 17 anticipated that local, miniaturized and independent sources of power supply could completely substitute fix cable and wire installation and would be a complement to wireless control systems. Progress in performance, size and weight of battery and fuel cell technology and reduced power consumption by diverse electrical installations are interpreted as weak signals by Company 17. To monitor and observe the current state of the art and future progress of these new technologies and possible household applications, Company 17 entered a shared and publicly subsidized research project together with other companies and research institutions. While this long-term research project will not develop a ready-to-build product for the company, Company 17 is using this low-commitment participation in the project as possibility to follow new developments. Although battery and fuel cell technology are not part of the company's intended technology strategy and are beyond its scope and resources, the company decided to passively follow these technologies. This approach reflects a dynamic anticipate, preempt and align pattern in technology strategy when facing weak signals.

In many cases, future incidents of technology turbulence are initially perceived as *weak signals*. In these cases involved companies reserve the right to act on these *weak signals* by creating an *intelligence option*. *Intelligence options* on *weak signals* are created by adequate observations and monitoring activities of the sources of emitted signals. If *weak signals* are indicating future technology turbulence an *intelligence option* generates the ability to follow current and future developments and to gather real-time information on the anticipated incident. Table 6-17 is identifying strategic option for the already introduced cases of *weak signals*.

Table 6-17: Strategic options to create intelligence for weak signals.

	Strategic Options for Weak Signals		
Company	Company 7	Company 11	Company 16
Weak Signal	Increasing potential of electrical cars and alternative materials in the automotive industry.	Increasing convergence of functionalities and applications into mobile phones and mobile digital devices.	Substitution of conventional internal combustion engines by alternative engine systems.
Timing of Initial Perception	Before occurrence.		
Quality of Perception	Very low		
Goal of Strategic Option	Real-time intelligence on incidents anticipated as weak signals.		
Creation of Strategic Option	Preempting by technology monitoring of relevant industries, markets and individual companies by a designated automotive trend group and mutual R&D and with other steel companies.	Establishing an observation team which identifies and communicates threats and opportunities for the current business model by mobile communication technology.	Preempting by monitoring progress of battery, fuel cell and other alternative technologies which make many produced parts manufactured with sintering technology obsolete.
Scope of Strategic Option	Designated but very broad and unspecific monitoring activities for weak signals.		
Exercise of Strategic Option	If significant substitution process becomes predictable, increasing efforts to find new applications, markets and industries for existing competence.	Realigning of technology strategy if mobile information and communication technology creates relevant opportunities or threats.	If significant substitution process are predictable, increasing efforts to find new applications, markets and industries for current sintering competence.
Linkage between Creation and Exercise	Cumulative and path-dependent decisions based on additional insight and only generally specified in intended technology strategy.		
Exercising Trigger	New relevant insights on or confirmation of an incident anticipated as a weak signal.		
Ex ante Determinability and Traceability of Trigger	Difficult – Indicators and conditions for exercising strategic options are not exactly known ex ante and are often difficult to recognize.		
Impact on Intended Technology Strategy	Successive – Exercising of option initiates a realignment or reformulation of intended technology strategy which orderly completely or partly replaces the existing one.		
General Characteristic of Created Flexibility	Opportunistic regarding the existing overall goals and strategies of an organization and generic regarding the eventually realizing incident.		

In all three cases an *intelligence option* was created by establishing an active or passive monitoring activity. Although the *intelligence option* is established because of an anticipation of a weak signal, its scope is usually broad. Because the quality of perception is low and the resulting ambiguity for the organization is high in the case of weak signals, the scope of an *intelligence options* usually covers the complete source of weak signals, if already identified. In the case of Company 7 a designated trend group was established with a broad intelligence assignment on a complete industry. Although not exactly knowing what there are really searching for, Company 11 is watching the consumer market of mobile digital devices. Company 16 is scanning emerging alternative technologies, which may threaten downstream markets of its current customers. Unlike *immunity, insurance and involvement options*, there is no ex ante determination when to exercise an *intelligence option*. The reasons and conditions for reformulating the intended technology strategy by exercising the established *intelligence option* are unpredictable and cannot be integrated in any what-if automatic of an intended strategic agenda. New relevant insights enabled by the generated *intelligence option*, may trigger various forms of necessary reactions. Although the exercising of an *intelligence option* may imply a realignment or reformulation of the currently intended technology strategy, it does usually not affect the actual realization of a pursued technology strategy. In this regard, the *intelligence option* can be seen as the ability to successfully recognize when the initially intended technology strategy has to be reformulated by taking into account the gathered insights on received *weak signals*.

6.3.3 Sense, Respond & Renew Pattern for Unknowns

The identified dynamic change pattern in technology strategy when organizations are facing the unanticipated occurrence of technology turbulence consists of these three distinguishable phases (see Figure 6-13):

- *Sensing* the realization of an incident of technology turbulence and its impact on the organization.
- *Responding* to the occurrence by immediate and designated initiatives to address resulting threats and opportunities in the currently realizing technology strategy.
- *Renewing* the initially intended but obsolete technology strategy and by considering the occurrence of and immediate response to the unanticipated incidents of technology turbulence.

This third basic pattern was identified in studying the behavior of involved companies when facing the occurrence of the reported 26 unanticipated incidents, both *sudden emergencies* and *converging evolutions*. The paraphrased and interpreted data for all 26 incidents can be found in the attachment to this thesis (see Appendix D).

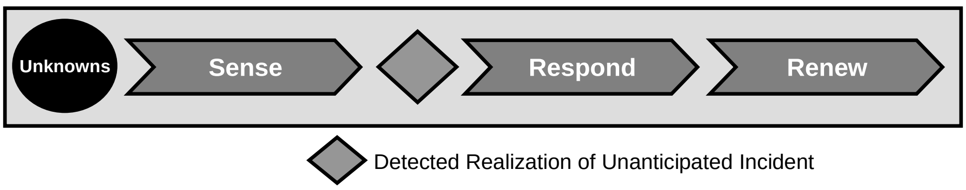


Figure 6-13: Identified dynamic pattern in technology strategy when facing unknowns.

6.3.3.1 Strategic Options for Sudden Emergencies

Figure 6-14 is showing the paraphrased and interpreted data of three reported incidents categorized as *sudden emergencies*. The paraphrased interview data for all incidents labeled as *sudden emergencies* can be found in Appendix D.

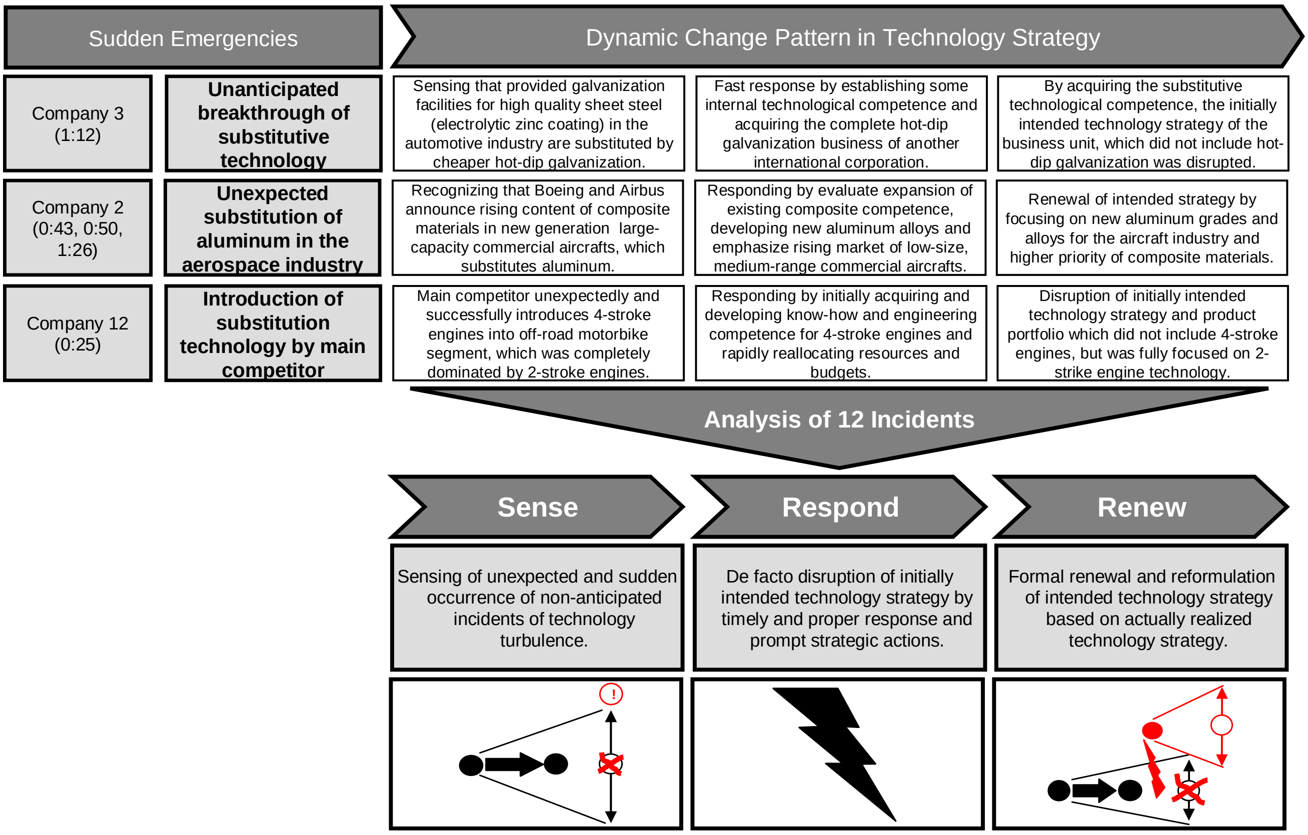


Figure 6-14: ***Sense, respond & renew pattern in technology strategy of organizations when facing sudden emergencies.***

In all three cases, which are shown in Figure 6-14, an unanticipated incident occurred and required immediate attention and a timely and proper response. Company 3 was surprised by an unexpected break-through of a substitution technology which allowed Company 3's customers an adoption of the competing technology. Company 2 was confronted with the surprising announcement that two key accounts in commercial aircraft manufacturing are adopting composite materials as substitution for aluminum. Company 12 experienced an unanticipated introduction of a substitution technology by a direct competitor in its current core market. The studied companies, confronted with an incident perceived as *sudden emergency*, responded by prompt strategic actions, which eventually disrupted the existing intended technology strategy. Company 3 never intentionally intended to enter hot-dip galvanization technology before the technology was perceived as a *sudden emergency*. Company 2 was not seriously thinking about entering composite materials and Company 12 was not prepared to enter 4-stroke gasoline engine technology. Their decision to do so was quite contrary to their initially intended technology strategy. Following the de-facto change of the technology strategy by prompt actions, the companies formally renewed the intended technology strategy. The external sourcing of technological competence via merger and acquisition activities by Company 3 or the prompt installation of new internal high priority projects by Company 12 have to be reflected in a new or significantly changed strategic agenda. Another paraphrased case of the response to a *sudden emergency* from the collected interview data is reported in Case vignette 6-23.

Case vignette 6-23: #4 Company 6: Unexpected quasi-standardization of particle filter as mandatory add-on technology for diesel engines.

Company 6 responded promptly when the European Union, unexpected by Company 6, adopted the concept of particle filters for car diesel engines in their emission legislation. Initially Company 6 was focused to realize the demanded emission reduction of particles by sophisticated engine and combustion modification within the engine. Especially Company 6's main customers in the German automotive industry preferred the reduction of emissions by avoiding producing it in the first place. While these optimizations of engine control systems and the combustion process within the engine demanded superior engineering skills and equipment, as provided by Company 6, it was also argued, that no additional add-on component as a filter would be necessary. It was the dominant opinion that the particle filter will make the already complex diesel engine even more expensive and that a filter in the exhaust system of the engine could imply negative effects on the whole engine system. French original equipment manufacturers always had a significant market position in small diesel engine cars but intended to reduce the particle emission by particle filter technology. As the relevant European and national regulation authorities recognized that more restrictive emission limits are possible by the deployment of add-on particle filters, they enacted future thresholds, which made particle filters mandatory and without alternative in the future. Company 6's initially intended technology strategy for diesel engines, which specifically avoided the add-on solution of a particle filter was disrupted by this development, as adopting particle filter technology was without any alternative. Induced by these unexpected technological implications, Company 6 promptly reallocated internal engineering resources and rapidly developed an internal competence in particle filter technology. When particle filter eventually became state of the art, Company 6's earlier efforts to reduce particle emission without any filter turned out to be advantageous. As emission legislation became even more restrictive, today's requirements of combined consumption and emission reduction for diesel car engines and acceptable durability of particle filters is only possible with a concerted system of sophisticated engine control systems, particle filter and optimized internal combustion. With the rapid response to the surprising but mandatory adoption of particle filters in the industry, Company 6 had to ignore its initially intended technology strategy. The response to this sudden emergency in the realized technology strategy followed a dynamic sense, response & renew pattern.

The analysis of how companies handled unanticipated *sudden emergencies* after detection, allows identifying the underlying strategic option. By definition, the surprising character of *sudden emergencies* does not allow any specific and designated proactive measures, but demands a more general preparation to enable a timely and proper response for unanticipated incidents. This general preparedness of the organization for unanticipated but strategically relevant changes in the technology context creates the option to be inducible for an adequate response. Table 6-18 summarizes three examples from the empirical data.

Table 6-18: Strategic options to create inducibility for sudden emergencies.

	Strategic Options for Sudden Emergencies		
Company	Company 2	Company 3	Company 12
Sudden Emergency	Unexpected massive substitution of aluminum in the aerospace industry by fiber-based composite materials.	Unanticipated breakthrough of substitutive product technology.	Unexpected introduction of substitutive product technology by main competitor.
Timing of Initial Perception	During / after occurrence.		
Quality of Perception	Prompt detection.		
Goal of Strategic Option	Inducibility for fast and adequate response to sudden emergencies.		
Creation of Strategic Option	General organizational preparedness for fast and adequate responses to unanticipated and sudden surprises in the technology context.		
Scope of Strategic Option	Very broad – No specific and designated measures for an incident.		
Exercise of Strategic Option	Responding by evaluate expansion of existing composite competence, developing new aluminum alloys and emphasize rising market of low-size, medium-range commercial aircrafts.	Fast response by establishing some internal technological competence and acquiring the complete hot-dip galvanization business of another international corporation.	Responding by initially acquiring and developing know-how and engineering competence for 4-stroke engines and rapidly reallocating resources and budgets.
Linkage between Creation and Exercise	Not integrated into current strategic agenda of intended technology strategy.		
Exercising Trigger	Detection of an unanticipated occurrence of a sudden incident in the technology context of an organization.		
Ex ante Determinability and Traceability of Trigger	Impossible – Indicators and conditions for exercising strategic options are highly individual and are not known ex ante.		
Impact on Intended Technology Strategy	Partly or complete disruption of currently pursued intended technology strategy by exercising strategic option.		
General Characteristic of Created Flexibility	Opportunistic regarding the existing overall goals and strategies of an organization and generic regarding the eventually realizing incident.		

All three reported events represent unanticipated incidents which demand a timely and proper response. In the case of *sudden emergencies* the creation of strategic options is basically distinguished in the established ability to handle any unanticipated but strategically relevant incident and the specific recognition that the occurrence of an incident demands immediate and specific actions. Company 2 immediately understood that it has to response to the announcement that commercial aircrafts manufacturers prefer composite materials over aluminum for future aircrafts. Company 3 was immediately aware that it has to adopt hot-dip galvanization somehow. Company 12 did instantly recognize that has to introduce 4-strike engines technology as soon as possible. Additionally to this ability to see the necessity to act, these companies had also the general organizational ability to do so promptly. Unlike *intelligence options* for *weak signal's,* which allow a company to orderly reformulate its intended technology strategy based on new insights, an *inducibility option* allows a company to act immediately and to disrupt parts of its intended technology strategy, which was originally pursued. The *inducibility option* can be described as the right but not the obligation to ignore the intended technology strategy partly or completely if *sudden emergencies* demand to do so. The *inducibility option* creates an opportunistic and very generic flexibility, which is independent from the existing goals and strategies of the organization and a specific incident.

6.3.3.2 Strategic Options for Converging Evolutions

Figure 6-15 shows the emergence of the *sense, respond & renew* pattern for incidents, which are perceived as *converging evolutions*. Although the pattern is the same, the emphasis and criticalness within the dynamic pattern is different. Sensing *sudden emergencies*, which in many cases become quite obvious to the affected company at the very moment they occur, is easier than sensing the convergence of independent and often non-obvious developments in- and outside the organization. The proper and timely response seems more critical in the case of *sudden emergencies*. Nevertheless, the identified dynamic pattern in the technology strategy of organization when facing converging evolutions is basically the same.

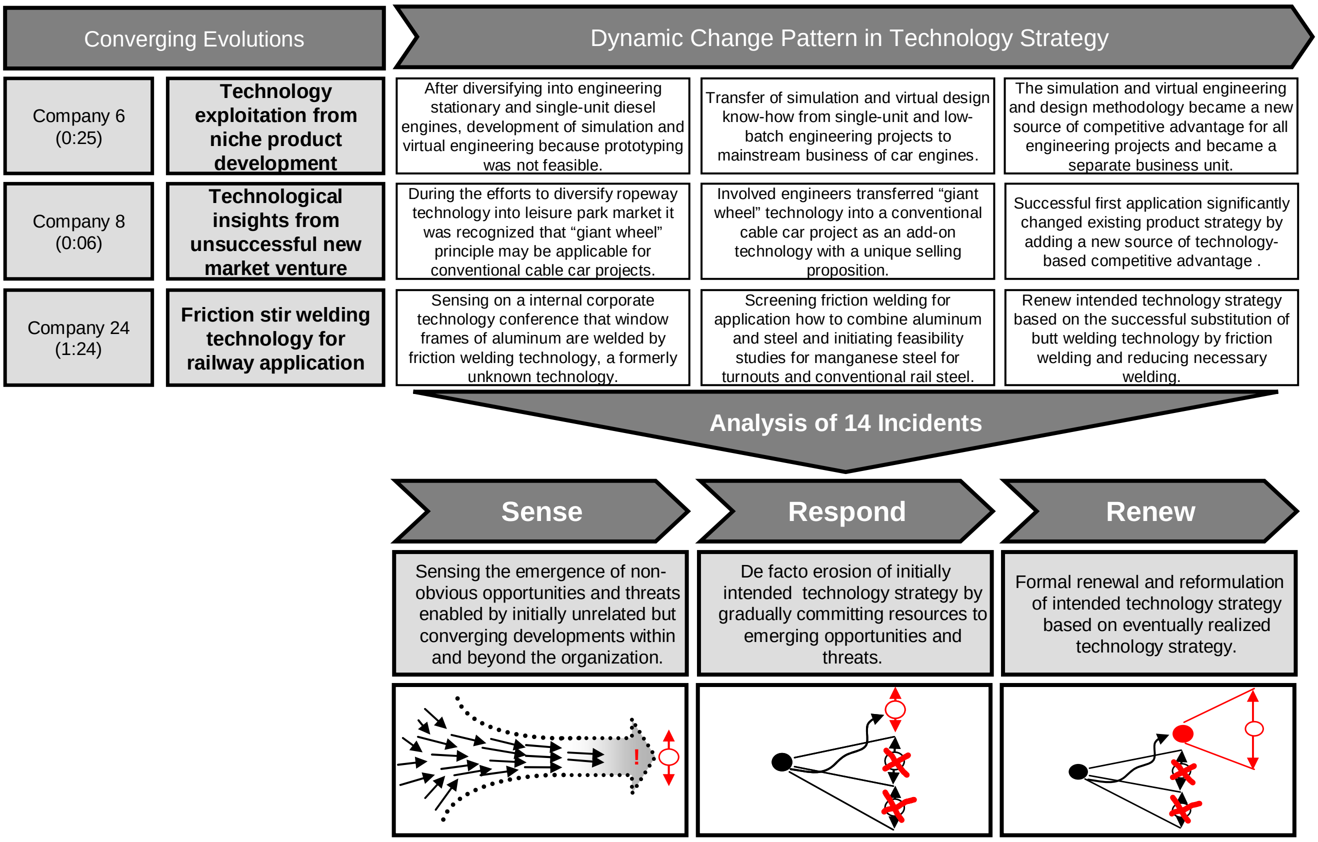


Figure 6-15: ***Sense, respond & renew pattern in technology strategy of organizations when facing converging evolutions.***

In all three cases, summarized in Figure 6-15, the incident was not anticipated or addressed in any intended technology strategy. Company 6 never specifically intended to become a provider of advanced simulation software technology, Company 8 never intended to transfer a technological concept from theme parks into its core markets, and Company 24 had initially no idea that there is a welding technology from a non-related industry with high potential for Company 24's core business. In all three cases initially unrelated activities and developments of the company enabled that involved employees with necessary expertise and organizational power sensed and surfaced an emerging opportunity. The initial response to this emerging opportunity by the involved organization was never part of the intended technology strategy, but developed in a process of gradual and alternating detection and response. Company 6 transferred the developed simulation techniques, tools and applications from its niche markets to its core markets and eventually established a completely new business unit to exploit these new technologies externally. Company 8 transferred a rejected construction design from a failed new market venture into a core market project, which turned out as a significant innovation and success. Company 24 is gradually embracing the identified welding technology and its new technology strategy to industrialize the new welding process for Company 24's applications. Another case of how the gradual detection of *converging evolutions* of initially unrelated developments changed the initially intended technology strategy of an organization is reported in Case vignette 6-24.

Case vignette 6-24: #9 Company 12: Unexpected opportunity for technology exploitation of unsuccessful technology and product development project.

The increasing success of All Terrain Vehicles (ATVs, Quads) of North American and Japanese manufacturers caused Company 12, a successful producer of off-road and enduro sports motorbikes to start an engineering project to explore the possibility of entering the ATV business in Europe. For an experienced producer of off-road motorbikes, ATVs as a new product category seemed a natural and comprehensible extension for Company 12's core market and its engine and chassis engineering and manufacturing capabilities. While technological feasible and reasonable, Company 12 learned during the project that the possibilities for the use of ATVs in Europe are highly limited by restrictive admissions and environmental protection. It was recognized by Company 12 that the use of ATVs in its intended designation was often prohibited, especially in the targeted European markets, which could afford these kinds of leisure activities. Independent from the ATV project, Company 12 also entered the 4-stroke combustion engine technology and the street motorbike business. While 4-stroke engines increasingly substituted the 2-strokes engines, which were usually dominating the off-road segments, the entry into the street motorbike business demanded the integration of additional engineering capabilities to face different driving dynamics on streets, vehicle operation with a passenger and the more demanding safety and emission regulations for regular vehicles in public traffic. Although not regarded as success, the ATV project brought additional insights and know-how into chassis, auto body and lightweight materials technologies, which are necessary for four-wheeled vehicles. These independent developments to enter 4-stroke-engine technology, street motor bikes business, and four wheeled ATVs created the know-how and opportunity to engineer and manufacture a four wheeled, two seated, and ultra-light street sport car, called X-BOW. While never intended when starting the ATV project, these initially unrelated decisions lead to the diversification into a specific niche of the automobile industry as an OEM. Parallel and initially unrelated to these efforts, Company 12 also explored the substitution of combustion engines of its bikes by electric engines and battery technology. As the feasibility of this technology was already successfully demonstrated by prototypes of Company 12, the potential combination with the experience and know-how from the X-BOW vehicle offers Company 12 the opportunity to manufacture *light-weight, 4 wheeled, electrical cars and to eventually become an OEM for urban electrical cars in the long-term future. The ATV project as part of an intended technology strategy enabled the convergence of different projects, which cumulated in Company 12's decision to enter the automotive industry as an OEM in a niche market and created a further opportunities for the Company 12's future. If emission policies for urban city centers continue to become more restrictive, ultra-light vehicles with electrical engines may be a feasible alternative for individual urban traffic. The current option for Company 12 to exploit all this initially independent initiatives and to enter the automotive industry was created by the ability to recognize non-obvious opportunities. The intended technology strategy to enter the ATV business and to develop necessary products and technologies was eventually eroded by the realized strategy to build an urban sport vehicle. The realized technology strategy of Company 12 followed a dynamic sense, respond and renew pattern when responding to converging evolutions.*

Similar to the case of *sudden emergencies*, *converging evolutions* do not allow for any designated proactive measure. The only possible preparation is the creation and maintenance of the ability to stimulate and detect their emergence. This strategic option allows detection and response to the non-obvious occurrence of incidents, which are perceived as a convergence of initially independent developments. Table 6-19 lists three cases of the qualitative data which show the management of converging evolutions by strategic option.

Table 6-19: Strategic options to create illumination for converging evolutions.

	Strategic Options for Converging Evolutions		
Company	Company 6	Company 8	Company 24
Converging Evolution	Technology transfer from product development projects of large-scale and single-unit diesel engines into core business.	Unexpected technology transfer from unsuccessful new market venture in non-core market into core market.	Unexpected technology transfer of alternative welding technology for railway turnout applications.
Timing of Initial Perception	During / after occurrence.		
Quality of Perception	Gradual detection.		
Goal of Strategic Option	Illumination of the emergence of converging evolutions.		
Creation of Strategic Option	General preparation of the organization to detect and respond to the gradual emergence of converging evolutions.		
Scope of Strategic Option	Very broad – No specific and designated measures for an incident.		
Exercise of Strategic Option	Transfer of simulation and virtual design know-how from single-unit and low-batch engineering projects to mainstream business of car engines.	Involved engineers transferred "giant wheel" technology into a conventional cable car project as an add-on technology with a unique selling proposition.	Screening friction welding for application how to combine aluminum and steel and initiating feasibility studies for manganese steel for turnouts and conventional rail steel.
Linkage between Creation and Exercise	Not integrated into currently intended strategic agenda.		
Exercising Trigger	Detecting unanticipated convergence of initially unrelated initiatives and developments.		
Ex ante Determinability and Traceability of Trigger	Impossible – Indicators and conditions for exercising strategic options are highly individual and are not known ex ante.		

	Strategic Options for Converging Evolutions
Impact on Intended Technology Strategy	Partly or complete erosion of initially intended technology strategy by exercising strategic option.
General Characteristic of Created Flexibility	Opportunistic regarding the existing overall goals and strategies of an organization and generic regarding the eventually realizing incident.

Company 6's involvement in stationary diesel engines triggered the development of a front-loaded development and engineering process with reduced prototype phases. The shortening of product life-cycles of a car generation due to increasing competitive pressure demanded an accelerated engineering process for power train systems of cars. The involvement in and detection of this convergence of initially independent developments within Company 6 and within its business environment created the strategic option for Company 6 to transfer the developed front-loaded engineering process and its simulation and design tools to its core business of drive train systems for cars. Company 8's unsuccessful venture into leisure parks created a strategic option to transfer a detected technological concept, which was able to fulfill an unsatisfied requirement in its core market. Company 24's presence at an internal technology conference of its corporate organization created the option to detect a highly relevant but unknown process technology. While one could dismiss these incidents as pure coincidences and simple good luck, the preparedness and ability of the organization to provoke, recognize and respond to coincidences is at the very core of strategic options for *converging evolutions*. This *illumination option* can be described as the option of a company to ignore its currently pursued strategy by a gradual process of detection and response to initially unanticipated and unrelated developments within the company and its environment. The exercising of *illumination options* partly or completely erodes the initially intended technology strategy. The form of flexibility a company establishes by creating an *illumination option* is generic and opportunistic. Neither is it designated to a specific incident, nor is it bounded to initially existing goals and strategies of an organization. Company 24 could have detected a completely different technology or no technology at all at this internal conference. Company 8's leisure park venture was never intended to transfer technologies to its core market of cable cars. Company 6's efforts for stationary and large-scale diesel engines were not driven by the intention to enter the simulation software business.

6.3.4 Concluding Summary

Depending on timing and quality of perception of an incident of technology turbulence by a company, different dynamic change patterns in their technology strategy were identified. *Known knowns* are managed by a *predict, prepare & enact pattern* with the final commitment decision when either a predicted change is realizing or a forecasted risk is occurring. *Known unknowns* are managed by an *anticipate, preempt & align pattern* with the final commitment decision when an *imaginable scenarios* is realizing or a *weak signal* is successfully interpreted and positively confirmed. *Unknowns* are managed by a *sense, response & renew pattern* with a commitment decision after either a *sudden emergenc*y or *converging evolutions* was successfully detected. These identified dynamic patterns are summarized in Figure 6-16. This figure also assigns identified steps in the dynamic change patterns to the domains of initially intended technology strategy and eventually realized technology strategy. While predicting and preparing for future and understood strategically relevant change can be addressed in the intended technology strategy, the eventual final enactment of the preparation is triggered by the realization of a predicted incident. If the incident is not realizing, there is no final commitment and no enactment of the prepared strategy. In the case of incidents perceived as *known unknowns*, the pattern is shifting towards the domain of realized technology strategy. The phase of preemption can be interpreted as a bridge between the two domains, as commitments to imaginable scenarios and weak signals are more incremental and gradual decisions over time as scenarios become more dominant or obsolete and signals can be interpreted and finally confirmed. As *unknowns* are completely unanticipated but strategically relevant, they cannot be specifically addressed in any intended technology strategy but demand an immediate response in the realized technology strategy after their detection. Successful sensing of *sudden emergencies* and *converging evolutions*, which cannot be addressed in any form on the intended strategic agenda, allows a company to respond by an adequate and timely commitment as part of the realized technology strategy.

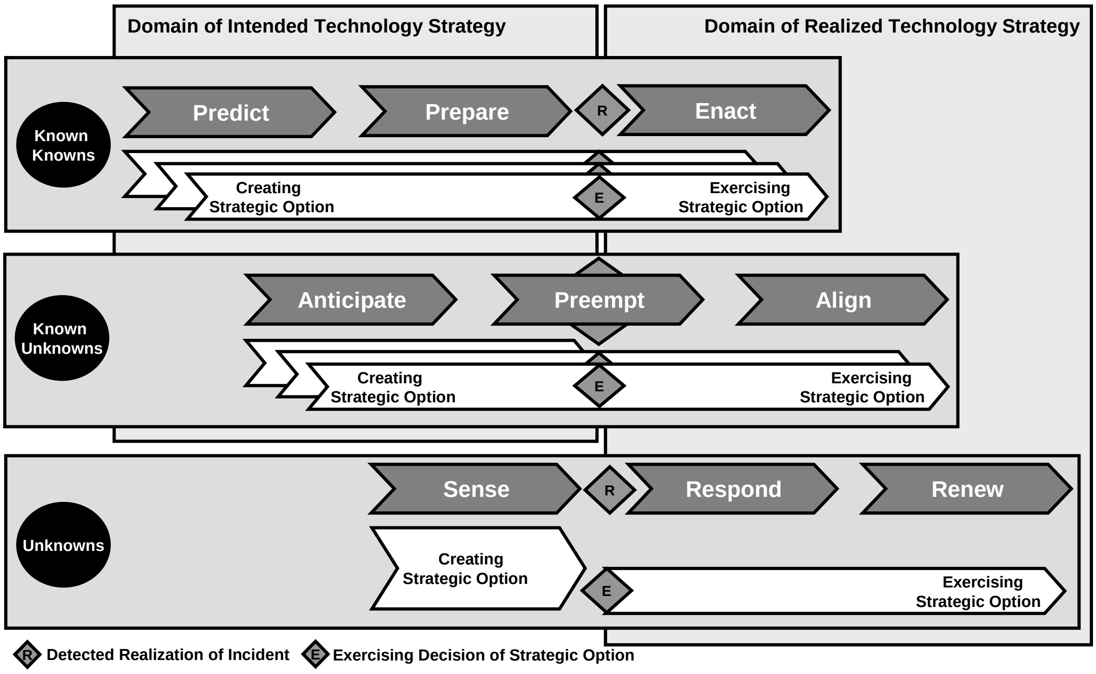


Figure 6-16: ***Realizing dynamic change patterns in technology strategy under technology turbulence by adequate alignment of strategic options.***

In chapter 3 strategic options were described as the right and ability but not the obligation to commit to certain decisions, which would affect the currently pursued strategy. Simplified and adopted to the domain of technology strategy, a strategic option is the right and ability but not the obligation to change the currently pursued technology strategy. The analysis and insights on incidents of technology turbulence, how companies perceive these incidents and how these incidents affected technology strategy when noticed, have two important implications. First, companies are confronted with good reasons in form of incidents of technology turbulence to commit to a new, different, additional or changed technology strategy. Second, depending on when and how good companies perceive these incidents, different dynamic patterns of strategic technology decisions are changing technology strategies. This confirms the general idea that in times of increasing non-sustainability of competitive advantage – in times of turbulence – the right and ability to change a strategy is something of increasing value for a company with the overall goal of survival and sustainability of its performance. This value of adequate strategic options is embedded in their functionality of creating a potential flexibility of choice and the ability to exploit this flexibility before it is actually needed.

Figure 6-16 suggests that the existence and ability to exercise strategic options, which are aligned with the perceived technology turbulence, enable dynamic change patterns in technology strategies of organizations. By studying the identified dynamic patterns of technology strategy when facing technology turbulence, it is concluded that these dynamic patterns are basically realized by adequate and aligned creation and execution of strategic technology decisions designed as strategic options. The underlying function of strategic options is to enable dynamic change patterns of in technology strategy over time, which allows organizations to respond to incidents in and adequate form and timing. *Known knowns* can be specifically addressed a set by designated strategic options within the intended technology strategy. As the quality of anticipation is high in the case of *known knowns*, it can be expected the many of these created strategic options are eventually exercised. As anticipated future changes in the technology context, *known unknowns* are also addressed by the creation of designated strategic options in the intended technology strategy. But these strategic options are of less scope and have an explorative character. It cannot be expected that all strategic options for incidents anticipated as *known unknowns* are eventually exercised. In the case of *unknowns*, no designated and specific strategic options can be created as a part of an intended technology strategy. Although unspecific and not designated for any later incident, the knowledge of a company that unanticipated incidents can occur and the general preparation for such incidents is interpreted as the creation of a strategic option to handle unanticipated changes. In all cases the alignment of the timing when to exercise a strategic option with the detected realization of an incident is what creates a state of strategic flexibility when needed.

Corresponding to the identified categories of technology turbulence, six different forms of strategic options were identified. Depending on the timing and quality of perception of an incident, companies create and exercise strategic options with different characteristics and goals. Table 6-20 is summarizing the identified attributes of theses strategic options.

Table 6-20: Strategic options for incidents of technology turbulence.

Strategic Option	Incident of Technology Turbulence	Timing of Initial Perception	Quality of Perception	Goal of Strategic Option	Scope of Strategic Options	Linkage between Creation and Exercise	Determinability and Traceability of Trigger	Impact on Intended Technology Strategy	General Character of Created Flexibility
Immunity Option	Probable Predictions	Before occurrence	High	Immunity for occurrence of predicted incident.	Very low	Integrated into intended strategic agenda.	Easy	Committing	Committed – Specific
Insurance Option	Possible Risks	Before occurrence	Medium	Adequate insurance for possible risk occurrence.	Low	Integrated into intended strategic agenda.	Easy	Protecting	Committed – Specific
Involvement Option	Imaginable Scenarios	Before occurrence	Low	Adequate involvement in realizing scenarios.	Medium	Integrated into intended strategic agenda.	Difficult	Refining	Committed – Specific
Intelligence Option	Weak Signals	Before occurrence	Very Low	Real-time intelligence on confirmed signals.	High	Beyond intended strategic agenda.	Difficult	Successive	Opportunistic – Generic
Inducibility Option	Sudden Emergencies	During/After occurrence	Prompt detection	Inducibility for fast response to sudden emergencies.	Very broad	Beyond intended strategic agenda.	Impossible	Partly or complete prompt disruption	Opportunistic – Generic
Illumination Option	Converging Evolutions	During/After occurrence	Gradual detection	Illumination of the emergence of converging evolutions.	Very broad	Beyond intended strategic agenda.	Impossible	Partly or complete gradual erosion	Opportunistic – Generic

Conclusion RQ 3: *Depending on the timing and quality of perception of incidents of technology turbulence, three dynamic change patterns in technology strategy over time were identified (see Figure 6-16). The identified dynamic change patterns in technology strategy are constituted by the creation and exercising of strategic options. The goal, content and scope of strategic options depend on the timing and quality of perception of an incident of technology turbulence (see Table 6-20). The temporal alignment with the perception and realization of incidents of technology turbulence and the adequateness of content and goal of strategic options is what creates the sate of strategic flexibility for the moment it is needed.*

6.4 A Conceptual Framework for Strategic Flexibility in Technology Strategy

Based on the analysis and interpretation of the interview data in the previous sections, a conceptual framework for strategic flexibility is developed, which reflects the identified forms of strategic flexibility in technology strategy when facing incidents of technology turbulence. The notion of strategic flexibility in technology strategy can be divided into two domains:

- The built-in strategic flexibility in the intended technology strategy, which is labeled *flexible technology strategy*.

- The strategic flexibility, which enables an organization to deviate from its intended technology strategy and which is labeled *technology strategy flexibility*.

When formulating an intended technology strategy, already anticipated future incidents of technology turbulence can be taken into account. Although they differ in predicted probability of occurrence, *probable predictions* and *possible risks* can be addressed in the intended technology strategy by *immunity* and *insurance options*, which enable a dynamic *predict, prepare & enact pattern* of technology strategy change over time. This *immunity* and *insurance options* are more ore less part of the core technology strategy of the organization. The adequate exercising or non-exercising of these options allow the enactment of a deliberate technology strategy, which is immunized for the occurrence of *probable predictions* and insured for the occurrence *possible risks*.

Although anticipated, the ambiguity created by *imaginable scenarios* and *weak signals* does only allow for a limited and gradual commitment within an organization's technology strategy. *Involvement options* on additional or competing scenarios create the possibility to gradually commit to realizing scenarios or to dismiss obsolete ones by exercising or non-exercising of these options. *Involvement options* can be seen as beachheads and literally serve as a bridge between the domain of intended technology strategy and realized technology strategy. A similar logic applies to *weak signal*. An intended technology strategy cannot ignore *weak signals*, which may be the first omens of an upcoming incident of technology turbulence. On the other hand, the analyzed incidents indicate that there is not much a company can really do about *weak signals* but to decrease ambiguity on it by an *intelligence option*. This is true whether a *weak signal* is prophesying an upcoming opportunity, threat or both. The exercising of *intelligence options* can be seen as the conscious decision to reformulate the intended technology strategy of the organization because new insights recommend doing so. *Involvement and intelligence options* for *known unknowns* enable a dynamic *anticipate, preempt & align pattern* in technology strategy.

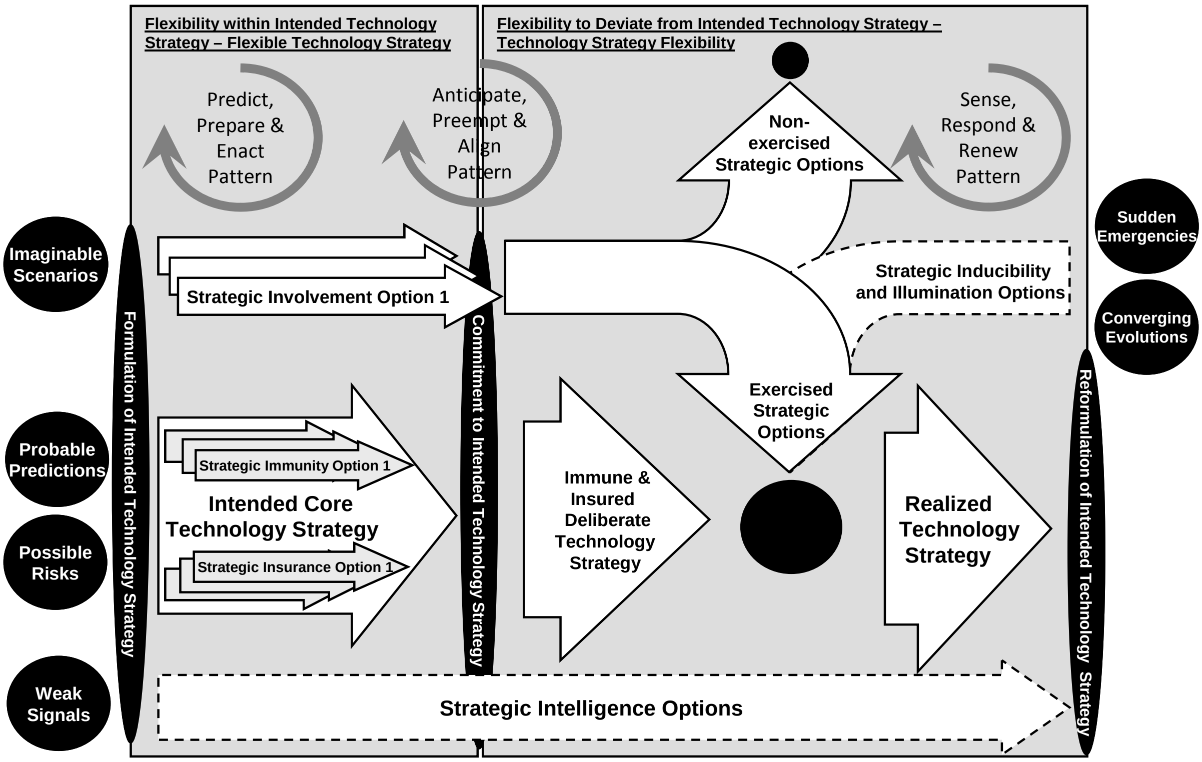


Figure 6-17: ***Flexibility within intended technology strategy and flexibility to deviate from the intended technology strategy.***

Unknowns are not anticipated incidents and therefore cannot be integrated in any intended technology strategy, at least not specifically. This does not mean that the company cannot prepare at all. The completely reactive dynamic pattern of *sense, respond & renew* is realized by the ability to sense and respond to the occurrence of unanticipated incidents. *Inducibility and illumination options* allow a company to realize a technology strategy, which deviates from the intended technology strategy. Only after the de facto change by exercising these strategic options, an orderly reformulation of the intended technology strategy follows. Figure 6-17 summarizes these identified dynamic patterns based on the distinction in flexibility in the intended technology strategy (*flexible technology strategy*) and the flexibility to deviate from the intended technology strategy in its realization (*technology strategy flexibility*).

The research presented to this point suggests that the overall and cumulated technology turbulence a firm is facing at any given time in its business environment is not something abstract or diffuse, but consists of more ore less anticipated, understood and distinguishable incidents. Different timing and quality of perception of these incidents create the demand for different forms of strategic flexibility in technology strategy. The analyzed companies, which are handling incidents of technology turbulence, show dynamic change patterns in their technology strategy by an adequate creation and exercising of strategic options. The insights of this empirical exploration suggest that different perceptions of technology turbulence demands for different forms of strategic flexibility realized by adequate strategic options.

As proposed by many authors in chapter 3, this confirms that strategic flexibility is highly polymorphous and multidimensional construct. As strategic fit is a state of optimal alignment between the organization's resources, its strategic positions and its current business environment, strategic flexibility is a state of alignment between the organization's resources, its strategic options, and future changes in the business context of the organization. Based on the distinction of technology turbulence in identified categories, the state or condition of an organization of being strategic flexible can be distinguished into six forms (see Table 6-21):

Table 6-21: Identified forms of strategic flexibility under technology turbulence.

	Form of Strategic Flexibility	General Description
Flexible Technology Strategy	***Strategic Immunity***	*Strategic immunity* is the established state of an organization of being immune for *probable predictions* in its technology context and is created by its intended technology strategy.
	Strategic Insurance	*Strategic insurance* is the established state of an organization of being insured for *possible risks* in its technology context and is created by its intended technology strategy.
	Strategic Involvement	*Strategic involvement* is the established state of an organization of being involved in *imaginable scenarios* for its technology context and is created by its intended technology strategy.
Technology Strategy Flexibility	***Strategic Intelligence***	*Strategic intelligence* is the established state of an organization of being sensitive and approachable to *weak signals* in its technology context, while pursuing an intended technology strategy.
	Strategic Inducibility	*Strategic inducibility* is the established state of an organization of being inducible for *sudden emergencies* in its technology context, while pursuing an intended technology strategy.
	Strategic Illumination	*Strategic illumination* is the established state of an organization of being teachable on *converging evolutions* in its technology context while pursuing an intended technology strategy.

The first three forms of strategic flexibility imply the commitment to a company's current overall goals and strategies and are constituted by designated efforts for specific incidents, which are anticipated in more or less quality. These forms of strategic flexibility are created by a build-in flexibility within the intended technology strategy. The option character allows determining reversibly the eventually realizing technology strategy within the boundaries of a *flexible technology strategy*.

The last three forms of strategic flexibility are more opportunistic, because they enable the company to deviate from its currently pursued intended technology strategy and are more generic regarding their designation for a specific incident. *Strategic intelligence, inducibility and illumination* allow companies to orderly reformulate, to disrupt or to erode their initially intended technology strategy and are independent from any build-in flexibility.

The analysis of the gathered qualitative data showed that dynamic change patterns in technology strategy, realized by the adequately aligned portfolio of strategic options, enable an organization to create and maintain a state of strategic flexibility (see Figure 6-18). In the very moment a strategic option is exercised, a company commits and the flexibility created by the existences of the relevant strategic option is lost. The contribution to the overall strategic flexibility by a strategic option is also lost, when the option expires or is abandoned.

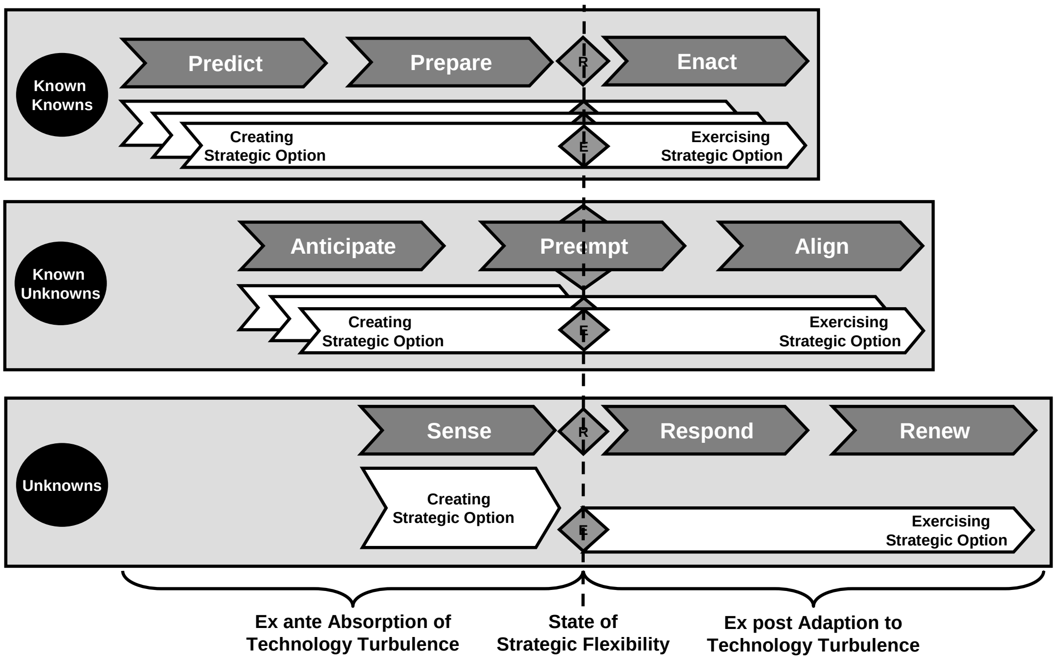


Figure 6-18: ***Absorption of and adaption to technology turbulence by creating and exercising strategic options.***

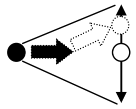
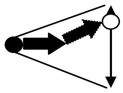
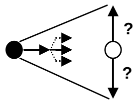
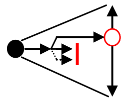
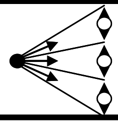
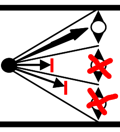
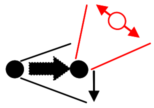
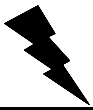
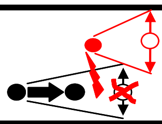
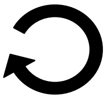
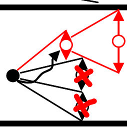
The adequate alignment of strategic options regarding content and timing, with the necessity for a dynamic change in technology strategy when facing incidents of technology turbulence is what creates the state of strategic flexibility in technology strategy. The creation of adequate strategic options is what reflects the ex ante absorption of technology turbulence of an organization by its technology strategy. The exercising of existing strategic options is the ex post adaption to technology turbulence of an organization by its technology strategy. To reach a state of strategic flexibility an organization must therefore absorb the perceived technology turbulence by creating an adequate strategic option and must also have the capability to adapt to an eventual occurrence of technology turbulence by exercising strategic options (see Figure 6-18). It is therefore concluded that strategic flexibility is not either an organizational state, a portfolio of strategic options or a set or organizational capabilities, but is constituted by all three elements: The state of strategic flexibility in technology strategy is realized by strategic options, which allow dynamic change patterns in technology strategy. The creation and exercising of strategic options is enabled and facilitated by organizational capabilities to absorb and adapt. At a generic level, these capabilities to ex ante absorb and to ex post adapt to technology turbulence were identified based on the explorative empirical research how companies perceive and handle technology turbulence (see Table 6-22).

When perceiving technology turbulence as *probable predictions,* companies should have the capability to absorb the technology turbulence by *re- and preprogramming* their intended technology strategy by creating adequate strategic options. If the incident occurs as predicted, the company should have the capability to adapt to the change by *adopting* the preprogrammed strategy and exercising the designated options. Only a company, which is able to change its intended strategy and to eventually implement it, can reach *strategic immunity for probable predictions*. A reformulated intended strategy for a predicted incident is irrelevant, if it is not adopted by the organization when necessary.

In the case of a future risk situation, a company needs the capability to absorb the technology turbulence by *hedging* the affected elements of its intended technology strategy with a strategic option, which takes into account the possibilities of occurrence and non-occurrence of the anticipated risk. If the risk occurs, the company needs the capability to adapt to the change by *correcting* its technology strategy. Only a company which is able to *hedge* its intended technology strategy and to eventually *correct* it can reach *strategic insurance for possible risks*. A prepared alternative course of action or a second-best plan B is obsolete, if the company cannot realize the correction.

If facing different *imaginable scenarios*, a company should have the capability to absorb technology turbulence by *versatility* in its intended technology strategy, which allows pursuing different scenarios by adequate and parallel strategic options. When it becomes obvious, which of the preempted scenarios are more realistic or obsolete, the capability to *adapt* gradually by selectively exercising strategic options, enables a company to suspend, abandon and commit to a scenario. A company that is able to formulate a versatile intended technology strategy, which can be continuously adapted over time, creates *strategic involvement for imaginable scenarios*. *Strategic versatility* in pursuing sometimes competing scenarios by strategic options is dangerous, if a company cannot adapt its strategy to future insights.

Table 6-22: ***Forms of strategic flexibility in technology strategy and necessary organizational capabilities to absorb and to adapt to incidents of technology turbulence.***

	Forms of Strategic Flexibility	Absorptive Dynamic Capabilities – Capabilities to Create/Identify Strategic Options		Adaptive Dynamic Capabilities – Capabilities to Exercise Strategic Options	
Flexible Technology Strategy	Strategic Immunity for Probable Predictions	Strategic (P)Reprogrammability		Strategic Adoptability	
	Strategic Insurance for Possible Risks	Strategic Hedging Ability		Strategic Corrigibility	
	Strategic Involvement for Imaginable Scenarios	Strategic Versatility		Strategic Adaptability	
Technology Strategy Flexibility	Strategic Intelligence for Weak Signals	Receptivity		Strategic Reformulation	
	Strategic Inducibility for Sudden Emergencies	Agility		Strategic Responsiveness	
	Strategic Illumination for Converging Evolutions	Learning Ability		Strategic Incrementalism	

Companies, which perceive *weak signals* for technology turbulence, should have the capability to absorb these signals by *receptivity* of the organization for further information. If further information confirms the *weak signals* a company needs the capability to *reformulate* currently pursued technology strategy. A company, which is receptive to *weak signals* and has the ability to interpret these signals correctly, can maintain a state of *strategic intelligence*. Strategic receptivity is worthless, if the company cannot reformulate its intended technology strategy in time.

To be prepared for unanticipated *sudden emergencies* a company should have an adequate level of *agility*. Unlike the previous absorptive capabilities, which enable companies to absorb different levels of anticipation and ambiguity of future changes, the organizational capability of *agility* absorbs the possibility that something completely unanticipated could happen. When *sudden emergencies* occur, companies need the capability to adapt by a timely and proper *response*, which may partly or completely disrupt the initially pursued technology strategy. A company, which is *agile* and has the capability for a fast and adequate *response* if necessary, can maintain a state of *strategic inducibility for sudden emergencies*.

Similar to *sudden emergencies*, a company cannot anticipate *converging evolutions* in its technology context. To be prepared for the possibility of *converging evolutions* anyway, companies should have the capability to absorb them when they occur. A general and undesignated *learning ability* of the organization allows for continuous and gradual detection of *converging evolutions* as they emerge. When companies gradually learn on *converging evolutions* as they emerge, *strategic incrementalism* allows the gradual erosion of the initially pursued technology strategy. A company, which has the absorptive capability to learn and the adaptive capability of strategic incrementalism can create a state of *strategic illumination on converging evolution* in its business environment. The ability of organization to continuously learn is worthless, when it has not the adaptive capability to change its strategy incrementally.

Based on the explorative empirical insights of this research, Figure 6-19 is composing a conceptual framework for strategic flexibility in technology strategy. Various incidents of perceived technology turbulence in the business environment demand for different forms of strategic flexibility in technology strategy. Strategic flexibility was proposed to be valuable, if strategically relevant changes in the business context are expected and the changes imply some form of ambiguity for the organization. Different timing and quality of perception demand for forms of strategic flexibility: An anticipated possible risk in the technology context, for example, demands a different form of flexibility in technology strategy, than a completely unanticipated sudden emergency. This demand for various forms of strategic flexibility is satisfied by dynamic change patterns in technology strategy, which are realized by the creation and execution of adequate strategic options. The demand for strategic involvements into an anticipated imaginable scenario, for example, is realized by an involvement option, which allows a company to gradually and reversibly commit its technology strategy to a scenario.

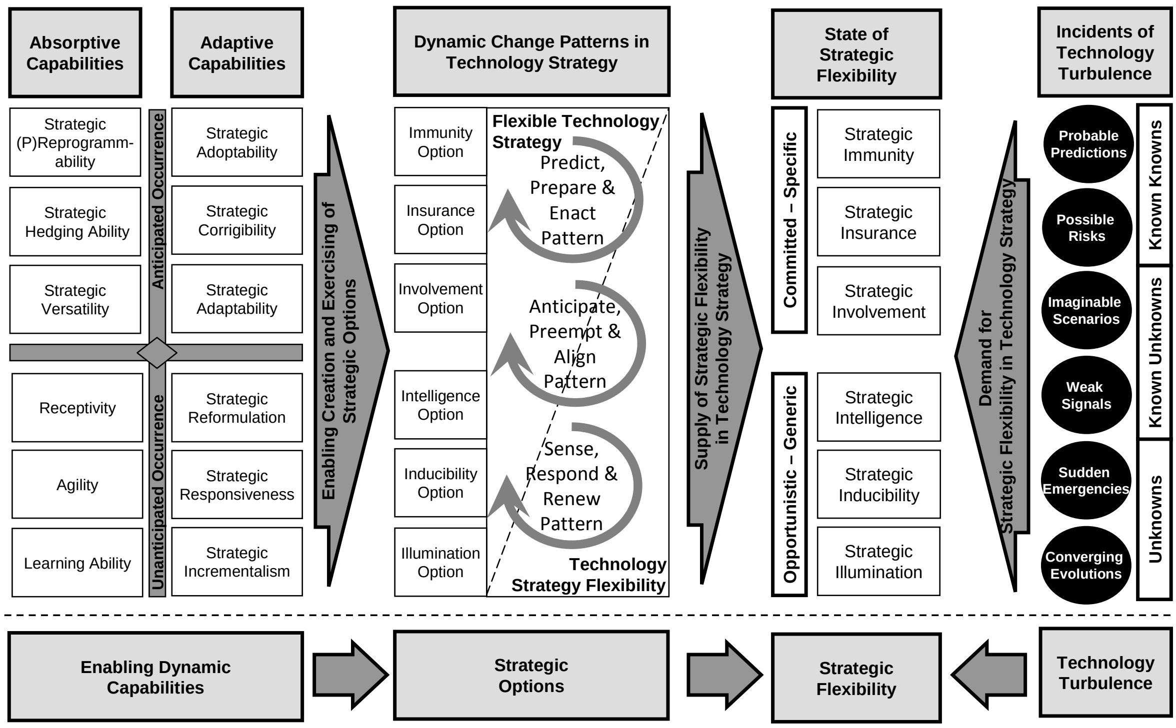


Figure 6-19: ***An empirically grounded conceptual framework for strategic flexibility in technology strategy.***

The final component of the conceptual framework consists of the underlying and basic organizational capabilities, which enable companies to align the creation and execution of adequate strategic options with the perception and realization of technology turbulence. It was concluded that an adequate alignment of the creation and execution of strategic options with incidents of technology turbulence demands an absorptive and an adaptive dimension. The next chapter specifically addresses the identification of efforts and routines for creating and maintaining these enabling dynamic capabilities.

7 ENABLING STRATEGIC FLEXIBILITY IN TECHNOLOGY STRATEGY

By analyzing dynamic change patterns in technology strategies of companies, which are confronted with incidents of technology turbulence, the last chapter identified six distinguishable forms of strategic flexibility in technology strategy. This chapter is presenting the analysis on how and by which underlying efforts the interviewed companies create and maintain these identified forms of strategic flexibility. While the previous chapter analyzed and described patterns in technology strategy to inductively derive an empirical grounded framework for strategic flexibility, the following sections present identified recommendations how the studied companies enable these forms of strategic flexibility. This analysis of the gathered data is guided by the identified forms of strategic flexibility and the developed conceptual framework for strategic flexibility and is addressing research question 4 (see Figure 7-1).

> *RQ 4: What enables industrial organizations to create and maintain identified forms of strategic flexibility in their technology strategy?*

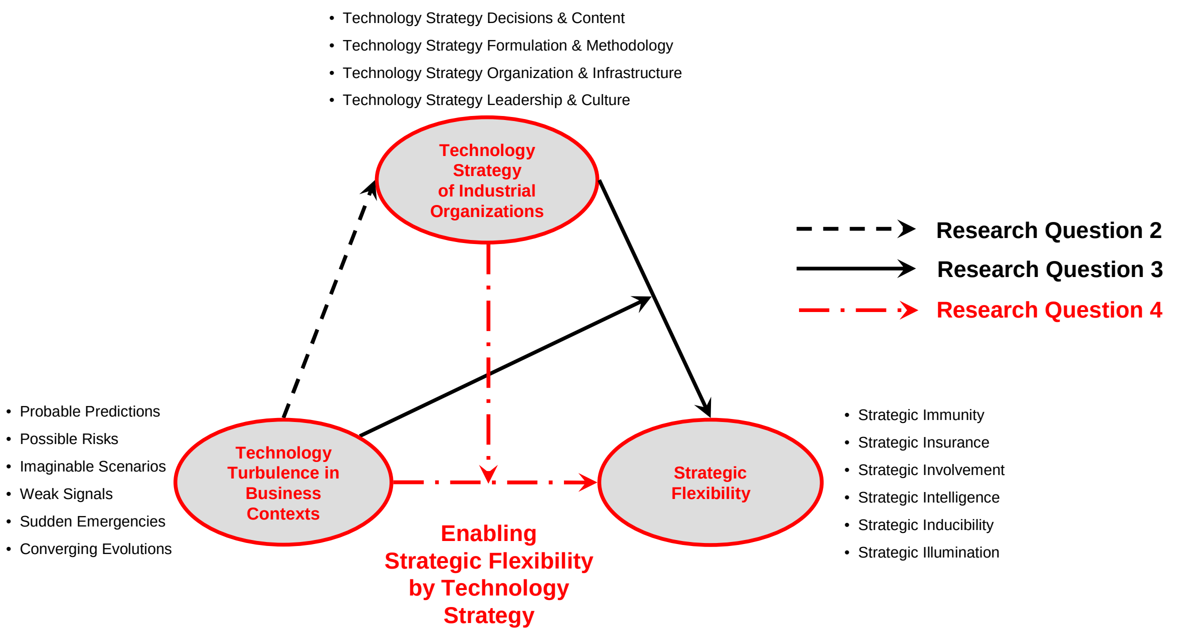


Figure 7-1: ***Enabling strategic flexibility for incidents of technology turbulence by characteristics of technology strategy.***

Based on the insights of the previous chapter, Figure 7-2 shows the employed conceptual framework for research question 4. Dynamic change patterns in technology strategy over time, realized by adequate creation and execution of strategic options, allow organizations to generate a mix of strategic flexibility for the perceived technology turbulence in their business environment. Depending on specifically anticipated or generally expected changes in the technology context, a company may consider flexibility within its intended technology strategy (*flexible technology strategy*) and the flexibility to deviate form its intended technology strategy (*technology strategy flexibility*).

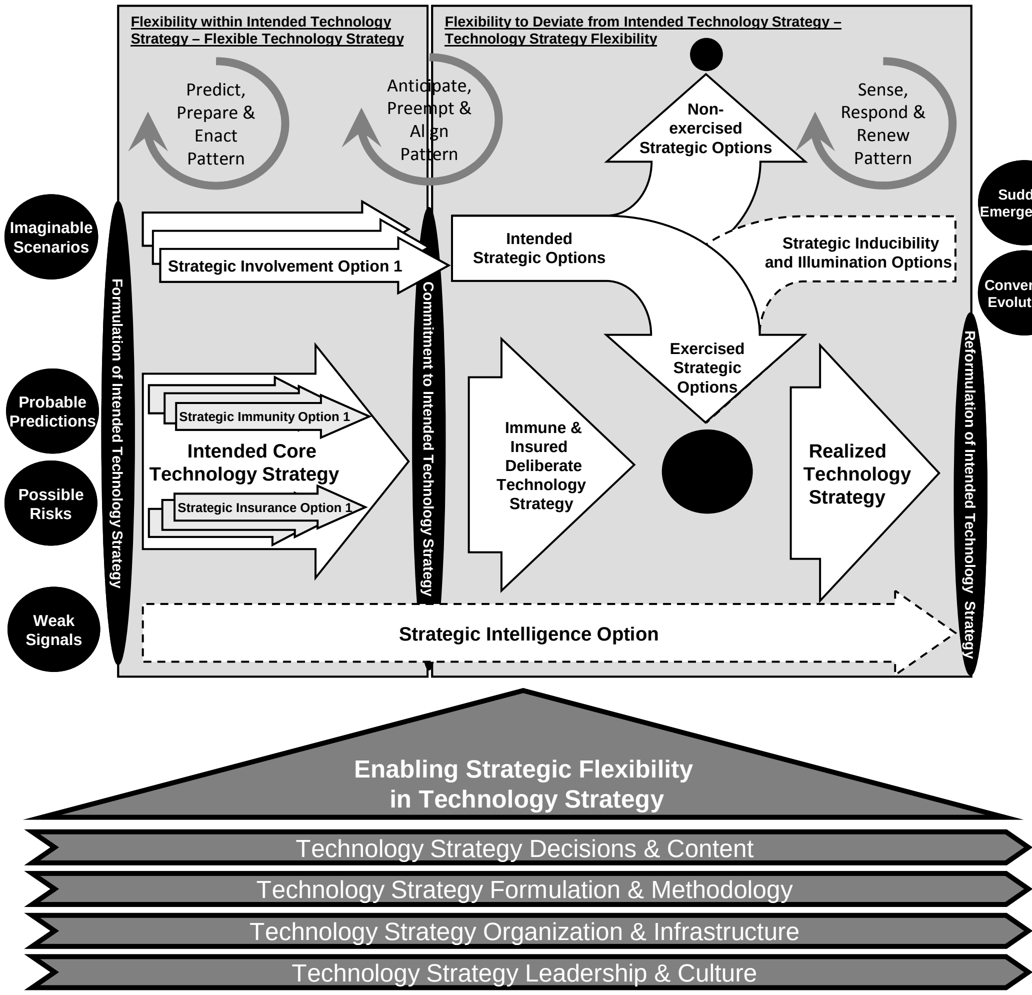


Figure 7-2: ***Conceptual framework of research question 4: Enabling strategic flexibility in technology strategy.***

The description and analysis of empirical data in the previous chapter showed, that companies employ strategic options to face strategically relevant future changes and the resulting ambiguity in their technology contexts. The focus of this chapter is to identify the underlying efforts and routines in the domain of technology strategy, which enable organizations to do so (see Figure 7-2). The goal is to find efforts and routines in the overall configuration of the technology strategy of a company (e.g. regarding content, methodology, organization of technology strategy), which enables strategic flexibility in the technology strategy.

7.1 Conduct of Analysis

The analysis in the previous chapter was highly specific to the individual company, its industrial context and the identified incident of technology turbulence. The analysis and coding procedure of the gathered interview data was purely inductive and exploratory. For research question 4, the analysis of the data followed a more deductive and confirmatory routine. The empirically grounded framework of strategic flexibility, proposed as a result of the previous chapter, served as a deductive searching grid (see Figure 6-19). The goal of this deductive coding process of the empirical data was to identify generalizable and transferable recommendations for efforts, which enable strategic flexibility in technology strategy. For this reason, the pre-formulated questions on general aspects of technology strategy decisions & content, formulation & methodology, organization & infrastructure and leadership & culture in the interview guide (see Appendix B) were complemented by numerous follow-up questions. These follow-up questions asked for details on how a reported incident was managed and also asked for the opinion of the interviewee on what enabled the company to manage an incident of technology turbulence successfully. The paraphrased and categorized interview data for this analysis with direct references to the relevant positions within the interview can be found in Appendix E. Contrary to the purely inductive data analysis, which was conducted to identify the forms of strategic flexibility in technology strategy and to generate an empirically grounded framework, the identification of enabling factors was a more deductive process (see Figure 7-3).

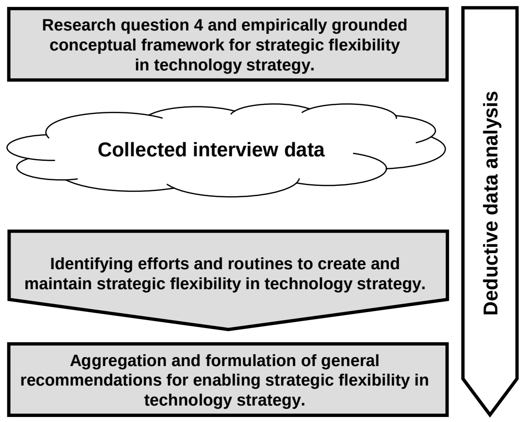


Figure 7-3: Conduct of deductive data analysis for research question 4.

Although the collected data was primarily designated for identifying forms of strategic flexibility in intended and realized technology strategies, it also contains rich information on efforts how the interviewees' organizations are actually enabling these forms of strategic flexibility. Analyzing the same data set by applying the identified grounded framework as a search grid allowed to identify and to suggest practical and transferable recommendations how industrial organization enable the creation and maintenance of strategic flexibility.

7.2 Enabling a Flexible Technology Strategy

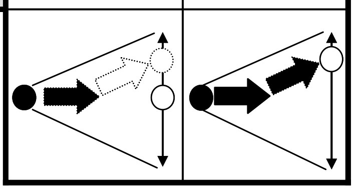
The build-in flexibility within the intended technology strategy of an organization was identified as one basic domain of strategic flexibility. Flexibility within intended technology strategy – a *flexible technology strategy* – is considered as strategic flexibility when it *immunizes* a company for *probable predictions*, *insures* a company for *possible risks* and *involves* a company into *imaginable scenarios* in its future technology context.

7.2.1 Recommendations for Strategic Immunity in Technology Strategy

Strategic immunity was described as the state of an organization of being immune for predicted and highly probable future incidents of technology turbulence by its intended technology strategy. The intended technology strategy of an organization therefore has to absorb these *probable predictions* by the creation of adequate strategic options, and the company must be capable to adopt the new intended technology strategy by exercising these options when appropriate (see Table 7-1). Simply stated, strategic immunity demands the ability of an organization to reformulate and enact a new intended technology strategy when facing strategically relevant, but predicted changes. Based on the analysis how the interviewed companies handled probable predictions and the opinions of the interviewed experts, four general recommendations on how to enable *strategic immunity* were identified (see Appendix E).

Table 7-1: Enabling strategic immunity by ex ante absorbing and ex post adapting to probable predictions.

Form of Strategic Flexibility	Absorptive Capability	Adaptive Capability
Strategic Immunity	Strategic (P)Reprogramm-ability	Strategic Adoptability



Recommendation 1: Dynamic planning routines for intended technology strategy.

No sophisticated planning routine can prepare an organization for an incident of technology turbulence, which was not anticipated at all. Especially historically very successful companies seem to have problems to change their technology strategy, even when facing obvious changes in their technology context. Many interviewed companies highlight the importance of establishing an overall planning architecture, which can promptly reflect predictable and strategically relevant changes and their impact on the company's currently planned R&D agenda and resources. Static and rigid planning routines, based on cyclical forecasting routines and extrapolation of historical data, are not regarded as suitable to absorb technology turbulence, even when obvious to the organization. Several interviewed companies therefore emphasize planning routines, which directly link identified future changes and confirmed trends in the competitive environment with today's R&D agenda, resource commitments and the existing technology portfolio. Interviewee 13 describes how anticipation of trends affects strategy in his organization:

> *"We have learned, since 2003 I guess, to develop and maintain so called trend roadmaps, which we continuously and permanently match against our current strategic position and agenda […] if one of the identified trends is affecting one or more elements of our technology strategy. If yes: Who is taking care of? You should never assume just because the topic "sustainability" was identified and announced as a major new strategic topic, that an "environment department" is starting to work and management says: That is your topic! If you want to address, for example, the topic "sustainability" it affects the complete organization, forestry, logistics, all research and development efforts and many others […]. We are really working hard to derive technology roadmaps from trend roadmaps and to keep them updated […]. This process emerges from a trend perspective bottom-up, but then top-management says: This identified trend seems very plausible to us, let's address it. And then all efforts go top-down again: Next year higher budget for this and that, because it will become important […]. This goes down to the level of individual innovation projects […]. It is important to see that, if we want to establish a technology for 2012 in our roadmap, I will need the adequate resources and skills before 2012." (I13, 0:23)*

Although very diverse and highly different across different industries and companies, theses approaches are based a permanent and dialog-based technology strategy development process with regular formal and informal meetings. General preliminaries for a more dynamic planning routine seem to be an actual overview on existing and potential substitutive and complementary technologies and products and a high sensitivity for existing and new drivers of technology innovation and progress in the industry. To enable sufficiently efficient planning routines, some of the studied companies emphasized the separation of technology planning and roadmapping routines for distinguishable modules, systems and platforms of products and processes, but without sacrificing an integrated and holistic view of identified changes in the technology context. Dynamic planning routines enable a company to reprogram its existing strategy and to preprogram a new intended technology strategy, which takes into account predicted future changes in the technology context. One interviewee highlighted:

> *"Our innovation database and project management is linked to our management information system – by pushing a button one can see the actual status of our technology strategy. Nobody needs a technology roadmap, which is not visible and which is only updated after six months for an executive board presentation. […] So our roadmaps are updated every day and cover all projects and resources. […] By pushing a button I can instantly see consequences of intended changes: If you want to have this technology tomorrow, I can show you how this will affect our research agenda today." (I16, 1:12)*

Recommendation 2: Strong but not rigid R&D&E management and controlling routines.

Dynamic planning routines, which allow for an organized and deliberate change in intended technology strategy when facing predictable future changes, are obsolete, if the change in intended technology strategy cannot be enacted by routines that manage and control the implementation of a strategy change. Several interviewees underscored the necessary ability of an organization to enact new or changed priorities of a reformulated technology strategy in R&D&E programs and project management routines for existing and new programs and projects. Companies are aware that direction, objectives, requirements and specifications for both long-term research projects and running product development projects cannot change on daily basis, but project management routines must allow for corrections and verifications of original assumptions at predefined milestones or stage-gates. Score-card systems for strategy controlling, established change management routines and the possibility to adjust the direction of continuous improvement processes were proposed to allow a company to fully adopt a changed strategy agenda. Interviewee 18 is emphasizing the importance of strong R&D&E management routines for implementing a change in intended technology strategy:

> *"Our developed strategic roadmaps are transferred into operational roadmaps by very specific and detailed steps. […] Within the operational roadmaps, the responsible technology manager of a business unit works together with R&D management to identify specific technology projects and necessary competences […]. This strategy implementation process is a result to internal best practice. All the [R&D management] tools we are using are embedded in our intranet, including, frameworks, templates and checklists. The "grown" project planning and management methodology, that we have established, was externally benchmarked and eventually two big European industrial corporations wanted to buy our system […]. It is probably a best-in-class tool today." (I18, 0:10, 1:09)*

Recommendation 3: Central and powerful CTO position.

Many companies underlined the importance of an integrated authority and responsibility for the complete domain of technology strategy at top-management level. This includes the responsibility for all research and development efforts, product development and engineering, and manufacturing and operations. While there are differences in the specific boundaries of responsibilities, labeling, vertical position of the function in the hierarchy (e.g. executive board member, president, vice-president) and existence of additional operational responsibilities for business units, many of the observed organizations have the organizational role of a chief technology officer that drives technology strategy formation and is responsible for its implementation. One interviewee described:

> *"We have a CTO position that is eventually responsible for the overall technology strategy. The CTO is a corporate executive and a board member, who is responsible for manufacturing, product engineering, R&D and all technology and energy topics within the organization." (I13, 0:29)*

A united responsibility at the very top of an organization for all vertical and horizontal efforts of technology strategy formulation and implementation, which is also representing the technology domain in all corporate and business strategy instances of an organization, is expected to facilitate the re- and preprogramming of a changed technology strategy and its eventual adoption. One interviewee reported that his company wants to create the function of a CTO for better horizontal alignment across the existing business units:

> *"Until today we have no central chief technology officer at corporate level, but four at business unit level. A super-ordinate function [of a corporate CTO], as described, is considered and intended within the next step of organizational development […] right now do not have this function, but very probably in one year from now we will have one […] because of organizational growth and the necessary and intended internal knowledge transfer. This is part of our intended organizational development but not realized yet […]. It is also a question of having the right candidate with the right personality. On one hand, this person has to be highly competent in our technologies, on the other hand, he has to be accessible […] people should want to go to him." (I23, 0:39)*

Recommendation 4: Participative technology strategy development process.

Some interviewed companies highlighted, that the way and style how a technology strategy is formulated and communicated, affects the speed and success of its adoption throughout the whole company. These companies emphasized the right vertical balance of bottom-up and top-down approaches in technology strategy formulation. While corporate and business strategies must take into account the technology element and must be informed by technology strategy (bottom-up), corporate and business strategies are shaping technology strategy and formulate the expected contribution of the technology function within the company to the overall goals of the organization (top-down). The adequate balance and transparency of these top-down and bottom-up feedback loops and the organizational implementation of interfaces and overlaps between corporate and business strategy and the technology strategy of the organization are important for a good communication, understanding and acceptance of a new or changing technology strategy. Some companies reported that they deliberately separate yearly planning, budgeting and review procedures and meetings at top-management level from real strategy making and formulation sessions. This separation reduces the sometimes negative effects of existing organizational units and their interests on strategy sessions and workshops. Enabled and requested participation of non-managing employees from R&D&E organizations in technology strategy formulation and a clear and repeated internal communication of changes in technology strategy is proposed to facilitate its successful adoption. One interviewee highlighted the important role of communication in technology strategy development:

> *"Actually we hired a new employee who is doing nothing else but information and communication management by connecting the center of technology excellence [where technology strategy is developed] and all of our regular plants. Next week he is starting a visiting tour of 20 of our plants to report the new insights and ideas to the local engineering people. […] He is horizontally collecting, distributing and exchanging all of our technology and innovation ideas and agendas over all of our facilities. That really is a very critical communication function. […] Maybe some of the collected ideas are better than something we have. […] The strategy and policy is: Openness between all plants!" (I4, 1:07)*

In some instances, companies decide to develop an extraordinary annual agenda for a specific business year to prepare the organization for a predicted fundamental change in the business environment (e.g. topics like “green energy” or “sustainability”). Internally and externally announced and communicated as an annual motto for the company, such extraordinary annual initiatives enable a clear prioritization within all innovation efforts and create, due to a temporal overemphasis, a clear commitment to an initiated change in strategy. Interviewee 10 emphasized the importance of an adequate communication of a new technology strategy:

> *“That is an issue of communication. I am not sure if everybody who should know actually does know our currently valid technology strategy. We increased our efforts to publish and communicate our current technology strategy compared to the past […] because the company was transformed from an equipment supplier into a technology corporation […]. A big issue within our company is and will always be that the technology strategy at corporate level has to be communicated down to a certain level of the organization. It must be clear what the current technology strategy of the organization is.” (I10, 0:14, 2:09)*

Table 7-2: Recommendations to facilitate strategic immunity for probable predictions in technology strategy.

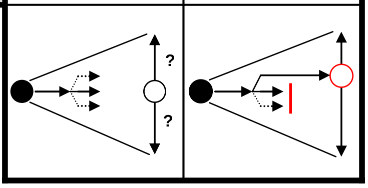
Recommendation 1:	*Dynamic planning routines for intended technology strategy.*
Recommendation 2:	*Strong but not rigid R&D&E management and controlling routines.*
Recommendation 3:	*Central and powerful CTO position.*
Recommendation 4:	*Participative technology strategy development process.*

7.2.2 Recommendations for Strategic Insurance in Technology Strategy

Strategic insurance was identified as the state of on organization of being insured for anticipated technology turbulence in form of future risk situations. The hedging ability of an organization enables a company to absorb anticipated strategic risks in its intended technology strategy. If anticipated risks eventually occur, the company should have the capability to correct its initially preferred course of action (see Table 7-3). Simply stated, *strategic insurance* demands the ability to prepare and enact a second-best plan B for the occurrence of an identified risk. Based on the analysis how the interviewed companies handled *possible risks* and the appraisal of the interviewed experts, four general recommendations on how to enable *strategic insurance* in technology strategy were identified (see Appendix E).

Table 7-3: ***Enabling strategic insurance by ex ante absorbing and ex post adapting to possible risks.***

Form of Strategic Flexibility	Absorptive Capability	Adaptive Capability
Strategic Insurance	Strategic Hedging Ability	Strategic Corrigibility



Recommendation 1: Hedging for internal risks by intended technology strategy.

Several companies emphasized the necessity to hedge the organization for identified risks which are internal to the organization and created by a currently pursued strategy. Some companies highlighted the importance of a hedging strategy when entering a new business activity. If this new activity can be realized by competing technologies or alternative technological principles, these companies initially consider all available alternatives. Even if there is an initial preference for a certain technological solution, the anticipation of a possible risk of “betting on the wrong horse” initiates a limited commitment to a second-best approach, which is pursued in parallel. One interviewee reported:

> *“Overlaps and redundancies [of technology projects] are controlled, that is one of my most important tasks. For some core topics we want to reach a very high probability of success by minimizing risks […]. We intentionally want to create some redundancies […]. When we say a topic is important to us, we work in parallel at least until certain milestones and decision points, where we eventually commit” (I13, 0:47)*

Especially when introducing new and non-mature technologies as part of an intended technology strategy, anticipated risks are hedged by pilot phases for a single market, platform, product or production line while the established and mature technologies are still working in parallel. Some companies hedge the production of new products by old manufacturing technologies and vice versa, even when the eventual goal is to produce the new products by new process technologies. In interview 5 it was stated:

> *“We always assess the risk of a new technology […]. We always prefer a “running change” when introducing new technologies, where we still have a back-up alternative: Stepwise and parallel introduction of new manufacturing technologies in a running production of an existing product, if a risk occurs. Limited application in a single plant, or staged investments and waiting how it develops and incremental implementation steps. Most critical is the introduction of new product project combined with a new manufacturing technology: We have already done that in the past. This is, by my experience, usually*

> *very expensive, because different risks occur in parallel. That should be avoided." (I5, 1:07)*

Some interviewed companies limit intended technological innovations at a certain time to one system, module or component of their products or processes and try to avoid too many technological innovations in one period. One interviewee emphasized:

> *"We split up our products in different components and isolate singular phenomena […]. That usually works fine. In most cases it works fine. Sometimes we maintain fallback positions: When this in not working, than that will work. […] We always ask: Known customer, unknown customer, known technology and unknown technology. We usually make only one step at once […]. In the case of a completely new project: When we have a new component, module or system, we do not integrate it into a completely new installation, which we intend to sell to the customer. Usually we get in touch with an existing customer who is employing one of our older installations and ask, if he wants to test a technology update. If it works, he can purchase it with discount or we grant him some temporary exclusivity. Most important is the risk analysis along various dimensions." (I22, 0:14)*

Recommendation 2: Hedging for external risks by intended technology strategy.

Some anticipated and strategically relevant risks have their origins beyond a company's boundaries and influence. Nevertheless, many of these risks can be addressed by absorbing them in the intended technology strategy when anticipated. Some of the interviewed companies hedge for a possible opportunistic behavior of suppliers for technological relevant components or equipment. If it is anticipated that the negotiation power of an equipment or factor supplier will increase because of protected intellectual property or market dominance, several companies highlighted the importance of proactively hedging this external risk in the intended technology strategy. One interviewee mentioned:

> *"This is intentionally pursued. […] Certainly we want to design contracts which give us a certain amount of exclusivity and which prevent our supplier to exploit his position. But you never have certainty that he is not using his exclusive negotiation power for the next contract and you loose the biggest part of the advantage to your supplier. You are at the mercy of your supplier. When we exclusively innovate with one partner, we also create a monopoly position for his technology. Here we decide to go together with a second partner somewhere else on the globe, with a similar and parallel pre-development project. Certainly we have to consider existing IPRs and nondisclosure agreements, but there are usually technological possibilities to engineer something similar based on different concepts. Such developments are intentionally triggered and controlled to eventually show our supplier, if necessary: You are not the only one! […] We certainly have to find an additional partner who is proactively interested. And then you have to support and develop him." (I4, 0:44, 1:32)*

Additionally, some companies emphasized the importance to hedge the outsourcing of technologies or manufacturing processes. Keeping a critical minimum of an outsourced technology and technological competence in-house, may hedge for external risk related to this technology. Two interviewees stated:

> *"We try to keep a basic competence for all outsourced manufacturing technologies in-house for the occurrence various risk situations." (I15, 0:21)*

> *"One externally sourced technology is quite important for our products. We therefore maintain basic level of competence within our organization. We buy this technology externally but we always recognize: It makes sense to have a portion of this technology in-house." (I5, 0:12)*

Recommendation 3: Substitute an "avoid risk"-culture by a "manage risk"-culture.

Possible risks are an integral part of any promising intended technology strategy under technology turbulence. A company culture, which develops risk-averse employees and decision makers, also limits the opportunities available to the company. Some interviewees highlighted the necessity of establishing a corporate culture, which does not avoid risk situations, but stimulates the identification, communication, valuation, and tracking of risks related to technology strategy. In interview 17 it was stated:

> *"If somebody is taking action beyond his competence and he justifies: I did know I was not allowed to decide alone, but I was thinking that it was better to make any decision immediately, even when it eventually turned out to be wrong and had to be corrected, than to make no decision at all. Such arguments are probably not rewarded, but certainly not punished – failure tolerance! If an employee has good arguments for taking risk, making a decision, not waiting and asking for allowance, it is usually no problem. Especially if he proposes how to handle the situation in the future and asks for support." (I17, 2:07)*

One interviewee highlighted that a certain amount of risk must be taken, especially if a company is pursuing technology leadership in its industry:

> *"When something happened, it happened. When you punish product engineers for taking some risks in a project, people become deeply discouraged and nobody comes up with a new out-of-the box idea anymore. […] When I remember what happened in our product development and engineering during the last years, there is a clear and obvious commitment that risk can be taken, but not ignored." (I10, 2:26)*

Recommendation 4: Integrate risk management approaches into technology strategy.

The integration of risk management approaches into technology strategy formulation and implementation was emphasized by several interviewees. Analog to risk management approaches from financial and project management, strategic risk management is addressing risks, which are affecting the success of pursued strategies or specific strategic initiatives. Two interviewees emphasized:

> *"All interesting technology options are internally evaluated by rough qualitative criteria: Priority, R&D relevance, risk analysis and market relevance. […] Risk is evaluated qualitatively in four categories: moderate, medium, high and maximum. […] This includes the pure internal technical risk and the probability of success and for technological advantage. (I17, 0:28)*

> *"For such strategic options we apply a structured risk assessment routine. We have a designated risk assessment group at corporate level, 2 or 3 people with a special tool set, which roughly estimates risks of a strategic option: What is the risk profile? How probable is the occurrence of identified risks? How strong would be the impact? How big is the financial impact? Here we have relative strong and verified working routines. (I20, 0:16)*

Integrating a risk management perspective into the formulation of intended technology strategies may enable the company to correct its course of action easier and faster, if one of the identified risks inherent to a pursued strategy is eventually occurring. Contingency planning techniques and the formulation of fallback positions for risky elements of a strategy are standardized routines for some of the interviewed companies. The implementation of a changed strategy in adequate stages and milestones and tracking and continuous reevaluation of the involved risks allows the activation or abandonment of prepared contingency plans and fallback positions. An interviewee stated:

> *"For all of our strategic projects we use a priority and risk portfolio analysis. How important and critical is the project to us and our goals, and how risky is its technological realization. Important but somehow risky projects are "diversified". Here we emphasize different technological approaches. We do not give the same problem to three different research institutions, but we want them to apply different core technologies. If we want do develop the wheel, we don't ask three firms to develop a wheel made of wood, but we give wood to one, and iron to another firm. […] We do not want our partners to think that we think they are not capable, but we want them to propose alternative ways […]. When we work with external partners we try always to work with the best, and we say: I trust you, but I do not know, whether the way you are proposing or the technology you are using is the best for our application: Some are using x-ray, some are using light waves […]." (I13, 0:48)*

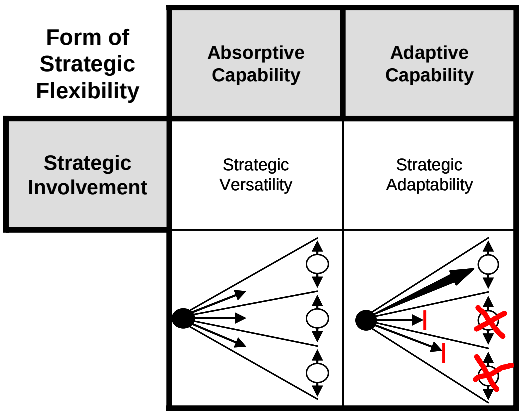
Table 7-4: ***Recommendations to facilitate strategic insurance for possible risks in technology strategy.***

Recommendation 1: Hedging for internal risks by intended technology strategy.
Recommendation 2: Hedging for external risks by intended technology strategy.
Recommendation 3: Substitute an "avoid risk"-culture by a "manage risk"-culture.
Recommendation 4: Integrate risk management approaches into technology strategy.

7.2.3 Recommendations for Strategic Involvement in Technology Strategy

Strategic involvement was identified as the state of an organization of being involved in anticipated alternative technology scenarios by its intended technology strategy. To enable *strategic involvement*, an intended technology strategy should not ignore *imaginable scenarios* but absorb them by an adequate level of versatility. *Strategic versatility* of an intended technology strategy has to be complemented by the capability to continuously and gradually adapt the level of commitment to and involvement in a certain scenario (see Table 7-5). Based on the analysis how the interviewed companies handled *imaginable scenarios* and individual appraisals by the interviewed experts, five recommendations on how to enable *strategic involvement* were identified (see Appendix E).

Table 7-5: ***Enabling strategic involvement by ex ante absorbing and ex post adapting to imaginable scenarios.***



Recommendation 1: Limit dominance of currently existing technological core competence.

Some of the interviewed companies emphasized the importance to limit the absolute level of dominance by current core businesses or product groups within the organization. Especially very successful businesses and product groups with high financial returns and growth rates, create the incentives to assign all available resources for its further development and to divest or exit businesses and products, which currently perform at lower rates of profitability. An overemphasis of a currently dominant business, product or competence may become dangerous in more turbulent environments, where sources and forms of competitive advantage are not sustainable. Several companies reported that they have a threshold limit for the relative share of R&D expenses and capital investments for one business, product group or core technology. Although not formulated as a strict policy, such approaches force companies to create a minimum of variety and diversity in its R&D and business development efforts and may stimulate a feeling of inconvenience of involved decision-makers when this threshold limit is reached. An interviewee reported:

> *"We have to define a rough innovation policy […] if we want to develop a certain existing business we have to take X% of our R&D resources for incremental improvements, but I reserve Y% for completely new technologies and Z% for external acquisitions of technologies […] such a commitment is necessary […]. We have to bring that in parallel with identified trends, which we anticipate for 5 years, for ten years an so on, similar to a roadmap approach. For relevant trends, which are actively pursued we have to ask, which projects and skills are necessary to be there in ten years. […] We also want to reduce dominance and dependency on a single industry, example: The automotive industry. That is why we decrease dependency, currently we have a 40% share, and this will definitely not increase." (I21, 0:40)*

Some companies apply similar rules to specific industries, key accounts or dominant customers. Several firms intentionally emancipate their technology strategies from a too strong influence of a single customer or customer group and try to formulate a core technology strategy which consists of no-regret moves, which are sufficiently relevant for all currently imaginable scenarios. One interviewee stated:

> *"Our three business units are highly focused on existing customers, products and technologies. My work is actually focused on emancipation from these existing commitments. We start by analyzing global trends […]." (I20, 0:03)*

Recommendation 2: "Scenario thinking" in technology strategy development.

Thinking in alternative pictures of the future during technology strategy making may stimulate increasing versatility of the intended technology strategy. Although very few companies really apply prescriptive and consistent scenario planning routines for strategy making, some of the interviewed companies highlight the importance of an explicit or implicit development of scenarios and a strategic conversation on additional or competing pictures of the future of the company and its business environment. One interviewee emphasized explicit scenario development as a difficult but necessary practice:

> *"We also develop scenarios – that is actually the most difficult thing. Picking up a trend is easy, but to develop scenarios for your industry – what does it really mean to us, for example 2nd generation of [technology A], how will that impact our industry, what are our opportunities, what are the threats? That has to be prepared diligently before any decision is possible. […] We are making our scenario development and analysis together with selected external partners like customers or technology experts form universities. These partners are usually changing. […] A typical question may be: What happens if the*

> *price for natural gas is increasing and staying beyond a certain value? Such considerations are directly affecting strategy making." (I13, 0:25, 0:57)*

While companies ask, what risks for their current core competences are represented by an anticipated scenario, they also ask for the risk of not being involved in a potential opportunity enabled by a scenario. Although only one company in the sample applied real option valuation technique for evaluating a quantitative option value of technology investments for different scenarios, several organizations emphasized the separation of a general technology assessment, which analyses the general impact and potential of a new or emerging technology for an industry, and the valuation of technologies in form of a business case proposal.

> *"For me the most import issue is to take each new technology idea seriously in the beginning, even when it sounds strange. We try to make a first assessment after a topic emerged. We first collect existing knowledge […] to get an idea, if the technology is something for us. From my point of view this first assessment is very important. We avoid saying, we had something similar ten years ago and it did not work. You have to take this very serious. […]. In this assessment we identify the overall and basic potential: Is this technology just anyhow relevant to our products? […] At first, we really try to assess these technologies completely open." (I4, 0:09, 0:31)*

Recommendation 3: Enable and allow "bypassing" of existing organization.

While the formulation of an intended technology strategy, which takes into account alternative versions of the future, is already described as a demanding task, the implementation of *strategic versatility* is not only difficult but delicate. It demands to temporarily pursue different and sometimes even competing technology strategies within one company. A no-regret core technology strategy, which includes common and dominant elements, can be easily pursued by the existing organization, but initiatives, which intend to enable an adequate level of designated involvement in an alternative scenario, may demand protection from the existing organizational structure and routines. Also, the existing organization should be protected from a possible "spoiling influence" of these initiatives. When preparing an organization for alternative or even competing versions of its own future business environment, it has to be ensured that the organization has the ability to oversee and control its initiatives for different scenarios. Over time, such initiatives, which have highly diverse forms like internal projects, external partnerships, participation in research consortia, or minority equity investments in start-up firms, may develop a life of their own and an individual momentum. This may lead to an escalation of commitment to a scenario, which has already become obsolete. Some companies emphasized the importance of a central business or corporate development function, which takes care of all innovative initiatives that cannot be integrated into an existing business unit. This function observes the relevance of initial justifications and assumptions for these ventures over time. Other companies highlight the importance of an idea broker role within the organization, which oversees all external technology relationships of the company and is establishing and maintaining internal and external networks. Several interviewed companies emphasized the necessity to create the possibility to bypass the existing organizational structure by temporary exceptions which are pursuing somewhat different objectives from the existing organization. Various forms of external partnerships, consortia, alliances and joint ventures with research institution, universities, and companies from the same, adjacent or emerging industries are employed for these initiatives. Larger companies also use own venture capital organizations or minority equity investments in selected technology start-ups. Internal start-ups or spin-off organizations, which are supported by a limited amount of resources but protected from the rigidities and rules of the existing organization, are vehicles to create *strategic involvement in imaginable scenarios*. While initiatives for *strategic involvement* can be embedded in numerous organizational vehicles, they all share the possibility to gradually increase or decrease the commitment to them over time. Two interviewees are emphasizing the ability of their organization to bypass existing structures and routines:

> *"Here we created a spin-off organization from one business unit, a small group of five people which has won two first small contracts and which transformed our technological know-how for a completely new market with different requirements. My merit was building a network by travelling around and hiring two additional people from the targeted industry for our spin-off organization. […] It is an independent team with an independent budget own sales structures, own technologies. […] You could never apply the same procedures and routines we use for our current core business, this would crush it. If you would report it regularly in all business reports, you would crush it. We protect it from our own organization." (I20, 0:03, 0:17)*

> *"We start initiatives like this in a so-called adjacency. When we recognize we cannot place a new product or technology in an existing business unit, this does not always mean "no-go". We are founding and establishing an internal start-up, and let them work under start-up conditions with regards to controlling and reporting etc. Nevertheless there is the idea that it will pay back later. If we have ambiguity and missing analogy to currently existing markets and/or technologies, we proceed like that." (I19, 0:47)*

Recommendation 4: "Fail early – fail cheap"-approach in new technology exploration.

Although the creation of versatility in intended technology strategy is important when facing alternative scenarios for the future, it is worthless and even dangerous, if it is not complemented by the ability to reduce versatility again when scenarios are eventually realizing or are becoming obsolete. A permanent monitoring and tracking of the realization of anticipated scenarios is mandatory. Regularly scheduled and also extraordinary strategy reviews must not only control for adequate goal conformance of strategic initiatives and projects but should also review the initial underlying assumptions and the overall relevance of pursued goals to avoid an escalation of commitment to an obsolete scenario. This is especially important, if several strategic initiatives should prepare the organization for alternative scenarios. R&D management should provide the organization with the sufficient ability to gradually rescale, abandon or suspend strategic technology projects, which are related to possible but not certain scenarios. An interviewee stated:

> *"It has to be stated that some topics within our technology strategy are dropped again, it happens regularly that we put a technology project or a complete technology path on hold." (I17, 0:29)*

Early and frequent stage-gates and milestones in technology development projects do not only allow tracking the project performance, or killing a project because of technological non-feasibility, but also enable a premature but well arranged dismissal, because of obsolescence of a pursued scenario over time. An experimental "fail early – fail cheap"-approach to technology development helps a company to afford an adequate level of versatility in its technology strategy, but also to focus and commit to a technology strategy when feasible and necessary. Although expenses without financial return in the short-run, a prematurely dismissed technology development project, that identified a technological dead-end or the obsolescence of a possible scenario, is also regarded as a valuable result by several interviewed companies. The generated insights decrease the overall ambiguity for the organization and may imply knowledge gains and exploitation possibilities over the long-run. One interviewee stated:

> *"Our basic approach regarding innovative ideas is experimental, positive and open […]. It is the message of the corporate executive board, if you have a good idea, start working on it, we will think where to put the costs later. […] But you definitely also need the ability to kill a technology project, to let it die, to put it on hold or to suspend it. […] We made the experience that saving money in early and cheap phases of new technology projects does not pay off. When you recognize too late that it does not work, it has already become expensive." (I10, 1:29, 2:11)*

Table 7-6: Recommendations to facilitate strategic involvement for imaginable scenarios in technology strategy.

Recommendation 1:	*Limit dominance of currently existing technological core competence.*
Recommendation 2:	*"Scenario thinking" in technology strategy development.*
Recommendation 3:	*Allow and enable "bypassing" of existing organization.*
Recommendation 4:	*"Fail early – fail cheap"- approach in new technology exploration.*

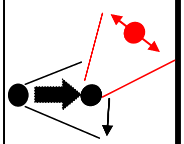
7.3 Enabling Technology Strategy Flexibility

The flexibility to deviate from an initially intended technology strategy was identified as the second domain of strategic flexibility. This deviation from an intended technology strategy – *technology strategy flexibility* – is considered as strategic flexibility, when it provides a company with *intelligence on weak signals*, *inducibility for sudden emergencies* and *illumination of converging evolutions*.

7.3.1 Recommendations for Strategic Intelligence in Technology Strategy

Strategic intelligence was described as the state of an organization of being sensitive and approachable to *weak signals*. A company needs to absorb weak signals on future technology turbulence by an adequate receptivity of the overall organization. If weak signals continue and are confirmed, the company needs to adapt by reformulating its intended technology strategy (see Table 7-7). Based on the analysis how the interviewed companies handled weak signals and individual appraisals by the interviewed experts, five general recommendations on how to facilitate *strategic intelligence* were identified (see Appendix E).

Table 7-7: Enabling strategic intelligence by ex ante absorbing and ex post adapting to weak signals.

Form of Strategic Flexibility	Absorptive Capability	Adaptive Capability
Strategic Intelligence	Receptivity	Strategic Reformulation
		

Recommendation 1: Increased range and sensitivity of "technology radar".

Several companies highlighted the importance of an increased scope for technology intelligence activities. An increasing scope for technology intelligence efforts increases the receptivity for *weak signals* of the overall organization. Some companies emphasized that they became more receptive for upstream and downstream activities in their value chain of their industry. This includes scanning activities beyond immediate suppliers and customers of a company. An interviewee stated:

> *"You have to apply a broader scope today. It is much more important to watch the whole environment for the application of your product and to accordingly align your products, materials and processes. For new technical topics, it is becoming especially important to view the linkages and interrelationships of a technology and its elements along the whole value-chain and beyond: An integrated view of the complete technological value-adding chain." (I21, 0:11)*

Some companies become directly involved in their customers' market research. They seek an early detection of shifts in requirements for their own products and are directly observing changes in end-consumer behavior, which may have an indirect and delayed effect on their industry. One interviewee vividly described the increasing efforts of his organization:

> *"What is becoming increasingly important for our product development and our strategies are ethnographic studies, no joke! You should never underestimate the insights if you send out researchers to [downstream and related markets] to observe actual behavior of*

> *people. We recognize early when something is out here: If [our product] is becoming obsolete or is substituted by [a different technology]. You have to send out such trend scouts. We are identifying and questioning the impact of trends on the behavior of people, but also identify consequences for us. […] It is important to sense such things, but you have to go out there yourself. We have a set of people which are actively watching the behavior of people out there [related to our products]. Additionally, we actively transfer the identified topics to our partnering research institutions. […] Several times a year we make global trips to partnering research institutions […] and we are involved in trend workshops with technology experts on their specific areas in a wide range of disciplines. Not just chemists and physicists […]. Here we are really hearing the grass growing: Here is something coming up, there is something coming up! A lot of traveling is necessary!" (I13, 1:00)*

Some firms also send employees to industry conventions, conferences and trade fares for emerging or new technologies, which are beyond the scope of currently employed or highly related technologies of the industry. They also emphasize the importance of informal external partner networks with universities and research facilities. One interviewee reported:

> *"One focus for us is the visit of technology expert symposia and conferences. We also emphasize the visit of these events in areas which are non-core to our company and beyond our current technological scope. We are also visiting conferences, which cover technological approaches that we have never employed at all and where we have no internal competence. The goal is to see: What else is out there! This is complemented by our large partner network of research facilities and universities from our regular project work, where partners call our attention on something new: Hey, have you already recognized this, there is something completely new!" (I4, 0:27)*

Recommendation 2: Steadiness of technology monitoring activities.

Several companies emphasized continuous and steady monitoring of identified technological topics and technological activities within the current industry boundaries and the importance of designated functions and roles for these activities within the organization. Some companies organize technology monitoring activities on product group, product, system, or module level within existing business units. Product or product group managers with the role of product champions or gatekeepers are responsible for a continuous observation of core technologies and activities of competitors. Depending on the relevance for the industry, these product champions and gatekeepers are highly involved in industry or technology specific network organizations and standardization boards, where industry-wide developments are monitored and influenced. These decentral monitoring activities within organizations are highly consistent with the current dominant design of the current product and manufacturing processes. In several companies this monitoring responsibilities are complemented by topic or competitor specific patent analysis activities, which are tracking filed and awarded patents in identified areas of interest. In several interviewed organization this patent analysis is usually a more centralized and sometimes even outsourced activity. One interviewee described:

> *"Especially in Europe we have a very good overview and network. [The European industry association for our industry] has a technology advisory board and for each core technology of the industry a designated technical group […]. Within each of these technical groups we have at least one of our employees – actual we are the only corporation with a representative in each group. Here we intentionally bring our people in relevant positions. These employees do a lot of monitoring, because they see nearly all significant research projects and proposals within the industry […]. That is intentionally that we are represented in each technical groups of the advisory board. [In another industry association] we are in all workgroups. Here we have a broader approach compared to our competitors. These involvements need time and resources, but we think it is worth the effort. Here we are really consequent. Another effort is the permanent screening of the patent landscape, where you can identify areas where patent activity is decreasing or patent activity is increasing." (I2, 0:43)*

Some companies emphasized the steadiness of technology monitoring activities and the relevance of this activity in creating an organizational capability to memorize and retrieve technological developments. Retrieving of already identified enabling or disabling factors for the introduction of a technology into a product or production process is focusing and improving future monitoring activities. One interviewee described:

> *"One result of a pre-assessment of a new technology could be the case that a technology is currently not interesting to us, we do not want to work on it right now. The important message in these cases is: We do not want to work on it RIGHT NOW! We are shelving all our ideas and findings and do not put them into the trashcan. Why? Because the suppliers of technology, know-how, and equipment usually continue their work on their ideas and technologies […]. Maybe in two or three years the technology is interesting to us. So it is important to remember the insights of a former pre-assessment of this technology and to shelve it. […] It happens regularly, that several years later we have to retrieve these insights and continue working on it, because things have changed: Recently, we had the case with [an alternative material]. This was a big topic ten years ago for a certain core element of our products. It was not feasible to use [the material] in series production, because of certain mechanical properties […]. During the last one or two years this topic is coming back again, because there are new alloys and new manufacturing technologies available. […] Today there are solutions to overcome the initial problems of the past. […] A shelved pre-development project from ten years ago is continued today. Ten years ago this was a dead end. […] Without the retrieved knowledge from the pre-assessment we would not even know the problems and the disabling factors [of this technology]. (I4, 0:12, 0:59)*

Recommendation 3: Corporate function of technology and innovation management.

Many companies emphasized the importance of a designated corporate technology and innovation management function, which can act beyond the focus and scope of an existing business unit. In many cases this function is organizationally implemented as a staff position to the corporate CTO. An interviewee stated:

> *“Technology and innovation management is a staff position to the CTO at corporate level. The first main task of this position is the identification, monitoring and pre-assessment of new technologies, the assessment of potential threats and opportunities of new technologies for the corporation.” (I21, 0:01)*

In many cases this position goes in parallel with an organizational separation of technology monitoring and technology scanning activities. Several companies highlight that technology monitoring activities, which are tracking developments in already employed or highly related technologies, should be a more decentral task within business units or product groups. Technology scanning should be a task at central and corporate level. Scanning activities are searching beyond the current industrial environment for new, emerging and even exotic technologies and industries, which are off the scope of any monitoring activity of a business unit, but which may have impact on one or more units in the future. One interviewee reported on the efforts of his organization to install an innovation management function as a central “eavesdropper”:

> *“Here we are currently establishing an innovation management function and adequate processes. […] Here we are expecting significant improvements. […] This coordinative function is getting input from various sources: From our sales organization, which is detecting unsatisfied demands, from product engineering and technology pre-development, which have their own sources, but also from the CTO or COO top-down […]. A new director position for innovation management, which is subordinated to the CTO, will be responsible for this process. This will become our new “eavesdropper”. It also about horizontal coordination across all business groups, plants and facilities: Maybe there are similar ideas at the same time in different plants. We should coordinate these innovation efforts and avoid wasting money by unintended parallel efforts in different parts of the corporation.” (I5, 0:44)*

Recommendation 4: Opening up the overall innovation process.

Many companies highlighted the importance of opening up the overall innovation process of the organization, internally and externally. Increasing complexity and diversity of technologies do not allow for a closed and purely internal innovation process anymore. The receptivity of the organization has to be increased along all phases of the innovation process. Several companies emphasized the importance of regular trend and scenario workshops with external participation. This includes technology experts from research facilities and adjacent industries. One interviewee described:

> *“We call that technology import. Three to four times a year we are organizing technology & scenario workshops with around 20 internal key employees from various areas and invited external technology experts on alternating technologies, which are new to us. Last year, for example, we had a laser-workshop with an institute from the Fraunhofer society on laser technology. […] Currently we do not have any laser-based technology in-house. The result of one of these workshops is typically a pool of ideas, suggestions and project proposals on how a technology could potentially affect our company and how this technology could be implemented into our organization.” (I20, 0:06)*

Some companies state the importance of regular formal and informal meetings with technology and equipment suppliers and the willingness to listen critically but unbiased to their new ideas and proposals. An established reputation for interest and openness regarding new and innovative technologies may attract many exclusive proposals by innovative companies. A limited rigor at the first strategic-filter-gate for idea and proposal assessment, which is checking the strategic fit of a proposed, may limit the threat of non-intended rejection of path-breaking innovation ideas in very early phases. One interviewee emphasized:

> *"I am strongly arguing that it is not possible to maintain a strategic filter for technology innovation in the early phases, because it may turn out as a too strong limit." (I4, 0:41)*

Incentive systems for the overall innovation process should transform a "not invented here"-approach into an "invented anywhere, innovated here"-approach. The opening of idea management platforms and routines for all parts of the overall organization and also for selected external partners is suggested by several organizations. One interviewee stated:

> *"The origin of today's openness of our company for innovation was the opening of the overall innovation process to all of our employees. We somehow established a feasible and sustainable internal idea management platform. […] It was not easy at all to motivate all of our employees to share their ideas. Somehow we found the right balance of incentives, indirect cultural changes and internal awareness of management over time. […] We started in 1997 with 43 new ideas, today we have 7000. […] In 2003 we said, if this works internally, we could possibly open the innovation process externally. […] Eventually we open the same channels for external partners as for internal employees. […] For the first pilot phase we limited these routines for research facilities and universities, but we intend to open it for customers and suppliers. […] We made several focus groups sessions with our current partner institutions on this topic, which showed that under certain conditions external partners may be willing to ally and even work together on one idea proposal." (I13, 0:50)*

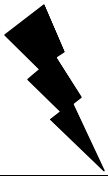
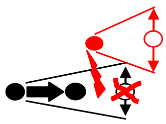
Table 7-8: Recommendations to facilitate strategic intelligence for weak signals in technology strategy.

Recommendation 1:	*Increased range and sensitivity of "technology radar".*
Recommendation 2:	*Steady technology monitoring activities.*
Recommendation 3:	*Corporate function of technology and innovation management.*
Recommendation 4:	*Opening up the overall innovation process.*

7.3.2 Recommendations for Strategic Inducibility in Technology Strategy

Strategic inducibility was identified as the organizational state of being inducible for technology turbulence in form of sudden emergencies in the business environment. The underlying capabilities, which are necessary to create this state, are the capability to absorb sudden emergencies by an overall agility of the organization and the adaptive capability for a rapid response, which may disrupt the initially intended technology strategy (see Table 7-9). Based on the analysis how the interviewed companies handled sudden emergencies and the opinions of the interviewed experts, five general recommendations on how to enable strategic inducibility were identified (see Appendix E).

Table 7-9: Enabling strategic inducibility by absorbing and adapting to sudden emergencies.

Form of Strategic Flexibility	Absorptive Capability	Adaptive Capability
Strategic Inducibility	Agility	Strategic Responsiveness
		

Recommendation 1: Create and enable an adequate sense of urgency.

A possibility to maintain agility in organizations is to create and enable a general sense of urgency within the organization. Although it is not possible to specifically prepare for an unknown sudden emergency, an existing sense of urgency may accelerate actions of the organization when necessary. More and more frequent cycles of technology strategy meetings and workshops may allow for real-time responses to changes in initial assumptions and a permanent or more frequent review of adjacent markets and technologies may enable an early detection of unexpected changes. To prepare for unexpected surprises, the company should create and establish organizational routines for urgent responses like fast product innovation and imitation. Approaches like concurrent or simultaneous engineering, rapid prototyping or reverse engineering and the ability to come up with "quick and dirty"-concepts when necessary, may allow an organization to respond rapidly for unexpected moves of competitors. Capabilities for fast industrialization of promising innovations and scalability of production capacity enable rapid exploitation of successful R&D projects. One interviewee emphasized the importance to replicate technological expert know-how ahead of time:

> *"The question is also how distributed technology competence is within the organization. Not just how much do we know, but also how many different people know it! How many people within our company are really experts in one technology? […] If we have only*

> *one "guru", we have problems, if he is not available for any reason. In many technological disciplines of our organization, where we think we have a critical mass, you can count the technology experts with the fingers of one hand […]. It is important to replicate critical technological expertise early. (I21, 0:57)*

Some interviewees also emphasized their preference for planning and communications tools, which show an explicit time dimension, to create adequate urgency in decision making.

> *"I prefer technology roadmaps over any portfolio technique, because I have a direct and visible time dimension and the communication with and presentation in front of the executive management board is more successful and comprehensible. The roadmap is saying: Time passes on! If it is important to have a certain technology by the end of 2009 I have to act right now! It creates urgency." (I13, 0:58).*

Recommendation 2: Avoid that technological core competences become core rigidities.

Especially companies with significant success in their current businesses have to be careful that the sources of competitive advantage of today are no limitation for the agility of the organization in the future. Several companies emphasized that it is important to avoid complacency and arrogance in successful R&D and manufacturing departments. Past and current success can make organizations rigid and slow over time. Especially, if a company was very successful with a technological core competence over a certain period of time, this domination of a core competence may create rigidity in thinking and acting for the whole organization.

> *"I think it is very important to establish a technology-life-cycle-management approach. Over the long run the amount of different technologies in an organization will rise automatically and this is additionally negatively influenced by the fact that companies stick to old technologies, because of their past success. In many cases these technologies became commodities and do not provide any cost advantage or factor for differentiation. It is always difficult to leave a technology, which you have perfectly mastered over years." (I19, 0:10)*

> *"There is no automatic technology dynamic in an organization, actually it is incredible difficult: Production people usually always fight the abandonment of a mastered technological competence. Even in our high-tech locations in high-wage countries that is true […]. Leaving a former core technology is very hard for a company." (I6, 0:13)*

Some interviewed firms emphasized to constantly strive for opportunities, to be proactively disruptive for competing technologies in their "home grounds", and to cannibalize own products and technologies in the existing markets before existing or potential competitors eventually do it. Some companies recommend to embrace emerging substitution technologies as early as possible and to try to turn them into complements to already existing competences.

> *"If we enter [technology A] it will negatively affect our existing business. But we are always saying: If we do not move there, someone else will! We think the technology and*

> *our company is mature for this step, and in such cases we enter competing technologies, although we know it may cannibalize some of our existing business." (I20, 0:20)*

Recommendation 3: Organizational fluidity.

A key in preparing an organization for sudden emergencies is that a company creates agility in its organization before it eventually knows for what exactly this agility is eventually needed. Several companies therefore emphasize temporary forms of organizations more than their formal organizational structure. These companies prefer to adapt their organizational structure regularly but gradually:

> *"Our environment is constantly changing, and so we are permanently adapting our organizational structure, which is absolutely necessary: Last year we introduced a new matrix organization with product groups and regional markets. This is a permanent topic and we make continuous adaptations, here we are not rigid but very dynamic […]. " (I5, 0:06)*

> *"In real-world practice this means that, over the last years, we stopped having a permanent and rigid organizational structure, which is stable for, let's say, 7 years and then there is an extensive re-organization. […] Today we gradually and incrementally adapt to changes by temporary organizational forms, which may turn out to become permanent." (I21, 2:40)*

When *sudden emergencies* disrupt the scheduled product development agenda, this organizational agility may allow faster and unhindered shifts of priorities and resources. Although inefficient in the short-run, intentionally undesignated "slack"-resources for spontaneous "fire fighting"-projects and intentionally endured overcapacities in R&D&E may be critical when *sudden emergencies* demand for a timely and proper response.

> *"We managed to establish a pool of special and undesignated resources, which enables us to say: Let's try this immediately without any bureaucracy." (I17, 0:16)*

> *"What we do right now, and we are currently in the middle of rearranging our organization, is to establish an intended free space for undesignated resources to handle unexpected developments." (I12, 0:25)*

Agility to shift financial and knowledge resources when necessary should be complemented by an organizational agility, which allows for "special-purpose"-organizations like internal start-up organizations or temporary spin-offs. These temporary organizations enable a company to respond to surprising developments, which cannot be handled within the existing organizational structure. Also, the organizational and financial capability of a company to acquire and successfully integrate another firm and its resources and capabilities was emphasized by interviewed companies, to enable timely and proper responses to *sudden emergencies* in the business environment.

> *"Here we nearly missed a replacement technology! Here we had to buy another company which had this technology […]. We had already the ability to immediately identify appropriate acquisition targets. […] Our market share was directly threatened, here we were very fast and we had the ability and liquidity to act that fast. Today, we are market leader again" (I22, 1:12)*

> *"If an already existing technology somehow becomes interesting to us, we also screen existing companies for acquisition targets. Because of our liquidity we are able to think about that. That is a clear strategic possibility before we waste too much time. […] In one case a breakthrough of a company in a technology we did not have in-house became a significant risk to us […]. From the detection of the threat until our formal offer to buy the company it took us a month" (I17, 0:45, 2:00)*

Recommendation 4: Unhindered communication and decision-making routines.

To enable organizational agility for the case of sudden emergencies, a company has to ensure that it has a corporate culture, which promotes open and unhindered communication within and across organizational boundaries and which avoids a "shoot the messenger"-approach in the case of surprising bad news. Creating the possibilities and stimulating the willingness for a direct communication of technology experts and relevant decision-makers and an "open door"-policy and accessibility of executive offices for employees may reduce avoidable delays in response to the detection of *sudden emergencies*. Reduced barriers for spontaneous and bypassing information requests and communication across vertical and horizontal organizational boundaries helps to accelerate decision making and may enable fast resource reallocation decisions. If a fast response of the organization is necessary, a "quick and dirty"-approach to decision making is emphasized by several interviewees to avoid "paralysis by analysis". Repeated and more feed-back loops ensure later improvements or corrections of initial decisions.

> *"There are no long discussions […]. Necessary and first reactions to become more informed and to verify things rapidly are a real strength of our company. We avoid discussions like, who is paying for that, what risk does exist, making a second or third feasibility study or analyzing a market which does not exist yet […] Just do it, than see what happens and react." (I15, 1:15)*

> *"The doors are always open, the ways are very short […]. We have some undesignated blank resources, because you never know what comes around." (I30, 1:15)*

Recommendation 5: Hire and develop flexible employees.

A valuable and very basic potential for overall agility of organizations is on the level of the smallest unit of any organization. Several companies highlighted the importance of flexible and mobile employees at all levels of the organization, especially when confronted with unanticipated changes in the business environment. The capability and willingness for flexibility by employees also contributes to the overall agility of the organization. While several companies highlighted the importance of hiring diverse and heterogeneous personnel, some emphasized the generation of the capability and willingness for flexibility by continuous education and training.

> *"Our employees in R&D have relatively broad duties and competences. The completely focused design engineer or developer does not exist in our organizations. The typical development engineer in one of our product projects covers, in general, all involved technologies […], and a typical project team consists of four or five engineers. As our engineers develop a relatively broad technological education and experience, the company and a single project does not depend too much on one engineer, even when we talk about specific tasks. Here we are relative flexible […]. The employees are used to that and are very mobile. Here we have a high maneuverability of the overall staff." (I30, 1:52)*

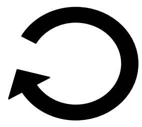
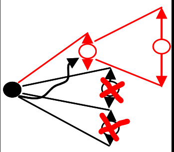
Table 7-10: Recommendations to facilitate strategic inducibility for sudden emergencies in technology strategy.

Recommendation 1:	*Create and enable an adequate sense of urgency.*
Recommendation 2:	*Avoid that technological core competences become core rigidities.*
Recommendation 3:	*Organizational fluidity.*
Recommendation 4:	*Unhindered communication and decision-making routines.*
Recommendation 5:	*Hire and develop flexible employees.*

7.3.3 Recommendations for Strategic Illumination in Technology Strategy

Strategic illumination was identified as the state of an organization of being teachable on technology turbulence in the business environments in form of *converging evolutions*, while pursuing an intended technology strategy. The underlying capabilities which are necessary to reach this state are the capability to gradually absorb *converging evolutions* by an overall learning ability of the organization and the capability for continuous adaption of the realized technology strategy by strategic incrementalism (see Table 7-11). Based on the analysis how the interviewed companies handled *converging evolutions* and the opinions of the interviewed experts, five recommendations on how to enable *strategic illumination* were identified (see Appendix E).

Table 7-11: ***Enabling strategic illumination by ex ante absorbing and ex post adapting to converging evolutions.***

Form of Strategic Flexibility	Absorptive Capability	Adaptive Capability
Strategic Illumination	Learning Ability	Strategic Incrementalism
		

Recommendation 1: Intentional creation of managed learning possibilities.

Some companies in the sample highlight the necessity to allow for and sometimes artificially create learning possibilities for R&D&E employees in the organization. A simple but easy way to execute this policy is to reserve a certain fraction the overall R&D budget for real long-term learning projects, which are not directly related to a currently existing business unit, key account, product group or core technology. These long-term involvements in learning initiatives with limited and variable resource commitments have various forms. Such initiatives were realized as purely internal projects, which are designated as a learning-platform for internal knowledge generation on a broad technological topic, or as a participation in a consortia-sponsored competence center at a research facility or university. In some companies learning possibilities are created by R&D workshops, which specifically promote "out-of-the-box"-thinking. In these special workshops the existing dominant design of current products and processes, which is often reflected in the organizational structure of R&D departments, is explicitly avoided as a unit of analysis. Some companies deliberately source technological machinery and manufacturing equipment, which offers applications and functionalities beyond what is currently necessary. While the asset may be underutilized, inefficient and over-engineered for its current purpose, it creates learning opportunities for the employees in the long run.

> *"If you have a look at our technology equipment in our company we have always the newest and technological most advanced equipment, which is beyond the average and necessary state-of-the-art […]. When we make decisions on sourcing new technological equipment and process technology, we take into account considerations about what the offered technology can do beyond our current needs. Most of the times the higher cost for the most-advanced technology is justified by these considerations and in many times the additional functionalities are eventually exploited. The existence of non-used functionalities and applications of an under-utilized technology triggers innovative ideas and thoughts on how to exploit it […]. This was exactly the case in [technology A] […]. What drives such decisions is the chance on a future opportunity."* (I23, 2:23)

Some companies also emphasize that, if economically possible and feasible, they prefer a higher vertical integration and a "do-it-yourself"-approach over external sourcing. They argue that unpredictable future learning possibilities and synergies in a vertically more integrated enterprise are usually not considered in outsourcing decisions that are mainly driven by short-term financial considerations.

> *"Another basic rule of our organization is, that we do not sell any technology to our customer that we do not have internally. We certainly do not base any of our products on a sourced technology […]. Step-wise and consequently we developed the necessary competence in-house or acquire other companies […]. This is valid for the breadth and depth of all technological competences." (I22, 0:07)*

Recommendation 2: Bring R&D&E people together face-to-face on a regular basis.

Many interviewed companies emphasized that the most important effort to create a learning environment across all R&D&E units within a company, is to enable and establish informal knowledge networks, which emerge from regular personal face-to-face contacts of the relevant people. Therefore the interviewed companies create multiple formal and informal opportunities to bring their R&D&E people together.

> *"My experience says that impersonal communication and knowledge transfer media do not work alone. The first inter-personal contacts are very important and should be face-to-face and a handshaking experience. Then eventually, people pick up the telephone. […] It makes a big difference how personal the introduction and integration of new colleagues across all relevant locations is managed. […] It cannot be overemphasized how big the influence of these practices is on mutual collaboration in innovative technology projects. […] Despite modern means of communication, I am highly convinced that the personal contact is still very critical." (I10, 2:23)*

Some of the interviewed companies organize annual or bi-annual events like internal product and technology conferences, trade shows or fairs which bring together the complete innovative capacity of the organization across all regions and businesses. Although a significant effort and resource commitment by the company, these meetings allow the emergence of private and professional contacts and networks across the complete company and beyond existing boundaries of organizations and competences. These informal contacts, created by the repeated celebration of such organized events, complement formal linkages within regular temporary or permanent organizational structures. Additional to these events, some companies highlight the importance of technology or competence specific networks, committees or teams across different plants, locations, product groups, or business units. Some company also proposed to integrate all research, development and engineering efforts into one locally dispersed but organizationally integrated innovation group. As most innovation tasks beyond continuous improvement processes within plants are processed in temporal, multidisciplinary, and locally scattered project teams anyway, the traditional distinctions in process development, product development, basic research and applied research may become obsolete. Exposing laboratory researchers and scientist to product and manufacturing engineering and vice versa, occasionally or on a regular basis, supports the emergence of learning and knowledge-sharing opportunities.

"We integrated this complete field of technological innovation and packaged it into one unit and it works very fine, currently. A project manager is leading various and different projects within his career, he can lead a product development project but also a basic feasibility project on a new input material. Everybody has more possibilities and the personal interlinkage and learning opportunities, which are created, are by far better. And it is by far easier to shift resources: Sometimes there are years when you have to invest more in research and pre-development projects […]. Sometimes we are mainly testing "incrementals" in our existing plants. By this pooled "innovation competence" everybody can work on everything in the long run. This is a real enrichment for the employees and keeps a steep learning curve, because people work on different technologies with different levels of maturity and at different facilities and plants of the organization. As long as it works and I do not find something better, we continue like this." (I13, 0:32)

Recommendation 3: Dynamic learning platforms instead of static knowledge databases.

Some interviewed companies emphasized the rising importance of knowledge management, but are also aware of its practical limitations. When it comes to valuable tacit knowledge, which is not explicit and seldom stable over time, knowledge management is eventually the management of knowledge carriers in form of technology experts. Detailed and holistic IT-based knowledge databases are regarded as problematic and the few interviewed companies, which tried to implement such systems, reported on low acceptance and low rates of active or passive use. Complementary to the emphasis of personal face-to-face contacts between technology experts, which were already outlined before, some interviewed companies use internal competence directories, which cover all relevant employees in R&D organizations of the company. These competence directories are regarded as "yellow pages" and "slimmed-down" versions of knowledge or competence databases, which were never finally realized. They should allow to identify and contact experts on a specific topic of relevance within the own organization. Although very simple and not a real knowledge database, these directories that contain all technical and scientific employees and a brief summary of their competences, experiences and past and current occupations and assignments, create learning possibilities within the organization and are easy to establish, to use and to maintain and can be easily integrated into common intra-net applications. Some companies identified social network software systems as a future chance to enhance these competence directories.

"There is the recurring idea of establishing a central knowledge database in our organization, but it was never implemented […]. It is never really up to date and what is really the benefit? I am fine when I know the name of the internal technology expert and I call him when I want to know something. If I want to know something on [technology A] I call the most relevant R&D program manager or send him my questions and he answers and it's done. Nobody really needs a database. I have the internal "yellow pages" and my own informal networks. I do not need it, because in the end it helps nobody […]. It would be a huge effort and eventually, after checking the database, you would call the internal expert and ask for help anyway." (I2, 0:45)

"From my point of view this [knowledge management] is an unsolved problem. We established various forms of knowledge databases during the last years, but the data is often

not up-to-date, nobody is really investing effort to actualize it and the systems are too anonymous […]. Recently, we had a discussion how we could transfer and communicate our latest R&D insights internally […]. Especially, if you are considering the breadth of topics and technologies which we are covering: For me a possible solution could be the establishment of decentral, web-based and dynamic knowledge sharing and learning platforms like Wikis." (I25, 0:49, 1:10)

"A downsized version of a knowledge database makes sense to us. The general internal name directory of individuals extended by competences and maybe some external links to allied research institutions – a simple competence database where anybody can easily find a first contact for a topic." (I20, 0:36)

Recommendation 4: Aspiring and enabling long-term employment of R&D&E personnel.

The development, identification and long-term employment of key-people in R&D&E units seem to be important for the learning ability of R&D organizations. Several firms emphasized that a key issue is to develop and keep experienced technology experts and decision-makers and to offer them possibilities for further development within the organization. If a company can avoid a "brain drain" of human capital, significant investments in further and continuous training and education of employees will pay back in the long-run. Some interviewed companies established internal management development programs or corporate academies and universities to institutionalize these efforts. It is also critical to offer researchers and engineers within the company alternative career paths beyond regular vertical steps in the hierarchy. Some companies encourage and stimulate horizontal mobility between different engineering, manufacturing and R&D units of the organization and develop horizontal career models for technology experts. This also enables a smoother internal technology and knowledge transfer from research and development into engineering and manufacturing by transferring employees. Some companies propose that technology experts, who were part of the initial pre-development team that brought a new or emerging technology into the company, should follow "their" technology over the life-cycle:

"You have to manage organizational boundaries within your company, […] if you have to handle technology transfer from R&D into a business unit you must ensure that all relevant information and insights are transferred. In these cases we are using a parallel transfer of employees. Parallel to the transfer of a technological topic, we are also transferring knowledge and relevant competence carriers. These employees are lost for research and development. Here we are emphasizing the long-term optimum for the overall organization. That goes in parallel with the personal development of the careers of people […]. A classical career at our company goes vertically through many organizational units within our company, only in few cases people end their careers in the same unit or department where it began, we prefer all-rounders […]." (I19, 0:24, 0:51)

"The horizontal mobility of employees over organizational boundaries within our company is very high. Employees change from manufacturing to engineering, from engineering to manufacturing, from engineering to sales and from sales to engineering […] but employees also stay significant periods of time at new occupations. […] We also provide

> *a generalist training for a pool of employees of 2 or 3 years. […] Intentionally we are driving this horizontal mobility […], which is wanted and promoted." (I30, 1:56)*

Recommendation 5: Corporate culture of mutual learning, teaching and knowledge sharing.

A corporate culture, which emphasizes the organization as a learning entity, seems to be a critical facilitator for a successful detection and response to *converging evolutions*. This seems to be especially valid for research, development and engineering environments within an organization. A corporate culture that emphasizes organizational learning can be realized by simple standardized routines in R&D project management. Several companies state that in the case of pre-development projects, additional learning goals for the organization and the involved team members are formulated, which are complementary to conventional project objectives. If a technology project is abandoned prematurely, it is important to identify, document and remember disabling factors within the organization. Lessons-learned and best-practice sessions as adequate closing ceremonies for successful, unsuccessful or suspended projects should address pre-formulated learning goals and additional unexpected insights. Several interviewees emphasized the potential impact of incentive systems in R&D&E on the learning culture of organizations. Primarily individual and purely financial incentives for R&D&E personnel are not regarded as adequate instruments to stimulate mutual learning and knowledge sharing within and across organizational units. Studied companies, which employ incentive systems in research and development, use a diverse mix of financial, non-financial, team-oriented and individual incentives, which is highly industry and company specific.

> *"We have lot of different things: Attractive and highly innovative customer projects, which are very interesting for all employees. That is an incentive for itself. Everybody can bring in ideas and work on his own initiative projects without too many restrictions in the very early and cheap phases. If there are results, he can continue. We have innovation competitions and innovation prizes; we have a patent competition and patent prizes. Which department and which employee came up with the best patent? It is a question of the innovation culture of the organization – all employees know that this is an important core topic to us […]. Innovation incentives we do have a lot, there are also organizational events where department and people are publicly awarded." (I25, 0:44).*

> *"We have a bonus system, and every department head in R&D can distribute the bonus individually. One year he can say: I assign no bonus this year! And in one year he can say: One employee had a positive impact because of his behavior, although he had no path-breaking innovation idea. But for the overall working of the team, he is assigned a bonus! We are completely free in awarding bonuses – individual and transparent, but without too much formalism. We had a lot of problems when we assigned monetary bonuses by counting innovation ideas: Then the discussion started: That was not his idea, but mine! My idea is more valuable! […] It was a huge mess […]. I think financial and monetary incentives may also hinder innovation: People stop talking openly to each other about their ideas and stop asking, what do you think? The mutual learning and knowledge sharing is blocked, because people say: I want my money! […] Within the last 40 years we have tried it twice, and both times it was stopped again." (I15, 1:30)*

> *"We have no financial incentive systems [in R&D]. […] Incentive systems for the whole technology and innovation field that we want to emphasize stronger in the future are: How do I stimulate that people are creative and open? How do I stimulate active participation in trend workshops, in idea generation and technology assessment workshops? Until today we have not found a systematic approach." (I21, 1:30)*

Some companies allow more senior and experienced technology experts to pursue spontaneous initiative projects outside formal boundaries of scheduled projects, research programs and budgeting routines. Although there are limits in terms of resources and number for these extra-ordinary projects, they facilitate an atmosphere of trust when a technology expert has the freedom to test a spontaneous intuition without formal proceedings and organizational hurdles. Similar to this approach, companies support or at least endure individual engagement of R&D employees in scientific and practitioner communities, which are beyond to the company's current technological competences.

Table 7-12: Recommendations to facilitate strategic illumination for converging evolutions in technology strategy.

Recommendation 1:	*Intentional creation of managed learning possibilities.*
Recommendation 2:	*Bring R&D&E people together face-to-face on a regular basis.*
Recommendation 3:	*Dynamic learning platforms instead of static knowledge databases.*
Recommendation 4:	*Aspiring and enabling long-term employment of R&D&E personnel.*
Recommendation 5:	*Corporate culture of mutual learning, teaching and knowledge sharing.*

7.4 Concluding Summary

Based on the interview data on how the studied companies handled incidents of technology turbulence and the opinions and suggestions of the interviewed experts, the previous sections presented transferable recommendations for strategic flexibility in technology strategy. The synthesis and categorization of these recommendations for enabling strategic flexibility is derived from the analysis of the primary data with a direct reference to the relevant interview section (see Appendix E). Based on the empirically grounded conceptual framework of strategic flexibility from previous chapters, these recommendations reflect building blocks, which eventually enable organization to develop and pursue flexible technology strategies and to successfully deviate from an initially intended technology strategy when facing incidents of technology turbulence in their business environment. Figure 7-4 is summarizing the recommended efforts and integrates them in the developed conceptual framework of strategic flexibility in technology strategy. Different incidents of technology turbulence demand different forms of strategic flexibility in technology strategy. An adequate alignment of the creation and exercising of strategic options with incidents of technology turbulence allows dynamic change patterns in technology strategy over time. The overall ability of an organization to create and exercise strategic options in technology strategy is constituted by organizational capabilities to proactively absorb incidents before they occur and to reactively adapt to incidents during or after their occurrence. Absorptive capabilities enable a company to create adequate strategic options in technology strategy, while adaptive capabilities enable companies to exercise or abandon these options selectively.

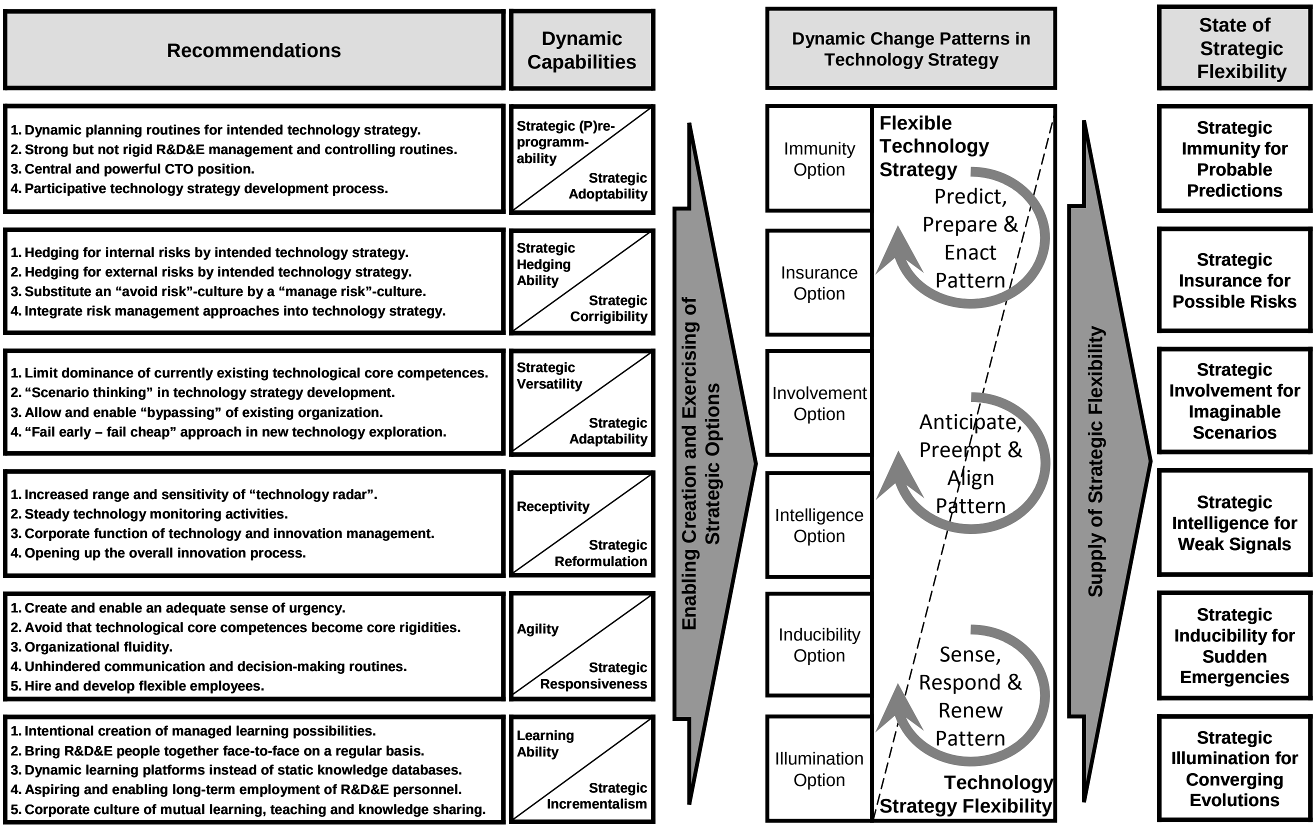


Figure 7-4: ***Recommending enabling efforts for strategic flexibility in technology strategy.***

Although conceptually different, absorptive and adaptive capabilities are eventually two sides of the same coin. Ex ante absorbing alternative *imaginable scenarios* in a versatile intended technology strategy by scenario planning techniques is futile and even dangerous, if a company is not able to gradually adapt its technology strategy to the realizing conditions by eventually emphasizing or killing scenario-specific initiatives. Absorbing predicted technology changes within the intended technology strategy of an organization by dynamic planning routines may be worthless, if a CTO is not able to implement and enact the change in technology strategy within his organization. Although different forms of technology turbulence demand different efforts by an organization to generate the necessary form of strategic flexibility, many of the identified recommendations may only generate strategic flexibility when cumulatively realized or complemented by other efforts.

Conclusion RQ 4: Eventually strategic flexibility in technology strategy is not enabled by strategic options or generic organizational capabilities, but by specific efforts and rou-

tines in the daily practice of industrial organizations. Strategic options in technology strategy are the instrument, which converts and transforms these efforts and routines into actual and observable flexible changes in technology strategy of organizations. Although these efforts and routines are highly company, industry and context specific in industrial practice, the aggregated analysis of why companies were able to manage technology turbulence successfully and the appraisal of the interviewed experts allowed to formulate recommendations on how the studied companies create and maintain the identified forms of strategic flexibility (see Figure 7-4).

PART D: FINAL REMARKS

8 FINAL DISCUSSION AND CONCLUSION

This final chapter summarizes and discusses the findings and implications of this research. Based on the research questions, the conceptual and empirical main results of this thesis are presented in section 8.1. Subchapter 8.2 identifies and formulates implication of this thesis for management practice and research. Finally, chapter 8.3 addresses limitations of this research and highlights further possibilities for related conceptual and empirical research.

8.1 Concluding Summary of Results

The main objective of this research was to identify and study forms of strategic flexibility in the technology strategy of industrial organizations that successfully faced technology turbulence in their business environment. Based on the literature review of relevant research and a-priori constructs for technology strategy and technology turbulence, an interview guide for expert interviews with senior technology managers of large and technology-intensive companies was compiled. Four research questions were specifically addressed in this research:

RQ 1: *How is the notion of strategic flexibility related to the general concept of strategy in the context of industrial organizations in competitive business environments?*

RQ 2: *Which forms of technology turbulence do industrial organizations perceive in their business context?*

RQ 3: *Which forms of strategic flexibility can be identified in technology strategies of industrial organizations when facing technology turbulence?*

RQ 4: *What enables industrial organizations to create and maintain identified forms of strategic flexibility in their technology strategy?*

While the first research question guided the desk research on the notion of strategic flexibility and its relation to the overall strategy concept in general, research questions 2, 3, and 4 were addresses by analyzing the collected qualitative data from expert interviews with senior technology managers of industrial organizations. The following sections summarize the key findings for each research question in this thesis.

RQ 1: How is the notion of strategic flexibility related to the general concept of strategy in the context of industrial organizations in competitive business environments?

Based on the review of related literature, it was observed that the notion of strategic flexibility is used in various disciplines of business management research as a broad attribute of industrial organizations, which successfully handle strategically relevant changes in their business environment. Compared to conventional or regular changes in the business environment, the notion of strategically relevant changes indicates that currently attained or pursued competitive advantages are threatened and are therefore not sustainable but only temporary. Under these conditions a reversible changeability of strategy was proposed to be advantageous. The review of related and relevant literature revealed three dominant and complementary aspects of strategic flexibility:

- Strategic flexibility as an organizational state.
- Strategic flexibility as strategic options.
- Strategic flexibility as an organizational capability.

Based on these dominant perspectives in the literature, this research described strategic flexibility as an organizational state, which is a complementary concept to the state or strategic fit emphasized by most conventional strategy concepts. If the overall goal of an organization is to sustainably survive as an independent entity, its strategy has to establish a balanced equilibrium between strategic fit and flexibility, which somehow corresponds with the degree of turbulence in the business environment. Regarding specific manifestations of strategically relevant change that companies face in their business environment, this condition of strategic flexibility is generated by adequate creation and execution of strategic options. These strategic options on the future adoption or abandonment of strategic positions of competitive advantage allow gradual, reversible and changeable commitments in a firm’s strategy. To be able to create an adequate set of strategic options that correspond to strategic relevant changes in the context of an organization, a company needs dynamic capabilities for ex ante absorption of strategically relevant changes in the business environment. To be able to adequately execute or drop strategic options that correspond to strategic relevant changes in the context of an organization, a company needs dynamic capabilities for ex post adaption to the occurrence of strategically relevant changes in the business environment. While absorptive capabilities are necessary to transform and convert insights on recognized strategically relevant changes into strategic options, adaptive capabilities are necessary to transform or convert strategic options into committed strategic positions of competitive advantage. The integration of the notion of strategic flexibility in the general strategy concept, which is proposed in this research (see Figure 8-1), has two major implications: Regarding the overall goal of sustainability and survival of a firm as an independent entity in turbulent business environments, strategic fit and strategic flexibility are complementary, as each of them is necessary but not sufficient to realize this overall goal. Regarding the currently available and limited resources of an organization, the pursuit and realization of both, strategic fit and flexibility, compete for these resources. An optimal firm strategy has to find a balanced equilibrium.

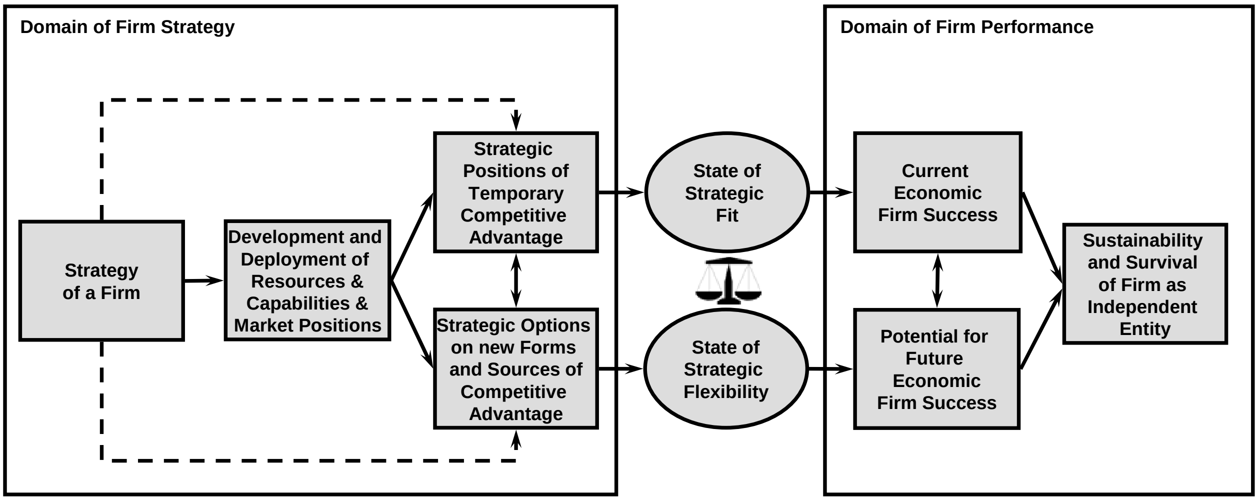


Figure 8-1: Integration of strategic flexibility into the strategy concept (equivalent to Figure 3-10).

In very stable business environments, where no strategically relevant changes occur, *survival of the* (strategically*) fittest* should be the guiding rule. Companies are most successful, if their pursued strategy perfectly matches their resources with their current business environment. In more turbulent environments, where phases of stability are disrupted by phases of strategically relevant changes, *survival of the sufficiently* (and strategically) *fit and flexible* is the maxim. Today’s survival and firm performance is ensured by an adequate strategic fit with current business conditions but complemented by an adequate portion of strategic flexibility, which makes sure that tomorrow’s survival is not limited by an overemphasis of a perfect but only temporary strategic fit for today’s environment.

RQ 2: Which forms of technology turbulence do industrial organizations perceive in their business context?

This research explicitly focused on strategically relevant changes in the technology context of organizations. The notion of technology turbulence was introduced to summarize incidents, which affect technology-based competitive advantages of studied organizations and are therefore of strategic relevance for these organizations. The analysis of the collected interview data reveled that industrial organizations perceive technology turbulence as distinguishable incidents of strategically relevant changes in their technology context. Analysis of 116 historical and recent incidents of technology turbulence, which were reported in the interviews, showed that these incidents can be distinguished by the initial timing and quality of perception of an incident by the affected organization. Regarding these criteria, three rough categories with two sub-categories in each were identified (see Table 8-1).

Table 8-1: Identified categorization for incidents of technology turbulence (equivalent to Table 6-13).

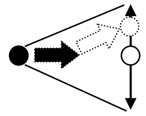
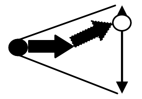
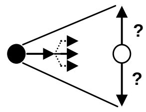
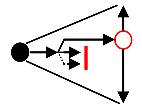
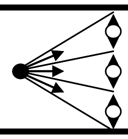
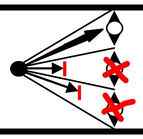
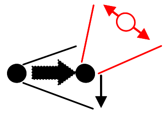
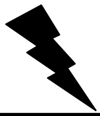
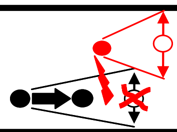
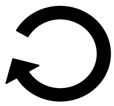
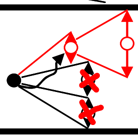
	Incidents of Technology Turbulence	Timing of Initial Perception	Quality of Perception	Resulting Ambiguity	Commitment and Specificity of Proactive Measures
Known Knowns	Probable Predictions	Before occurrence	High	Low	Very High
	Possible Risks	Before occurrence	Medium	Medium	High
Known Unknowns	Imaginable Scenarios	Before occurrence	Low	High	Medium
	Weak Signals	Before occurrence	Very low	Very high	Low
Unknowns	Sudden Emergencies	During / after occurrence	Prompt detection	None – Unawareness	Low / None
	Converging Evolutions	During / after occurrence	Gradual detection	None – Unawareness	Low / None

It was concluded that the way how organizations perceive an incident of technology turbulence, has significant influence on the triggered behaviors and actions to manage this incident and therefore demand specific and different forms of strategic flexibility in technology strategy.

RQ 3: Which forms of strategic flexibility can be identified in technology strategies of industrial organizations when facing technology turbulence?

As the research was limited to strategically relevant changes in the technology context of an organization, it was expected that these changes affect intended and realized technology strategies of these organizations over time. Analysis of the reports on how companies perceived and managed historical and recent incidents of technology turbulence revealed three different patterns of technology strategy formation and change. Depending on initial timing and quality of perception of specific incidents, six different forms of strategic options were identified within these dynamic change patterns in technology strategy. These six basic and generic forms of strategic options stand for six forms of strategic flexibility they generate. The phenomenon of strategic flexibility in technology strategy was divided into two domains: The build-in flexibility within an intended technology strategy, which was labeled as *flexible technology strategy,* and the flexibility to deviate from an intended technology strategy during realization, which was labeled *technology strategy flexibility*. It was concluded that each form of strategic flexibility demands different capabilities to ex ante absorb technology turbulence and to ex post adapt to technology turbulence (see Table 8-2).

Table 8-2: ***Forms of strategic flexibility in technology strategy and necessary organizational capabilities to absorb and to adapt to incidents of technology turbulence (equivalent to Table 6-22).***

	Forms of Strategic Flexibility	Absorptive Dynamic Capabilities – Capabilities to Create/Identify Strategic Options		Adaptive Dynamic Capabilities – Capabilities to Exercise Strategic Options	
Flexible Technology Strategy	**Strategic Immunity for Probable Predictions**	Strategic (P)Reprogrammability		Strategic Adoptability	
	Strategic Insurance for Possible Risks	Strategic Hedging Ability		Strategic Corrigibility	
	Strategic Involvement for Imaginable Scenarios	Strategic Versatility		Strategic Adaptability	
Technology Strategy Flexibility	**Strategic Intelligence for Weak Signals**	Receptivity		Strategic Reformulation	
	Strategic Inducibility for Sudden Emergencies	Agility		Strategic Responsiveness	
	Strategic Illumination for Converging Evolutions	Learning Ability		Strategic Incrementalism	

A *flexible technology strategy* demands absorptive dynamic capabilities from an organization, which enable it to ex ante absorb insights on anticipated changes in its intended technology strategy. A flexibility potential is created within intended technology strategy by the creation of adequate strategic options. As anticipated incidents eventually occur or dissolve, a *flexible technology strategy* demands ex post adaptive capabilities of an organization to either implement or reverse the intended technology strategy adequately. The generated flexibility potential is exploited by selectively exercising or abandoning open strategic options. *Technology strategy flexibility* demands quite generic absorptive dynamic capabilities from the organization, which allow an organization to successfully absorb the occurrence of unanticipated events that are not on the current agenda of the intended technology strategy. The existence of these absorptive capabilities creates the strategic option on an immediate and adequate response to unanticipated events. The related adaptive capabilities enable an organization to deviate from the currently intended technology strategy with an adequate response to unanticipated incidents and to formulate a new intended technology strategy based on the new conditions.

RQ 4: What enables industrial organizations to create and maintain identified forms of strategic flexibility in their technology strategy?

While the previous research question was addressed by identifying, observing and describing dynamic patterns in technology strategy formation and change over time when companies were confronted with specific incidents of technology turbulence, this more practical oriented research question was aimed to identify recommendations for the underlying enablers of these dynamic patterns. By applying the identified forms of strategic flexibility in the analysis of efforts by studied companies to successfully handle incidents of technology turbulence, transferable recommendations for the design of technology strategy activities were derived from the collected data. These identified recommendations cover various issues in the domains of technology strategy content & decisions, technology strategy formulation & methodology, technology strategy organization & infrastructure and technology leadership & culture. The results of the analysis revealed that creation and maintenance of strategic flexibility in technology strategy is eventually enabled and facilitated by quite basic efforts, routines and principles within these domains. The accumulation of these efforts, routines and principles enables a company to absorb and adapt to strategically relevant changes in its technology context by creating and selectively exercising strategic options. Figure 8-2 is summarizing 26 recommendations, which were proposed to facilitate the identified forms of strategic flexibility in technology strategy.

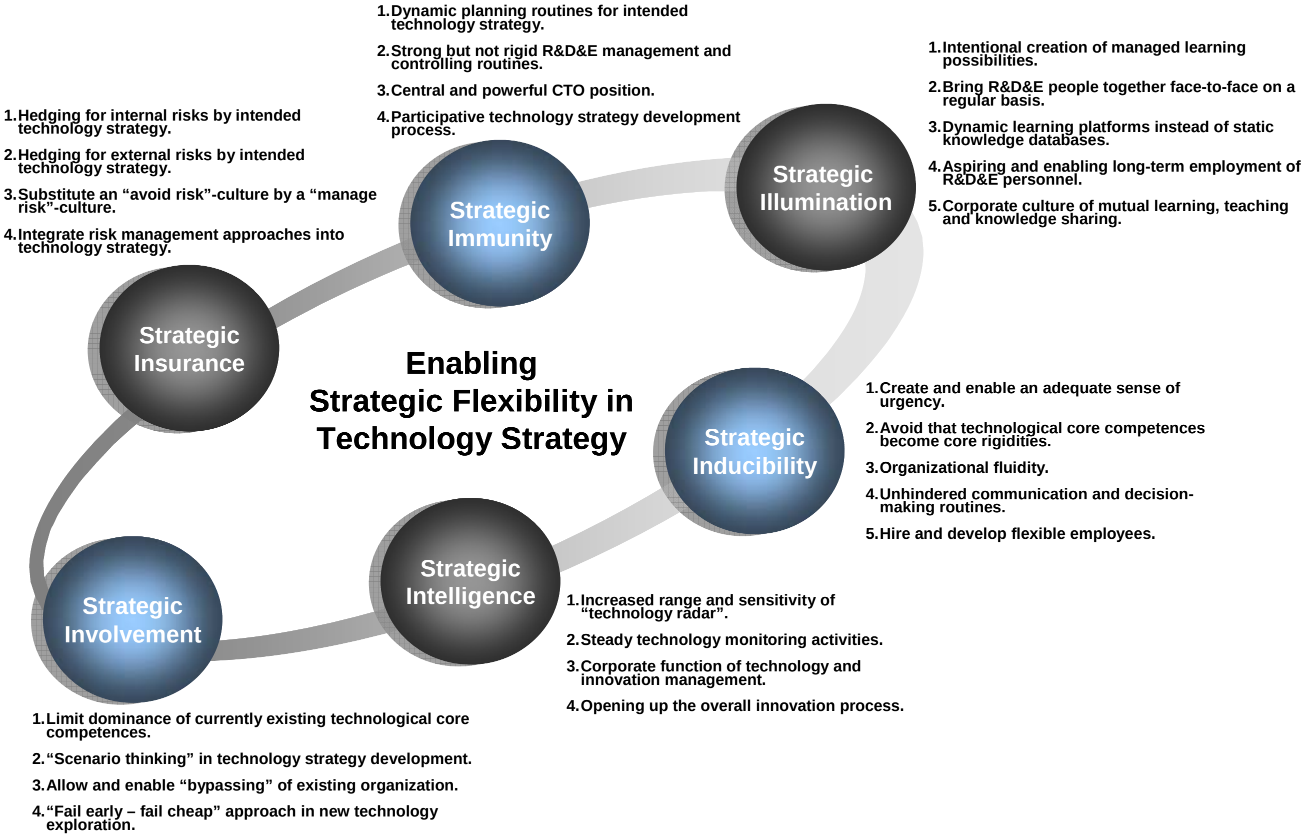


Figure 8-2: ***Transferable recommendations for enabling identified forms of strategic flexibility in technology strategy.***

These 26 recommendations claim to be independent from any specific context, industry or firm and were constituted by clustering diverse and similar or equivalent efforts, routines, and principles reported and emphasized by the interviewed experts (see Appendix E).

8.2 Implications for Management Practice and Research

The findings of this research are proposed to have implications for both management practice and research. As this research followed a grounded theory research design, it has a more descriptive character rather than a prescriptive one. It basically observed and conceptualized forms of strategic flexibility, which industrial organizations showed in their technology strategy when managing incidents of technology turbulence and did not suggest a prescriptive model or concept to strategic flexibility.

An implication of the notion of strategic flexibility is the necessary awareness of general management of industrial organizations that competitive advantage is not sustainable in today's businesses environment but only temporary. This is especially true for technology- and knowledge-intensive manufacturing companies in western high-wage countries, which compete on international or global markets. All companies in the sample reported past, recent and current incidents of technology turbulence, which were and are challenging competitive advantages in their industries. Even if a form or source of competitive advantage can be sustained for some time, the period of this sustainability is difficult to predict and may end promptly and unexpectedly. The analysis of reported incidents of technology turbulence showed that companies are also confronted with unanticipated occurrence of changes, which does immediately affect their strategic position, and not only with foreseeable changes, which can be prepared.

Another insight of this research conforms to an argument in the current discussion on capitalism, free market economy, short-term bias of decision-makers and incentive and bonus systems for general mangers, triggered by the economic crisis of 2008/09: If shareholder value and profitability maximization are the overall objectives of companies, strategic fit will always be overemphasized. This demands that strategic decisions of top-management are aligned with these objectives via adequate incentive and bonus systems. These incentive systems will guide top-management to follow a strategy, which streamlines the organizations for a highly efficient strategic fit with its current resources and businesses environment. Therefore, all available resources will be assigned to businesses and initiatives, which have highly profitable return-ratios. Underperforming businesses, which are not able to match the same financial return-ratios, are rather divested or liquidized, to invest all available capital into the high-performing businesses. Usually an announcement of corporations to leave or liquidate such underperforming business delights shareholders. The share price and/or the dividends increase and the management is rewarded via the incentive system by an adequate annual bonus or a stock option program. The *strategy paradox*, which was reviewed in chapter 3, suggests that the highest-return strategy is eventually also the highest-risk strategy. As competitive advantages are not sustainable, the return-rates will eventually decrease, either by competition, imitation, innovation, obsoleteness or some other form of exogenous change. Shareholders and equity investors are usually able to diversify these risks via parallel investments in unrelated industries and are usually faster in leaving stagnating or shrinking businesses than a company can build a succeeding high-return business. It is therefore questionable, if quarterly or yearly observations of shareholder value and profitability and related incentive systems for top-managers ensure the sustainable survival and success of companies in the long-run. Because of these or similar arguments advocates of sustainable corporate governance and general management intend to link incentive and bonus systems for top-management of industrial organizations with real long-term indicators for sustainable corporate growth and firm success. In this case, managers of companies who are creating strategic options are rewarded.

This research emphasized that strategic flexibility indeed is a polymorphous and multidimensional phenomenon. Depending on how good and when an incident of technology turbulence is perceived by a company, the necessary organizational capabilities to handle this incident change. Anticipated incidents can be explicitly addressed in planning and controlling routines before or during their occurrence. The possible occurrence of unanticipated incidents is implicitly addressed by certain attributes and characteristics regarding the organizational structure, routines, culture and leadership approaches which allow a company to respond to unanticipated changes. This general observation was confirmed by the identified and clustered recommendations in chapter 7. While the recommendations to enable a *flexible technology strategy* emphasize more issues of planning and formulating a technology strategy and controlling the adequacy of its eventual implementation, the recommendations for the ability to detect the necessity to deviate from intended technology strategy and the ability to do so, implies more general aspects of how to organize and lead the overall organization. These findings underscore that strategic flexibility is grounded in all domains of general management: Planning, controlling, organizing and leading.

Another suggested implication of this research is the possible adverse effect of too focused orientation on either current businesses or on current core competencies. Strategic options are basically options on changing the current strategy, either by entering a new market, industry or product category where a current technology may be exploited in a new or modified way, or by building access to new technologies or technological innovations which may become tomorrow's new core competence. The idea of strategic flexibility by strategic options may also promote initiatives which contradict the market-based view and resource-based view of strategy. A strict *stick-to-your-knitting* mentality, regardless if market- or resource-oriented, does not leave any room for limited and partly reversible experiments in form of strategic options.

8.3 Limitations and Further Research

This research addressed four research questions, all with an explorative characteristic. Overall goal of this research was to study the phenomenon of strategic flexibility in the context of technology strategy of industrial organizations and technology turbulence in business environments. Due to necessary limitations of this research, several important topics were raised but not specifically studied. Furthermore, several new issues were identified as a result of this research that may be worth further investigations in form of conceptual and empirical research.

Scope of Research

To be able to identify, observe and describe specific forms and enablers of strategic flexibility, the setting of this research was limited to a specific unit of analysis, technology strategy, and a specific exogenous factor of influence, technology turbulence in the business context. Especially in the case of strategic flexibility for unanticipated changes in the technology context, it was observed that interviewees raised and emphasized issues which go beyond the boundaries of technology strategy of this research. It was concluded that the micro-foundations of generic strategic flexibility in industrial organizations, which are not specific for a certain incident or context, should also be studied on the more general level of corporate strategy of the overall organization. The current response of industrial organizations in western high-wage countries to the unexpected implications of the financial crisis of 2008/09 for the real economy may be an adequate context and probably unique chance for qualitative and quantitative empirical research on strategic flexibility when confronted with the occurrence of exogenous *unknown unknowns*. Longitudinal and multi-level research on generic strategic flexibility for unanticipated and significant changes, conducted in industrial organizations with a history of long-term success, may reveal underlying and maybe generalizable enablers and facilitators for strategic flexibility.

Research Design

The conducted research in this thesis has explorative and qualitative character and is applying a pragmatic approach, which combines elements of grounded theory with case study research. Given the fact that this research did not apply statistical and quantitative methodology for sampling, data gathering and analysis, its results cannot be generalized beyond the context of the observed organizations. The results and findings of this research may help to conceptualize and operationalize strategic flexibility for further quantitative research. This research may verify hypothesis, which are based on the proposed empirically-grounded conceptual framework of strategic flexibility and the suggested recommendations for enabling and facilitating strategic flexibility. The findings of this research on the phenomenon of strategic flexibility suggest that longitudinal and multi-level research of industrial organizations may reveal further insights, especially on the relationship between the sustainable success and survival of companies in the long-run and organizational capabilities, which enable strategic flexibility.

Company Sample

As described in chapter 2, the sampling of 25 companies for this research did not follow routines of random sampling, but applied the idea of theoretical sampling of the grounded theory approach combined with pragmatic considerations of firm and interviewee access. The one theory-driven limitation regarding the industry affiliation of studied companies claimed that the company should be from the manufacturing industry sector with facilities in western high-wage countries. This diversity allowed the identification of patterns which seem to be independent from a specific industry affiliation. A further possibility for research on strategic flexibility could be the parallel observation of very similar companies regarding size, location, markets, and industry in a comparative longitudinal study. A highly comparable content and context of strategic decision making when facing the same turbulences in the same business environments over a significant period of time would probably reveal insights regarding the trade-off between strategic fit and flexibility in different companies.

Excess Investments in Strategic Flexibility

This research focused on strategic flexibility as positive attribute of an organization, which is confronted with change. While strategic fit and flexibility are complementary concepts regarding the overall goal of sustainability and survival of a firm as an independent entity in the long-run, this research also proposed that the generation of a state of strategic flexibility is competing for the same pool of resources as initiatives for strategic fit. When budgeting R&D expenditures, funds and resources assigned to create strategic options on an emerging technology may directly reduce non-risky and profitable investments in the further development of a current core technology. As strategic options are only exercised if they pay-off later, the amount of created but non-exercised strategic options should be small. Excess investments for strategic options may occur for *known knowns*, *known unknowns* and *unknowns*. Excess investments for *known knowns* may be labeled *costs of perfectionism* and may occur when a company overinvests available resources in a perfect preparation for all predicted changes and risks before they occur and underinvests in its current strategic position. Excess investments for *known unknowns* may be labeled *costs of schizophrenia* because a company overinvests in the parallel observation and pursuit of all anticipated and imaginable technological scenarios and trends and spreads its resources over too many competing strategic options. Excess investments for *unknowns* may be labeled *costs of paranoia*, because a company overinvests in the general preparation of the organization for unanticipated catastrophes and crises. These excess investments in strategic flexibility are as fatal as a pure focus on strategic fit of all investments. Research on adverse and negative aspects and issues related to excess investments in strategic flexibility may reveal interesting phenomena. An overemphasis of strategic flexibility in the long-run may generate highly diversified corporations without any visible and valuable core, or it may reduce orientation and commitment of employees within the organization. As a permanent overemphasis on strategic fit is proposed to lead to strategic rigidity, which disables a company to renew a historically successful but obsolete strategy even when facing very obvious environmental changes, an overemphasis on strategic flexibility may create strategic fragility and complete arbitrariness or disorientation in strategic decision making.

Strategic Flexibility, Dynamic Capabilities, and the Agile Enterprise

During the literature review conducted for this research it was observed that diverse academic and practitioner-oriented research streams in the field of business management are approaching a similar goal from different perspectives. This research advocates notions like *Agile Enterprise*, *Adaptive Enterprise*, *Living Company*, *Intelligent Organization*, *Learning Organization*, *Ambidextrous Organization* and *Super-Flexible Companies* and describes an archetype of company which is able to successfully survive all kinds of changes in its business arena by mechanisms, which are often compared to biological evolution of successful species in nature. These contributions share the common proposition of increasing magnitude, frequency and complexity of change in today’s global business environment and the criticism of the conventional and traditional logic of the strategy concept in this kind of environment. Research in academia is currently studying, which *dynamic capabilities* organizations have or should have to be successful in these environments. Although the number of these contributions has steadily increased since the first mentioning of the notion of *dynamic capabilities* in the late 1990s, there is still no dominant research agenda or paradigm in the field of strategic management. Further academic and practitioner-oriented research should also increase efforts to integrate, merge or organize these conceptual ideas, and empirical findings to enable the emergence of a mutually accepted research agenda. One reason for the current conceptual confusion may be the difficulty (or even impossibility) to research these phenomena, like strategic flexibility, dynamic capabilities and sustainable firm performance by the currently dominating approach of quantitative, positivistic and cross-sectional research in academic research of strategic management. The financial and economic crisis of 2008/2009 also demonstrated that punctual observations of financial or accounting data from annual and quarterly reports and stock price related measures are neither sufficient indicators nor reliable predictors for sustainable firm performance. The applied indicators and ratios very often exclusively reflect and emphasize short-term thinking in decision-making and aspects of rationalization, optimization and efficiency for profit maximization.

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APPENDIX A – EXPERT INTERVIEW GUIDE

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Graz, …………

Betreff: Experteninterview zum Thema „Strategische Flexibilität durch Dynamische Technologiestrategie“

Sehr geehrte Damen und Herren,

im Zuge des Forschungsprojekts „Strategic Flexibilty by Dynamic Technology Strategy“ führt das Institut für Unternehmungsführung und Organisation an der TU Graz momentan eine explorative Studie durch. Dies erfolgt in Form von qualitativen Experteninterviews und wird von Wiss.-Ass. Dipl.-Ing. Björn Fellner im Rahmen seiner Dissertation durchgeführt.

Ziel der Expertenbefragung ist es, den Stand der Technologiestrategieentwicklung in der industriellen Praxis quer über verschiedene Branchen und Unternehmungsgrößen aktuell zu erfassen, um daraus Möglichkeiten und Empfehlungen zur Erhöhung der strategischen Flexibilität einer Unternehmung ableiten zu können. Dabei geht es vor allem um die Fragestellungen, den Ablauf und die benutzten Methoden und Techniken, die bei der Entwicklung von Technologiestrategien bzw. bei entsprechenden Entscheidungen bevorzugt werden, sowie natürlich um den geschäftlichen und industriellen Kontext, in dem diese stattfinden.

Mit einem ausgewählten Kreis von Erfahrungsträgern, welche die Schnittstelle zwischen Technologieentscheidungen und Geschäftsstrategie in Ihrer Organisation kennen bzw. mitgestalten, sollen bestehende Lösungen, Erfahrungen, etwaige Defizite und Verbesserungsmöglichkeiten besprochen werden. Zielpersonen für die Interviews sind somit Entscheidungsträger, beratende Stabstellen und Technologen der Organisation, welche an der Schnittstelle zwischen Technologie und Geschäftsstrategie tätig sind (z.B. hins. der Vorbereitung strategischer Technologieentscheidungen, Planung und Koordination der erforderlichen Maßnahmen u.a.m.).

Es würde uns sehr freuen, Sie bzw. Ihre Unternehmung in diese Untersuchung einbeziehen zu können und mit Mitarbeitern Ihrer Unternehmung, welche mit der Themenstellung vertraut sind, sprechen zu dürfen.

Wir haben bei ähnlichen Forschungsprojekten die Erfahrung gemacht, dass allein durch die gezielte Fragestellung das Bewusstsein der Interviewpartner geschärft wird und Sachverhalte bewusst werden, an die man vorher nicht oder nicht gründlich genug gedacht hat.

Das Projekt wird von unserem Institut selbst finanziert und hat keinen externen Geldgeber, dem wir in irgendeiner Art verpflichtet wären. Es besteht natürlich die Absicht, die Ergebnisse dieser Forschungsarbeit in einer Dissertation und – wenn genügend Interessantes gefunden wurde - auch in Fachartikeln zu veröffentlichen. Wenn wir selbst meinen, an die Grenze der Vertraulichkeit zu kommen, legen wir die beabsichtigte Formulierung vor einer Veröffentlichung unseren jeweiligen Informationspartnern zur Genehmigung vor. Dies geschieht auch in unserem ureigensten Interesse: Unser Forschungslabor ist die industrielle Praxis und wir werden uns hüten, es durch unbedachtes Verhalten zu beschädigen.

Die Zeitdauer für ein derartiges Interview beträgt voraussichtlich 90 Minuten. Dieser Zeitraum ist notwendig, um die Thematik ausreichend vertieft und in der nötigen Breite behandeln zu können. Aus Erfahrung darf ich Ihnen mitteilen, dass bei ähnlichen Projekten in der Vergangenheit seitens der Firmenvertreter vielfach der Wunsch nach einem längeren Gespräch geäußert wurde bzw. zusätzliche Gesprächstermine vereinbart wurden.

Es würde mich sehr freuen, wenn Sie selbst und der eine oder andere von Ihnen genannte Mitarbeiter Interesse und Zeit für das erbetene Experteninterview finden könnte. Herr Fellner wird sich erlauben, im Falle Ihrer Zusage, einen konkreten Termin zu vereinbaren.

Mit freundlichen Grüßen,

Reinhard Haberfellner
o.Univ.-Prof. Dipl.-Ing. Dr.sc.techn.
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Leitfaden für die Datenerhebung
in Form von Experteninterviews

Strategische Flexibilität durch Dynamische Technologiestrategie

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Anstoß und Problemstellung

Zunehmende Technologiekomplexität und -dynamik, teilweise massive Veränderungen und Verschiebungen innerhalb der Wertschöpfungssysteme und kürzer werdende Produkt- und Entwicklungszyklen, geben der Technologiestrategie als Schnittstelle zwischen der Geschäftsstrategie und den technologischen Möglichkeiten bzw. Notwendigkeiten eine große Aktualität und Gewichtung in vielen Industrien. Dies trifft in zunehmender Weise auch auf technologisch reife und stabile Branchen zu, besonders in westlichen Hochlohnländern. Zusätzlich erhöhen neue und konvergierende Technologien mit schwierig absehbarer Relevanz die Notwendigkeit, Geschäftspotentiale über die ursprünglichen Grenzen der eigenen Organisation und Industrie hinaus rechtzeitig zu suchen bzw. einzuschätzen.

Zielsetzung der Expertenbefragung

Ziel der Expertenbefragung ist es, den Stand der Technologiestrategieentwicklung in der industriellen Praxis quer über verschiedene Branchen, Unternehmungsgrößen und Wertschöpfungsstufen aktuell darzustellen und Möglichkeiten und Empfehlungen für die Erlangung von strategischer Flexibilität abzuleiten. Dabei stehen vor allem die Inhalte, der Ablauf und die Methoden und Techniken strategischer Technologieentscheidungen, der Technologiestrategieentwicklung und der geschäftliche und industrielle Kontext in dem diese stattfinden, im Vordergrund. Mit einem ausgewählten Kreis an Erfahrungsträgern, welche die Schnittstelle zwischen Technologieentscheidungen und Geschäftsstrategie in Ihrer Organisation darstellen bzw. mitgestalten, sollen bestehende Lösungen, Defizite und Verbesserungsmöglichkeiten erfasst werden. Typische strategische Fragestellungen im Zuge der Technologiesstrategie einer Unternehmung lauten beispielhaft:

- In welchen Technologien wollen wir die technologische Entwicklung aktiv und führend vorantreiben und in welchen nehmen wir eine abwartende, beobachtende bzw. passive Position ein?
- Welche Technologien werden wir zukünftig in unseren Produkten bzw. Produktionsprozessen einsetzen bzw. welche nicht (mehr)?
- Wie gestaltet sich der vorgelagerte Analyse- und Entscheidungsprozess für strategische Technologieentscheidungen, was müssen wir bei diesen Entscheidungen berücksichtigen?
- Wie stellen wir den Zugang zu diesen potentiell relevanten Technologien zeit-, risiko- und kostengerecht sicher?

- Welche neue Technologien bedrohen von uns beherrschte technologische Kompetenzen, Märkte bzw. unser Geschäftsmodell und sollten zumindest beobachtet werden?

Zielpersonen der Expertenbefragung

Zielpersonen sind Entscheidungsträger (CEO, CTO, Geschäftsführer, Vorstand oder Vice President für Technologie, R&D&E-Leiter), beratende Stabstellen dieser Entscheidungsträger (Technologiemanagement, Innovationsmanagement, Strategische Planung, Corporate Development) und Technologen der Organisation, welche im Zuge Ihrer Schnittstellenfunktion zwischen Technologie und Geschäftsstrategie, strategische Technologieentscheidungen vor- und aufbereiten, analysieren bzw. durchführen oder dies mit anderen Geschäftsbereichen wie z.B. der Konzernführung, anderen Geschäftseinheiten und der Produktion horizontal und vertikal abstimmen.

Eingliederung der Expertenbefragung

Die Expertenbefragung dient als qualitative, empirische Studie mit explorativem und deskriptivem Charakter innerhalb des Forschungsprojekts „Strategic Flexibility by Dynamic Technology Strategy“. Neben dem aktuellen Stand in der wissenschaftlichen Forschung und den Ergebnissen der Vorstudie dient sie als Grundalge für die Konzeptualisierung einer dynamischen Technologiestrategie, welche die strategische Flexibilität einer Unternehmung positiv beeinflusst. Ganz bewusst werden Praktiken, Methoden und Vorgehensweisen in verschiedenen Industrien mit ganz unterschiedlicher Technologiedynamik erfasst.

Aufbau bzw. Ablauf der Expertenbefragung

Das Experteninterview wird als teilstandardisiertes, offenes Interview mit Unterstützung eines Leitfadens geführt. Dieser Leitfaden kann jedoch nicht als Fragebogen gesehen werden, sondern stellt nur eine Empfehlung für Abfolge und Gruppierung der Fragen dar. Die Gesamtdauer des Interviews beträgt normalerweise 90 Minuten. Das Interview wird auf einem digitalen Tonträger aufgenommen, aber nur in anonymisierter Form ausgewertet, dokumentiert bzw. archiviert. Als Teilnehmer an der Expertenbefragung erhalten Sie, falls gewünscht, den Endbericht mit der Auswertung dieser Studie.

Vertraulichkeit der Angaben

Die Entscheidung welche Daten Sie uns in welchem Detaillierungsgrad zur Verfügung stellen liegt ausschließlich bei Ihnen. Die Auswertung, Dokumentation bzw. Präsentation der Daten erfolgt ausschließlich in anonymisierter Form bzw. nach weiterer Rücksprache mit Ihnen.

Leitfragen für die Gestaltung des Interviewleitfaden

Aus den Forschungsfragen der Untersuchung werden folgende, explizite Fragestellungen abgleitet, die bei jeweils einem Experteninterview fallspezifisch beantwortet werden sollen und als Leitfragen dem Interview zu Grunde liegen. Alle im Interview gestellten Fragen beziehen sich auf die jeweils spezifizierte Organisationseinheit und dienen der vertiefenden Beantwortung folgender Leitfragen:

- Wie sieht der industrielle, technologische und organisationsspezifische Kontext aus, in dem Technologieentscheidungen getroffen werden?
- Welche Inhalte haben strategische Technologieentscheidungen und wie werde diese in der Organisation implementiert und operationalisiert?
- Wie und mit welcher Methodenunterstützung bzw. mit welcher Vorgehensweise erfolgen diese strategischen Technologieentscheidungen in der Organisation?
- Gibt es in der Organisation so etwas wie eine formulierte und kommunizierte Technologiestrategie? Worin besteht diese, aus welchen Aussagen bzw. Festlegungen? Wie ist diese entstanden bzw. wie entsteht sie?
- Wie belastbar, korrekturfähig, anpassungsfähig, aufnahmefähig, reaktionsschnell, und lernfähig gegenüber technologischem Wandel will die Unternehmung sein und warum?

Graz, …………   Björn C. Fellner

FRAGENKATALOG

Einleitende Fragen

1. Welche Funktion bzw. Rolle nehmen Sie in Ihrer Organisation wahr uns was ist Ihr wesentlichster Beitrag zur erfolgreichen Steuerung des Unternehmens und deren Zukunft?

2. Wie wichtig ist der Faktor Technologie im Produkt und in der Produktion generell für den Unternehmenserfolg in Ihrer Branche? Ist Technologie in Ihrer Industrie eine wichtige Quelle für Wettbewerbsvorteile?

Fragen zur Wahrnehmung des technologischen Wandels

3. Wie verändert sich momentan in Ihrer Wahrnehmung die Anzahl bzw. der Komplexitätsgrad der in Ihren Produkten und Prozessen eingesetzten Technologien?

4. Wie groß sind die aktuelle Vielfalt und die potentielle Auswahlmöglichkeit von konkurrierender bzw. substituiver Technologien in der Ihrer Industrie?

5. Wie würden Sie die Dynamik des schrittweisen technologischen Fortschritts in den Produkten, deren Funktionalitäten und den verwendeten Produktionsprozessen Ihrer Industrie beschreiben?

6. Standen früher oder stehen momentan Technologiesprünge oder massive Technologieveränderungen an, an deren Bewältigung sind momentan arbeiten? Kommen Technologiesprünge in Ihrer Industrie regelmäßig vor?

7. Die Bewältigung neuer technologischer Entwicklungen aber auch die Erforschung bzw. Einführung einer neuen Technologie sind im Allgemeinen mit hohen Unsicherheiten und Risiken aber auch hohen Investitionen behaftet. Wie begegnen Sie bzw. Ihre Unternehmung diesem Konflikt im Allgemeinen?

8. Wie langlebig sind Wettbewerbsvorteile die auf Produkt-, Prozess- oder Materialtechnologien beruhen in Ihrer Industrie?

Anekdotische Fragen zur Technologiestrategie

9. Was war einer der wichtigsten, strategischen Entscheidungen für oder gegen die Implementierung einer Technologie oder die Verfolgung einer Technologieentwicklung in der Unternehmung?

10. Hat eine ausgeprägte technologische Kompetenz der Unternehmung schon einmal dazu beigetragen, dass man neue Produkt/Markt Kombinationen erschlossen bzw. eröffnet hat?

11. Hat Ihrer Unternehmung technologische Kompetenzfelder (Produkte oder Produktionsprozesse) verlassen (De-investments, Outsourcing etc.), welche ursprünglich Teil des Kerngeschäfts waren?

12. Hat Ihre Unternehmung Märkte oder Marktsegmente verlassen oder verlassen müssen, weil die eigene Technologie durch eine andere ersetzt wurde?

13. Hat man für die Verteidigung oder Neuerschließung eines Marktes schon einmal ein komplett neues Technologiefeld erschließen müssen?

14. Wurde eine Technologie aus einem Unternehmensbereich in einen anderen übertragen weil sich dort eine Technologieverwertung angeboten hat?

15. Gibt es momentan technologische Bereiche und Entwicklungen innerhalb oder auch außerhalb des momentanen technologischen Spektrums Ihrer Unternehmung, die Sie besonders genau beobachten?

16. Wurde eine Technologie oder eine technologische Entwicklung schon einmal „übersehen“ oder zu spät wahrgenommen, die sich später als relevant erwiesen hat?

17. Wurde eine neue und durchaus erkannte Technologie bzw. eine technologische Entwicklung schon einmal in Ihrer Relevanz falsch eingeschätzt und bewertet?

Faktfragen zur Technologiestrategie

18. Wie und wo adressieren Sie den Faktor Technologie und technologischer Wandel in Ihrer Unternehmens- bzw. in Ihren Geschäftsstrategien?

19. Verfügt Ihre Unternehmung über eine formulierte Technologiestrategie bzw. einen formalen Technologiestrategieentwicklungs- bzw. –planungsprozess, in deren Rahmen dann die wichtigsten, technologischen Entscheidungen behandelt oder entschieden werden?

20. Verfügt Ihre Unternehmung über einen übergeordneten Verantwortlichen für Technologiestrategie der Unternehmung?

21. Wie sind F&E, Produkt- und Produktionsentwicklung und deren Planung organisatorisch implementiert? Welche Personen bzw. Stellen in der Organisation sind für diese hauptverantwortlich? Wer koordiniert Ihr Zusammenspiel?

22. Gibt es eine aktuelle Übersicht der beherrschten technologischen Kompetenzen in der Unternehmung?

23. Wird interne und externe Technologieverwertung (z.B. interner Technologietransfer, Lizenzierung von Patenten) systematisch betrieben?

24. Wie ermöglicht sich Ihre Unternehmung den Zugang zu neuen Technologien?

25. Gibt es viele technologisch motivierte Außenbeziehungen (Partnerschaften, Kooperationen, Allianzen etc.) die über die normale Lieferanten- und Kundenkontakte hinausgehen?

26. Gibt es in Ihrer Unternehmung Policies, Verhaltensnormen oder eine spezielle Unternehmenskultur die den allgemeinen Umgang mit neuen Technologien und technologischem Wandel adressiert? Wenn ja, wie werden diese operationalisiert?

27. Welche Methoden bzw. Planungstools werden in Ihrer Unternehmung im Zuge der strategischen Planung, insbesondere im Bezug auf Technologie, technologischen Wandel und Forschung und Entwicklung eingesetzt?

28. Analysieren und evaluieren Sie aktuell beherrschte Prozess- und Produkttechnologien standortübergreifend nach wirtschaftlichen und technologischen Kriterien?

29. Verfügt Ihre Organisation über eine Vorgehensweise zur Auffindung, Beobachtung und Diagnose von relevanten Technologien bzw. Technologieentwicklungen außerhalb der Unternehmung?

30. Gibt es ein eigenes Bewertungsschema für potentiell relevante neue Technologien?

Abschlussfragen

31. Was scheint Ihnen momentan im Bereich Technologiestrategie bzw. technologischer Wandel in Ihrer Unternehmung die wichtigste Fragestellung bzw. das größte Problemfeld zu sein zu sein?

32. Welchen Fragen, Probleme, wichtigen Faktoren im Bereich Technologiestrategie bzw. strategische Technologieentscheidungen haben Sie im Interview vermisst, die Sie für sehr wichtig halten?

APPENDIX B – INTERVIEW PROTOCOL & COMPANY FACT SHEET

Phase	Position / Function	Interview Date	# Interviewees	Duration	Recorded	Face-to-face	On-site interview	Transcribed
Exploratory Phase	Vice President Corporate Development	10.04.2007	1	1:17h	Y	Y	Y	Y
	Vice President R&D & R&D Management	18.09.2007	2	0:59h	Y	Y	Y	Y
	Head of Research and Development	27.11.2007	1	1:48h	Y	Y	Y	Y
	Head Advanced Technology Engineering	25.10.2007	1	1:36h	Y	Y	Y	Y
	Director Manufacturing Strategy Global	03.10.2007	1	1:31h	Y	Y	Y	Y
	Chief Technology Officer	20.11.2007	1	1:24h	Y	Y	Y	Y
	Corporate Technology & Innovation Management	16.04.2007	1	2:07h	Y	Y	N	Y
	Corporate Technology & Innovation Management	24.09.2007	1	2:09h	Y	Y	N	Y
	Chief Executive Officer	03.10.2007	1	0:40h	Y	Y	Y	Y
	Vice President Product Development	28.09.2007	1	2:37h	Y	Y	Y	Y
	Chief Executive Officer	11.12.2007	1	1:19h	Y	Y	Y	Y
	Corporate Technology & Innovation Management	06.12.2007	1	1:19h	Y	Y	Y	Y
Confirmatory Phase	Director Innovation and Technology	13.06.2008	1	1:44h	Y	Y	Y	N
	Corporate Technology & Innovation Management	18.06.2008	1	1:54h	Y	Y	N	N
	Chief Technology Officer & Assistant to the CTO	02.04.2008	2	1:33h	Y	Y	Y	N
	Corporate Innovation Management, Head of R&D	16.06.2008	2	2:02h	Y	Y	Y	N
	Corporate Technology & Innovation Management	25.06.2008	1	2:08h	Y	Y	Y	N
	Corporate Technology & Innovation Management	03.04.2008	1	1:41h	Y	Y	Y	N
	Corporate Technology & Innovation Management	01.04.2008	1	1:15h	Y	Y	Y	N
	Chief Technology Officer	04.04.2008	1	1:13h	Y	Y	Y	N
	Corporate Technology & Innovation Management	07.05.2008	1	2:47h	Y	Y	N	N
	Chief Technology Officer	14.04.2008	1	1:29h	Y	Y	Y	N
	CEO, Head of Supervisory Board	26.05.2008	1	2:55h	Y	Y	Y	N
	Chief Technology Advisor	12.06.2008	1	1:42h	Y	Y	Y	N
	Chief Technology Officer & Assistant to the CTO	06.06.2008	2	1:52h	Y	Y	Y	N
	Head of Research and Development	23.06.2008	1	0:46h	Y	Y	Y	N
	Corporate Technology & Innovation Management	17.06.2008	2	1:35h	Y	Y	Y	N
	Chief Technology Officer	09.07.2008	1	1:09h	Y	Y	Y	N
	Chief Technology Officer	30.06.2008	1	1:10h	Y	Y	Y	N
	Chief Technology Officer	27.06.2008	1	2:02h	Y	Y	Y	N

#	Corporate Headquarter	Company	Industry, Markets or Customers' Industries	Main Products / Services	Number of Employees (2007)	Revenue (Mio € 2007)	Corporate Structure (2007)	Number of Business Units (2007)	On-site graduate student	Additional on-site visits	# Interviews / Interviewees
1	I	Company 1	Household and commercial electrical appliances industry.	Household and industrial compressors and motors.	6,500	700	Product Groups	4	2	Y	1 / 1
2	CA/ F / CH	Company 2	Aerospace, automotive, transportation, electricity, energy industry, special industrial applications.	Cable, rod and strip, hard and soft ally extrusions, large profiles, forged and die-cast aluminum, composite materials, specialty sheets.	15,000	7,100 (US$ 2007)	Business Units	7	N	N	1 / 1
3	A	Company 3	Pulp and paper, steel, electricity and energy, mining industry, special industrial applications.	High-tech systems, machinery and services for the production of pulp and paper, steel, animal feed and wood pellets.	12,300	3,283	Business Units	5	N	N	1 / 1
4	A	Company 4	Chemical, pharmaceutical, food and beverage, cosmetic industry, basic and applied research facilities.	Measuring and analysis instruments, contract manufacturing of high-precision mechanical assemblies and electromechanical components.	1,100	105	Product Groups	4	N	Y	1 / 1
5	A	Company 5	Communication, medical and automotive industry.	Analogue integrated circuits, customized and standard analogue semiconductors.	1,070	194	Business Units	4	N	N	2 / 2
6	A	Company 6	Automotive industry.	Development of drive train systems, simulation and engineering systems and software, engine instrumentation and test systems.	4,100	625	Business Units	3	N	N	2 / 3
7	A	Company 7	Automotive, tool, machinery, aircraft manufacturers, consumer goods, electronics, wood, textile, paper, steel, apparatus construction, chemical, petrochemical, power generation, oilfield technology and plant construction industry.	Specialty steel and materials, high performance metals, welding consumables, precision strip, special forgings.	15,453	2,759	Business Units	4	N	N	1 / 2
8	A	Company 8	Material and passenger transportation industry.	Passenger ropeways, material transport systems, avalanche blasting ropeways, rope-propelled local transport systems, automated elevation systems.	2,605	680	Product Groups	6	1	Y	1 / 2

#	Corporate Headquarter	Company	Industry, Markets or Customers' Industries	Main Products / Services	Number of Employees (2007)	Revenue (Mio € 2007)	Corporate Structure (2007)	Number of Business Units (2007)	On-site graduate student	Additional on-site visits	# Interviews / Interviewees
9	CH	Company 9	Automotive, gas and water utilities, building technology, after treatment and chemical industry, special industrial applications and tool making industry.	Iron casting, light metal castings, plastic components, electric discharge machines, high speed milling machines, comprehensive tooling and automation solutions and services.	13,500	4,497 (CHF 2007)	Business Units	3	N	N	1 / 1
10	FL	Company 10	Construction and building industry.	Drilling, demolition, coring, cutting, sanding, fastening, screwing, anchoring tools, measuring, installation, fire stop and foam systems and instruments.	18,930	4,667 (CHF 2007)	Product Groups	10	N	Y	1 / 1
11	A	Company 11	Electronic and communication industry.	Traffic management, tolling, communication, telematic, wire and wireless network systems and infrastructure.	2,417	470	Business Units	3	N	N	1 / 1
12	A	Company 12	Automotive and motorbike industry.	Street and off-road motorbikes, ATV, automobiles.	1,964	606	Product Groups	3	N	N	1 / 1
13	A	Company 13	Textile and nonwovens industry.	Pulp, high-quality cellulose fibers, special cellulose fibers, high-tech plastics polymers.	6,043	1,260	Business Units	6	N	N	1 / 1
14	CA/ A	Company 14	Automotive supply industry.	Engine, transmission, AWD, axle and mechatronic components, modules and systems, engineering and integration services.	11,000	3,809 (US$ 2007)	Product Groups	6	3	Y	3 / 3
15	CA/ A	Company 15	Automotive and aerospace industry.	Engineering and integration services, engineering, production and assembly of automotive and aerospace modules and system and complete vehicles, fuel components, modules and systems.	10,000	4,008 (US$ 2007)	Business Units	6	3	Y	2 / 2
16	A	Company 16	Automotive, engine, energy, electricity, transportation industry.	Sintered components, engine bearings, friction materials, polymer coatings.	2,700	387	Business Units	4	N	N	1 / 1
17	D/A	Company 17	Electrical component, modules and systems.	Power distribution, switching and protection systems, switchgear and buildings automation system.	4,000	512	Business Units	3	N	N	1 / 2
18	ZA/ A	Company 18	Paper industry.	Uncoated fine paper.	14,000	2,300	Product Groups	2	N	N	1 / 1

#	Corporate Headquarter	Company	Industry, Markets or Customers' Industries	Main Products / Services	Number of Employees (2007)	Revenue (Mio € 2007)	Corporate Structure (2007)	Number of Business Units (2007)	On-site graduate student	Additional on-site visits	# Interviews / Interviewees
19	A	Company 19	Consumer goods industry.	Complete hair cutting, shaving, epilations and clipper and trimmer systems for personal and medical applications, engineering and assembly services for industrial applications.	1,100	81	Business Units	3	N	N	1 / 1
20	CH	Company 20	Private and public health care, medical care, life science, pharmaceutical, biotech industry, basic and applied research facilities.	Diagnostic systems for research facilities, laboratories, point of care testing, self-management for patients.	23,062	9,350 (CHF 2007)	Product Groups	4	N	N	1 / 1
21	A	Company 21	Mobile fire-fighting vehicles and equipment.	Municipal and aircraft rescue and fire fighting vehicles, industrial fire fighting vehicles, advanced fire fighting components, fire & safety equipment.	1,650	425	Product Groups	6	N	N	1 / 1
22	A	Company 22	Aerospace, agricultural, construction, building, machinery, automotive, commercial vehicle, electrical, furniture, household appliance, oil and energy supply, plant, engine and steel construction, railway infrastructure, steel trading, transport, storage and lifting industry.	Automotive components, foundry products, heavy plates, household appliance components, industrial mineral products, railway infrastructure, sections/profiled tubes, special steel, steel blooms, steel strip, steel trade products, storage technology, tubes, welding consumables, wires.	41,490	10,481	Divi-sions	5	N	Y	1 / 2
23	A	Company 23	Automotive, automotive supply, household appliance, electrical, construction and building supply, mechanical engineering industry.	Hot-rolled, cold-rolled, electrical, electrolytic galvanized hot-dip galvanized, organically coated steel strips, coal by-products, and metallurgical by-products, recycled products, regeneration products.	3,600	532	Product Groups	6	N	N	1 / 1
24	A	Company 24	Inner-, extra-urban and industrial railway and transportation industry.	Turnout systems, high speed, heavy haul, metro and tram, grooved rail turnout systems, electro-hydraulic hybrid systems, electronic systems, switch logistics, special track work components.	9,592	3,680	Business Units	11	N	Y	1 / 1

#	Corporate Headquarter	Company	Industry, Markets or Customers' Industries	Main Products / Services	Number of Employees (2007)	Revenue (Mio € 2007)	Corporate Structure (2007)	Number of Business Units (2007)	On-site graduate student	Additional on-site visits	# Interviews / Interviewees
25	D	Company 25	Paper, pulp and packaging industry.	Engineering, manufacturing and servicing of paper machine components, modules and systems for graphical papers, board and packaging papers, specialty papers and tissue papers.	10,548	1,980	Product Groups	7	1	Y	1 / 1

APPENDIX C – LIST OF INCIDENTS & INTERVIEW TAGS

#	Company	Reported Incidents of Technology Turbulence	Interview positions (min.)
1	Company 1	Environmentalism, energy efficiency and resource sustainability as dominant drivers and enablers of technological innovation.	0:12, 1:16;
2	Company 1	Rising world market price for currently employed material resource.	0:40, 1:09;
3	Company 1	Scenario of “intelligent white goods”.	1:20, 1:31;
4	Company 1	Alternative cooling technologies in other industries and markets which make compressors and engine obsolete.	0:10;
5	Company 1	Unexpected possibilities for material substitution in electro motors and compressors.	1:09;
6	Company 2	Global upstream consolidation and concentration in raw aluminum mining, production and processing industry.	0:29, 0:48, 1:33;
7	Company 2	“All-aluminum car”-scenario.	0:38, 1:18, 1:25;
8	Company 2	Aluminum as dominating material for railway vehicle bodies.	0:36;
9	Company 2	Unexpected massive substitution of aluminum in the aerospace industry by fiber-based composite materials.	0:43, 0:50, 1:26;
10	Company 3	Environmentalism and optimization for energy efficiency demand vertically integrated technology expertise of complete value chain.	0:06, 0:51, 1:28
11	Company 3	Emerging market of bio-fuel and renewable and sustainable energy production.	0:40, 1:07;
12	Company 3	Unanticipated breakthrough of substitutive product technology.	1:12;
13	Company 3	Unexpected exploitation opportunities for dewatering and drying technologies of paper and pulp production.	0:10, 0:43, 1:03;
14	Company 4	Usability and simplicity as new drivers of technology development because of changing end-users of produced products.	0:10, 1:19;
15	Company 4	Decay of the local glass manufacturing industry for industrial applications.	1:21, 2:11;
16	Company 4	Potential substitution of core product technology.	0:12, 0:20, 1:44;
17	Company 4	Unanticipated technological product innovation of competitor.	2:31;
18	Company 4	Unexpected external exploitation of technological competence in sophisticated manufacturing technologies.	1:23, 1:30, 2:23;
19	Company 5	Global commoditization and off-shoring of wafer fabrication for standard CMOS technology of digital applications.	0:13; and 0:02, 1:15;
20	Company 5	Convergence of new functionalities, applications and technologies into mobile phones and portable electronic devices.	0:09;
21	Company 5	Increasing availability, demand and use of electronic mobile applications and services for hand-held devices.	0:12, 0:33 and 0:06 0:18, 0:44;
22	Company 5	Potentially disruptive downstream innovation in assembly technology (wafer level packaging).	0:37 and 1:21;
23	Company 6	Insufficiency of current technological core know-how for most probable future drive train scenarios for passenger cars.	0:05, 0:16, 0:23 and 0:11;
24	Company 6	Alternative engine and drive train technology scenarios.	0:32, 0:39;
25	Company 6	Magnesium as a possible material for modules and components in drive train systems.	1:37 and 0:07;
26	Company 6	Unexpected quasi-standardization of particle filter as mandatory add-on technology for diesel engines.	0:34;
27	Company 6	Technology exploitation from niche product development of large-scale and single-unit diesel engines.	0:25;
28	Company 6	Unexpected exploitation opportunity of unsuccessful and pre-mature technology development in completely different context.	0:39 and 0:11;
29	Company 7	Increasing potential of electrical cars and alternative materials in the automotive industry.	0:50;

#	Company	Reported Incidents of Technology Turbulence	Interview positions (min.)
30	Company 8	Comfortableness of passenger transportation as increasingly important driver of technology integration and innovation.	0:38;
31	Company 8	Global warming scenario of significant climate change and snow free alps.	0:19;
32	Company 8	Scarcity of parking space in urban centers as enabler for technology transfer from Japan.	0:56;
33	Company 8	New and enabling cable car technology which allows operation under special environmental conditions.	0:09;
34	Company 8	Cornering technology as potential enabler for various additional applications of cable-car technology.	0:41;
35	Company 8	Unexpected applications for ropeway technology for special conveyor applications.	0:14;
36	Company 8	Unexpected introduction of planetary gear set into ropeway systems by competitor.	1:02;
37	Company 8	Unexpected technology transfer from unsuccessful new market venture in non-core market into core market.	0:06;
38	Company 9	Partial substitution of core product technology by alternative and improving process technology.	0:13, 1:08;
39	Company 9	Complete substitution of metal by plastic in core business.	0:12;
40	Company 9	Composite material as a potential material for auto body and chassis parts.	0:14, 0:19, 1:03;
41	Company 9	Unexpected applications of existing technological competence in emerging and fast growing business of life science.	0:03, 0:17, 0:21, 0:59, 1:06;
42	Company 9	Unexpected application for laser technology in existing business units.	0:07, 0:10, 0:36.
43	Company 10	Restrictive legal regulations of acoustic and noise emissions as enabler of technological innovation in core markets.	0:12, 0:48;
44	Company 10	Increasingly restrictive legal regulation and sensitivity for energy-efficiency as enabler of technology substitution on adjacent market.	0:47;
45	Company 10	Unexpected transfer and application of laser technology into new application context.	0:39;
46	Company 11	Diffusion of new functionalities, applications and technologies into street and highway infrastructure and vehicles.	0:22;
47	Company 11	Increasing importance of a technology based on shared intellectual property right and cross-licensing contracts.	1:50;
48	Company 11	Multiple scenarios for standards and global technological dominant design.	0:03, 0:40;
49	Company 11	Increasing convergence of functionalities and applications into mobile phones and mobile digital devices.	1:52;
50	Company 11	Unexpected breakthrough in potential complementary technology of video surveillance technology and algorithms.	2:00;
51	Company 12	Increasing potential, availability and industrialization of carbon-fiber composite materials.	0:22, 0:56;
52	Company 12	Rising importance of sourced complementary technology due to rising technology complexity of engines.	0:13, 0:54;
53	Company 12	Combustion engine vs. electro engines and battery technology.	0:09, 0:12, 0:33;
54	Company 12	Unexpected introduction of substitutive product technology by main competitor.	0:25;
55	Company 12	Unexpected opportunity for technology exploitation of unsuccessful technology and product development project.	0:25, 0:31 0:50;
56	Company 13	Imitation and increasing commoditization of current process and product technologies by Asian competitors.	0:01, 0:11, 0:44;
57	Company 13	Energy efficiency and environmentalism as new dominant drivers of technology development and process innovation.	0:03, 0:16, 0:44;
58	Company 13	Rising importance, demand, industrialization and mass-production of fiber-based composite materials.	0:32;

#	Company	Reported Incidents of Technology Turbulence	Interview positions (min.)
59	Company 13	External exploitation of internal technological know-how and integrated process optimization competence.	0:28;
60	Company 14	Substitution of chipping technology by advancing chipless molding and forming technology.	0:24;
61	Company 14	Increasing potential of alternative drive train concepts enabled by shifting drivers of technological innovation.	0:23;
62	Company 14	Further performance improvements of increasingly critical but sourced sintering technology.	0:12;
63	Company 14	Rising importance and criticalness of bevel gear and crown wheel manufacturing.	0:15;
64	Company 14	Advanced forging technology for tooth gears of automotive transmissions systems.	0:45;
65	Company 14	Potential commoditization of current core product.	0:54;
66	Company 14	Increasing relevance and technological complexity of main transmission systems.	0:37;
67	Company 14	Magnesium as a possible material for modules and components in drive train systems.	0:59;
68	Company 14	Unexpected application of rotary swaging technology for automotive applications.	1:08 and 0:10;
69	Company 15	Alternative and supplementary scenarios for future engine and drive train scenarios.	0:23;
70	Company 15	Composite materials for auto body applications.	0:46 and 1:15;
71	Company 15	Enabled car to car and car to infrastructure communication.	0:31;
72	Company 15	Unexpected success of hybrid engine technology of main customers' competitors.	0:26 and 0:29;
73	Company 15	Unexpected exploitation of aerospace cryogenic technology for automotive applications.	1:01 and 0:27;
74	Company 16	Strength and stiffness as additional and new requirements for sintered components additionally to precisions, quality and price.	0:13, 0:20;
75	Company 16	Outsourcing of technological expertise and know-how by main customers.	2:11;
76	Company 16	Increasing successful substitution of sintering by stamping technology in low-end markets.	0:16, 2:09;
77	Company 16	Material substitution in engine and transmission components.	1:25, 1:42, 2:26;
78	Company 16	Commoditization and decreasing criticalness of products and technological competence in high volume markets.	1:58;
79	Company 16	Substitution of conventional internal combustion engines by alternative engine systems.	0:16, 0:23, 1:08;
80	Company 17	Increasing imitation and commoditization of pure electro-mechanical systems in existing product portfolio.	0:24, 1:17;
81	Company 17	Competing international industry standards for radio communication of wireless product technology.	0:18;
82	Company 17	Slow market adoption of new digital product generation.	0:24, 1:36;
83	Company 17	Possibilities for wire-less and decentralized energy supply in buildings by fuel cell technology.	1:24;
84	Company 18	Energy efficiency and sustainability of production process as new drivers for process technology development and innovation.	0:11, 0:16;
85	Company 18	Energetic versus enzymatic technology for bio-fuel production as a by-product of paper production.	1:19;
86	Company 18	Different future technology scenarios for different global locations and facilities.	0:05, 0:36;
87	Company 18	Diverse substitution and obsolescence scenarios for uncoated fine paper.	0:09, 0:12;
88	Company 18	Complete virtualization and digitalization of information.	0:09;

#	Company	Reported Incidents of Technology Turbulence	Interview positions (min.)
89	Company 19	Commoditization of technological core competence in current business portfolio.	0:38, 0:56;
90	Company 19	Outsourcing of technological expertise and know-how by OEM customers.	0:08, 0:23, 1:09;
91	Company 19	Substitution of steel and metal by ceramic material in current core business.	0:13, 0:18, 0:34, 1:00;
92	Company 20	Usability and simplicity as new drivers of technology development and innovation because of changing end-users.	0:14, 0:39, 0:47;
93	Company 20	Convergence of new functionalities and applications into existing diagnostic products suggested by clinical medical research.	0:06, 0:12, 0:33;
94	Company 21	Substitution of pure electro-mechanical systems by electronic and digital technology in fire fighting equipment and vehicles.	0:15;
95	Company 21	Modularization of products and manufacturing processes to fulfill compulsory local content requirements of international markets.	0:10, 0:32;
96	Company 21	Significant substitution of conventional material by carbon-fiber in future aircraft bodies.	1:41;
97	Company 21	Real-time information system for fire fighting operations enabled by mobile information and communication technology	0:17, 0:48;
98	Company 21	Substitution of mobile fire fighting by stationary fire fighting facilities enabled by legal requirements and facility modernization.	1:22;
99	Company 21	Frame construction vs. self-supporting body design for fire fighting vehicles.	1:27;
100	Company 21	Development, mass production and application of sophisticated sensor technology in adjacent industry.	0:58;
101	Company 21	Unexpected application of product technology in adjacent businesses.	1:20;
102	Company 21	Unintended potential and possibilities of modular product architecture.	0:32;
103	Company 22	Increasing employment of aluminum and composite materials and substitution of steel in the automotive industry.	0:35;
104	Company 22	Disintegrated mini mill process technology for high quality and requirement applications.	0:59;
105	Company 22	Alternative scenarios for exploiting unit injection technology.	0:29;
106	Company 23	Increasing future potential and demand for electrical and hybrid cars.	0:41;
107	Company 23	Competitors' increasing and steady investment in high-alloyed steel grades.	0:33;
108	Company 23	Enabled hot stamping process technology.	0:13;
109	Company 23	Low-emission and low-energy steel mill scenario	0:20;
110	Company 23	Future potential of thin sheet casting process technology.	0:21;
111	Company 24	Technological know-how and engineering outsourcing of liberalized and privatized national railways organization.	0:24;
112	Company 24	Significant and IP protected product technology of competitor as potential dominant design.	1:16;
113	Company 24	Unexpected technology transfer of friction stir welding technology for railway application.	1:24;
114	Company 25	Switching drivers of technology development as innovation enabler.	0:08, 0:18, 0:28;
115	Company 25	Potential of carbon fiber and composite materials in all business units.	0:56, 0:59, 1:54;
116	Company 25	Optimization for energy efficiency of integrated systems as dominant driver of technology development and innovation.	0:34, 0:53, 1:12;

APPENDIX D – PARAPHRASED & CODED INTERVIEW DATA ON REPORTED INCIDENTS

#	Probable Prediction		Predict	Prepare	Enact
1	Company 1 (0:12, 1:16)	**Environmentalism, energy efficiency and sustainability as new technology drivers**	Predicting that pure focus on cost reduction as driver of technology development will be complemented by aspects of environmental regulation and energy efficiency (energy label).	Preparing by focusing on new product development and engineering which is aligned to the ne trade-off between conflicting objectives (costs, NVH, performance and sustainability).	Completely new product line (Kappa) which reflects a new technology-based competitive advantage.
2	Company 2 (0:29, 0:48, 1:33)	**Global upstream consolidation in raw aluminum mining and production**	Prediction that increasing up-stream consolidation of raw aluminum mining and production will demand more product innovation of aluminum-based technology conglomerate.	Preparing by reformulation of innovation and technology strategy which is not based on advantageous access to aluminum but on aluminum-based product innovation.	Enactment of new innovation and technology strategy which focuses on product innovations when disintegration of aluminum resource base is initiated.
3	Company 3 (0:06, 0:51, 1:28)	**Environmentalism and energy efficiency demand integrated technology expertise**	Predicting that overall equipment optimization of paper and pulp mills for energy efficiency and environmental friendliness will demand integrated solution providers.	Preparing by triggering internal and organic competence building by R&D and identifying and acquiring complementary acquisition target along the complete value chain.	Enacting new technology strategy of forward and backward integration of complementary technologies.
4	Company 4 (0:10, 1:19)	**New drivers of technology because of changing end-users**	Predicting that in many international markets produced products and systems will not be used by chemical professionals but by regular manufacturing and production workers.	Preparing by building internal competence in embedded PCs, modular systems and software engineering to increase usability and simplicity of current products.	Implementing new software and system design to most product groups and maintaining an software engineering team and necessary complementary production technology (e.g. SMD).
5	Company 5 (0:13, and 0:02,1:15)	**Commoditization of standardized CMOS technology for digital applications**	Predicting that integrated ICs in the niche segment of non-commodity analogue and mix-signals processing must satisfy high demanding customers in the automotive industry.	Although most western companies of similar size were going fabless, it was decided to invest into a new wafer fab for analogue high-voltage CMOS technology and to stay integrated.	Building a new wafer fab to supply business units and external customers with non-commodity analogue high-voltage CMOS technology.
6	Company 5 (0:09)	**Technology convergence into mobile phones**	.Predicting that progress in miniaturization of linear motors allow to integrate real optical focus and zoom function in thin handheld mobile devices.	Develop magnetic encoder technology for digital camera mobile phones to extend the existing and pure digital focus systems by miniaturized mechanical and optical focus systems.	Partnering with designer and manufacturer of innovative linear micro motors and introducing integrated system of magnetic encoder technology and micro motors.
7	Company 5 (0:12, 0:33 and 0:06 0:18, 0:44)	**Increasing availability of electronic mobile applications**	Predicting that increasing amount of applications and functionalities in all kind of mobile and hand-held devices has higher demands on battery consumption and power management.	Preparing new generation of advances high-voltage CMOS process technology by broad cross-licensing agreement with IBM.	Offering and producing intelligent power management ICs which are necessary to manage and regulate a range of power requirements, resulting in more efficient battery consumption.
8	Company 6 (0:05, 0:16, 0:23 and 0:11)	**Probable insufficiency of technological core know-how**	Predicting that scope on engineering of combustion engines may become irrelevant relative to the engineering and integration competence for complete drive train systems.	Developing expertise and know how in complementary and substitutive technologies like gear, transmission, axle, battery, electro engine and electronic control systems.	Enacting the new technology strategy by offering the engineering, integration and optimization services and know-how for complete drive train systems.

#	Probable Prediction		Predict	Prepare	Enact
9	Company 8 (0:38)	**Comfortableness as increasingly important driver of innovation**	Predicting that comfortableness of cable cars and chair lifts will be an increasingly dominant driver of technological development next to capacity, speed and safety.	Preparing necessary technologies to enable heating and air condition systems for cabins (e.g. photovoltaic and battery technology, engineering of customized air condition system).	Offering and enacting new product technologies in projects as dominant design for product technology emerges.
10	Company 9 (0:13, 1:08)	**Substitution of core product by alternative process technology**	Predicting that current progress of high speed and performance milling systems will substitute functionalities and applications of wire and die-sinking electric discharge machines.	Preparing for predicted substitution by developing internal expertise and competence in high speed drilling and seeking opportunities for M&A activity.	Enacting new technology strategy by three major acquisitions in the area of high speed drilling tolls and technology and complementing existing EDM competence.
11	Company 10 (0:12, 0:48)	**Regulations of acoustic emission as technology enabler**	Predicting that most high-wage countries will adopt more restrictive regulations of acoustic emissions in the future, which will affect traditional rotary drill hammer technology.	Intensifying research and product development efforts in technologies which allow to reduce acoustic emissions before customers are forced to adopt it (e.g. diamond drill).	Enacting new product strategy based on alternative technology when customers are increasingly adopting diamond drills for certain applications forced by regulation.
12	Company 11 (0:22)	**Diffusion of new functionalities and technologies into street infrastructure**	Predicting that improved sensor and communication technology in vehicles and restrictive traffic emission and safety regulation will demand new functionalities of infrastructure.	Exploring of and investing in vehicle-to-infrastructure communication and sensor and camera technology (e.g. organic computing, odor perception, traffic surveillance, incident detection).	Entering new business field and establishing new product group traffic safety and control as an add-on to existing conventional toll systems.
13	Company 12 (0:22, 0:56)	**Increasing potential and availability of composite materials**	Predicting the increasing importance and criticalness of composite materials as a substitute for steel and aluminum and a prerequisite for all kinds of lightweight construction.	Preparing by developing internal expertise and know-how and acquisition of a manufacturer of composite frames.	Enacting the new technology strategy by applying the acquired technological competence in first innovation "learning" projects (X-Bow).
14	Company 13 (0:01, 0:11, 0:44)	**Imitation and increasing commoditization of main technology**	Although in an niche of global fiber production (cellulose fibers) the main technology (viscose fiber) is threatened by imitation and commoditization driven by Asian competitors.	Defocusing R&D&E from pure process improvements to more product, application innovations and leveraging advantage full process integration (on-line and "wet" pulp production).	Enacting new strategy by introducing IP and technology protected cellulose-based specialty and premium fibers (Modal, Lyocell/Tencel) for new markets which are based on full-integrated mills.
15	Company 13 (0:03, 0:16, 0:44)	**Energy efficiency & environmentalism dominant drivers of technology**	Predicting that importance of energy efficiency (increasing energy prices) and environmentalism as underlying drivers for technology development will increase, especially in Western Europe.	Focusing the process and product development on innovations which reduce pollution and energy consumption and building internal expertise on energy recuperation.	Full enactment of new strategy by establishing an independent an cross-sectional business unit energy which handles energy supply, distribution, recuperation and energetic recycling.
16	Company 14 (0:24)	**Substitution of chipping by molding and forming technology**	Prediction that sophisticated molding and forming technologies will substitute current core technologies like conventional forming and subsequent chipping technologies.	Various projects with potential suppliers and partners to explore and prepare adoption of technologies like. impact extrusion and orbital forging.	Adoption and industrialization of new and customized process technologies to manufacture gear tooth systems in a very different way and by a new process and cost structure.

#	Probable Prediction		Predict	Prepare	Enact
17	Company 14 (0:23)	**Alternative drive trains enabled by shifting drivers of technology**	Prediction that alternative drive train and engine systems will demand more complex and controllable transmissions and gear systems.	Preparing by various engineering and pre-development projects like torque vectoring, dual mass fly wheel, active rear wheel steering and diversification and control mechatronics.	Entering and integration of adjacent markets and products and introduction of new business and product groups.
18	Company 16 (0:13. 0:20)	**Strength and stiffness as new drivers for sintering technology**	Predicting that stiffness and strength of sintered parts will be at least as important as precision as driving factors for future technology development to avoid commoditization.	Partnering with equipments and resource suppliers to develop new sintering powders and processes, to successfully compete with case hardened steel in terms of strengths.	Enacting new technology strategy by developing an engine gearwheel with a surface densificated, sintered component together with automotive OEM.
19	Company 16 (2:11)	**Outsourcing of technological expertise and know-how by customers**	.Predicting that automotive OEM will increasingly outsource engineering and manufacturing competence and know-how of sintering technology for engine and transmission parts.	Preparing by increasing internal designing and engineering capabilities and the ability to integrate and assembly complementary technologies, components and materials.	Enacting a more integrated business model by offering additional engineering an integration services to customers parallel to the pure "blueprint manufacturing" business.
20	Company 16 (0:16, 2:09)	**Substitution of sintering by stamping technology in low-end markets**	Predicting that increasing precision of stamping technology by incremental technological innovations will allow to substitute sintering technology in low-end markets by price advantages.	Identifying new applications and markets for sintering technology and increasing effort to substitute other manufacturing technologies by further technological innovations.	Incrementally leaving markets where more precise stamping technology realizes cost advantages, entering manufacturing of more complex and stressed sintered components.
21	Company 17 (0:24, 1:17)	**Commoditization of electro-mechanical systems**	Predicting that with conventional product technology existing competitive advantage will dissolve and will lead to pure price competition.	By partnering with technology supplier, existing electro-mechanical system is combined with digitally controlled electronic power management system.	Establishing of new product group which does not compete on price but by enhanced product functionality.
22	Company 18 (0:11, 0:16)	**Energy efficiency and sustainability as new drivers for process technology**	Predicting that energy efficiency and sustainability of paper mills will be increasingly dominant and necessary as drivers of technology development in the future.	Preparing by explicitly including new parameters for technological process innovation projects (project "water-less paper mill" with 3 competitors) to conventional performance indicators.	Enacting of new technology strategy, when new dominant trade-off for paper-mills is triggered by energy prices and legislation.
23	Company 19 (0:38, 0:56)	**Commoditization of core technology in current businesses**	Predicting that current technological competence of metal blade engineering and manufacturing is becoming a commodity in the market of contract manufacturing of consumer products.	Preparing by initiating a strategy reformulation centered around the core competence of cutting technology to identify new potential and adjacent businesses and markets.	Exploiting current technological competence in two new business units industrial solutions and health care solutions and transferring personal care to low cost countries.
24	Company 19 (0:08, 0:23, 1:09)	**Outsourcing of technological expertise and know-how by customers**	Predicting that main customers (electronic consumer goods OEMs) will increasingly outsource up-stream activities via contract manufacturing and engineering and turn-key suppliers.	Forward integration of engineering, designing, material, manufacturing and system integration competence and initiating transfer of manufacturing plants to low-cost countries.	Enacting new CDM/ODM and late-customization business model enabled by acquired technological competence and transfer of production facilities to Eastern Europe and Asia.

#	Probable Prediction		Predict	Prepare	Enact
25	Company 20 (0:14, 0:39, 0:47)	**New drivers of technology because of changing end-users**	Predicting that future diagnostic products and tools will be increasingly used by patients and not by medical professionals and central medical labs.	Building internal competence and establishing new partnerships to enable usability, simplification, miniaturization, convenience of maintenance-free diagnostic devices.	With increasing adoption by health care system, introducing mobile and end-user friendly diagnostic devices with high usability and convenience for patients and end.-users.
26	Company 21 (0:15)	**Electrification and digitalization of fire fighting equipment**	Prediction that break-through in information and communication technologies allow for new and improved functionalities in fire fighting vehicles.	Preparing fire-fighting vehicles by introducing open and flexible CAN-bus systems to allow absorption of new technologies and future upgrades.	With increasing acceptance of information and communication technologies by customers, full adoption and substitution of old electro-mechanical systems.
27	Company 21 (0:10, 0:32)	**Modularization of products because of local content requirements**	Prediction that successful business with many public entities on international markets include local content terms, when moving from European to global markets.	Preparing market entry by introducing modularization concepts of products in product engineering and manufacturing (semi-knocked down, completely knocked down).	Enacting local content manufacturing strategy by necessary investment in local final assembly of supplied product modules.
28	Company 21 (1:41)	**Material substitution in aircraft bodies**	Prediction that future aircraft for passenger transports (e.g. Boeing A380, Dreamliner) will use alternative body materials with higher stiffness and strengths.	Developing and testing advanced, hydraulic piercing nozzle technology which can pierce through all future aircraft body materials.	Offering alternative piercing nozzles as add-on or upgrade for existing vehicle fleet and as an optional product feature.
29	Company 22 (0:35)	**Aluminum and composite materials in the automotive industry**	Predicted demand for materials with increasing stiffness and decreasing weight in the automotive industry will privilege substitution material for steel.	Horizontal alliance with competitors to develop tailor welded blanks and tailor hybrid blanks to combine cost advantage of steel with the need of more stiffness and lower weight.	Introduction and establishing of tailor welded blanks and tailor hybrid blanks as industry product standard.
30	Company 23 (0:41)	**Increasing potential for electrical and hybrid cars**	Predicted demand for electrical steel in the automotive industry because of increasing success and potential of hybrid and electrical cars.	Preparing for increasing demand by developing customized electrical steel for application in cars with electrical engines and drive train systems.	When mass production of hybrid and electrical cars increases as predicted, introduction and production of customized electrical steel grades.
31	Company 24 (0:24)	**Know-how and engineering outsourcing of national railways**	Prediction of increasing demand for low maintenance turnout systems with optimal life-cycle costs because of rapid outsourcing of national railways.	Preparing new low-maintenance product by entering several new technological disciplines like hydraulics, telematics and electronics.	Introducing integrated and add-on solutions for railway companies, which have to reduce personnel costs, as a new product group within the company.
32	Company 25 (0:34, 0:53, 1:12)	**Optimization for energy efficiency as dominant technology driver**	Predicting that energy efficiency and environmental topics will be the dominant issue for existing and potential customers which employ the manufactured paper mills.	Holding a trend and idea workshop on the topic "Energy and Environment" with customers, suppliers, technology experts and researchers and participants from similar industries.	Enacting an new technology strategy (vertical integration, M&A) which allows to optimize the complete paper mill for energy efficiency over the complete life cycle.

#	Possible Risks		Predict	Prepare	Enact
1	Company 1 (0:40, 1:09)	**Rising market prices for material resource**	Predicting the possibility that an further increasing copper price will have an significant impact on the overall cost structure of the product.	Preparing by engineering and testing of an aluminum electro engine which completely substitutes copper.	If copper prices continue to increase the conventional copper engine can be substituted by the fully prepared and tested aluminum engine.
2	Company 4 (1:21, 2:11)	**Decay of glass industry for industrial applications**	Predicting decay of local existing supplier base of necessary high quality and low scale glass products for industrial applications, which are a necessary upstream activity.	Preparing by partial vertical upstream integration by building internal technological know-how in glass and quartz manufacturing and processing.	Although it was preferred to source the necessary glass externally, the situation in the supplying industry made it necessary to fully integrate the supply as an in-house activity.
3	Company 5 0:37 and 1:21)	**Potentially disruptive downstream innovation**	Predicting the risk that architectural innovation (wafer level packaging) in downstream assembly activities which were outsourced before may demand vertical downstream integration.	Preparing for risk of obsoleteness of current dominant technological process and business model by ensuring access to necessary technological know-how, licenses and patents.	If significant competitive advantage of fully integrated wafer fabs is recognized and wafer level packaging becomes dominant, prepared access to technology allows fast introduction.
4	Company 11 (1:50)	**Increasing importance of an technology based on shared IPR**	Predicting the risk that competitor may terminate a cross-licensing agreement and initiates an IPR litigation for a technology which is of increasing importance.	Engineering and testing alternative technological solution for laser measurement and surveillance methodology.	Although it is preferred to stay with the current technology which includes an cross-licensing agreement with a competitor, an alternative solution is prepared which could be enacted.
5	Company 12 (0:13, 0:54)	**Rising importance of sourced complementary technology**	Mandatory substitution of carburetors by fuel injection increases importance and criticalness of externally sourced electronic control system for engine management.	Establishing and supporting alternative and local sources for electronic control systems which are becoming increasingly important as complexity of engines increase.	If opportunistic behavior of current quasi-monopolistic supplier becomes evident, alternative sources are available.
6	Company 14 (0:12)	**Quality improvements of sintering technology**	Predicting risk of increasing importance of sintering technology and increasing concentration of sintering technology competence within the supplier base.	Establishing and maintaining a basic internal competence in sintering technology and increasing efforts to stimulate and broaden supplier base.	Extending sintering competence if dependency on suppliers or partners increases or importance of sintering continuous to increase.
7	Company 14 (0:15)	**Rising importance of bevel gear and crown wheel manufacturing**	Predicting potential dependence on two main suppliers for bevel gear and crown wheel manufacturing technology, which is increasingly critical.	Preparing future alternatives for current suppliers by assessing backward integration and internal competence building by partnering with equipment supplier or M&A.	Enactment of internal investment project as current supplier behave monopolistically and acquisition were not feasible.
8	Company 14 (0:45)	**Advanced forging technology for tooth gears of transmissions**	Predicting major advantages by more sophisticated forging technology innovated by equipment supplier.	Combining own product and market know-how with forging know-how of first equipment supplier, but sharing basic idea with second equipment supplier to create alternative IPRs.	If triggered by opportunistic behavior of initial equipment supplier, the possibility or at least credible threat to switch to an second-best alternative exists.

#	Possible Risks		Predict	Prepare	Enact
9	Company 16 (1:25, 1:42, 2:26)	**Material substitution in engine and transmission components**	Predicting increasing commoditization and of sintered engine parts and substitution by steel if no significant improvement of material characteristics is enabled.	Initiating three parallel projects based on three distinctive technological concepts to increase properties of sintered components to be more competitive with steel.	As potential and probability of success for each technological variant became obvious, efforts were focused on the most promising while the other projects were temporarily suspended.
10	Company 16 (1:58)	**Commoditization of technological competence in high volume markets**	Predicting that friction bearings for the high volume passenger vehicle industry will eventually become a mass market commodity where technology leadership is obsolete.	Identifying alternatives for exploiting the existing technological competence without increasing the risk to become too dependent on the highly competitive and price-sensitive automotive industry.	Selling the technological competence via licenses and contract engineering and manufacturing to a cooperating company without bearing any risk but having a share of the business.
11	Company 17 (0:18)	**Competing industry standard for radio communication**	Predicting the risk that current in-house solution for the emerging wire-less building automation industry may not become international technological standard.	Preparing own systems and products for different technological standards and frequency bands for radio communication of building automation applications (single chip solution).	Easy enactment and abandonment of prepared alternatives, when dominant technological product design for industry emerges.
12	Company 17 (0:24, 1:36)	**Slow market adoption of new digital product generation**	Predicting the risk that new product generation which was already based on digital, electronic technology may be pre-mature and adoption by customers' may be slow.	Preparing by parallel product developed project which was based on conventional and mature, analogue, electro-mechanical system.	If new digital product technology is not or only slowly adopted by customers, production of old product technology can be enacted.
13	Company 18 (1:19)	**Energetic versus enzymatic technology for bio-fuel production**	After the decision was made to enter bio-fuel production as a valuable by-product of integrated paper-mills, it was predicted that two basic technological principles will compete.	While existing technological equipment of plants privileged one technological concept, the second technology is also pursued in parallel.	When a dominant technological design for combined bio-fuel and paper production emerges, enactment of technology and abandon of second option.
14	Company 19 (0:13, 0:18, 0:34, 1:00)	**Material substitution in current technological core competence**	Predicting that ceramic materials may substitute metals as materials for cutting blades and knives and will make existing competences in stamping, grinding and lapping obsolete.	Preparing by internal technology pre-development projects on ceramic materials and alternative materials and the necessary engineering expertise and manufacturing technology.	If significant substitution process is regarded as potential threat to existing core competence of steel blade manufacturing, realignment of intended technology strategy.
15	Company 22 (0:59)	**Disintegrated mini mills for high quality applications**	Prediction that if scrap steel and energy prices continue to decrease and further quality improvements, alternative technology may become superior.	Starting of own mini-mill development program to evaluate further possibilities and preparation of investment commitment.	Permanent observation of scrap steel, energy prices and further quality improvements for triggering investment decision.
16	Company 23 (0:33)	**Competitors' heavy investment in high-alloyed steel grades**	Recognizing that direct competition is heavily committing to research of high-alloyed steel grades, while own results show only minor potential.	Minor but regular investments into researching further applications of high-alloyed steel grades because of competitor's engagement.	If competitor's motives are disclosed and promising, minor but existing competence and capacity can be upgraded and enacted.

#	Imaginable Scenario		Anticipate	Preempt	Align
1	Company 1 (1:20, 1:31)	**Scenario of "intelligent white goods"**	Anticipating that the most innovating white goods OEMS present digitalized and electronic white goods with add-on functionalities.	Preempting and experimenting with add-on technologies for electric engines like electronic controls and variable-speed motors which enable digitalization of white goods.	If scenarios seems feasible, alignment of intended technology strategy by entering new technological disciplines in electronics and the integration into the existing electro-mechanic system.
2	Company 2 (0:38, 1:18, 1:25)	**"All-aluminum car"-scenario**	Increasing interest of the automotive industry to reduce weight of vehicles, facilitated the scenario of pure aluminum cars, which substitutes steel in auto bodies by aluminum.	While preempting by developing technologies like hydro-forming, laser welding and mutual realization with an automotive OEM, parallel increase of steel competence for hybrid solutions.	Although the "pure aluminum car"-scenario never realized, necessary process technologies, pure aluminum and hybrid components were established in the automotive industry.
3	Company 2 (0:36)	**Aluminum for railway vehicle manufacturing**	Anticipating that especially the increasing market for high speed railway systems demands low-weight engineering and construction for railway vehicles.	Establishing a designated engineering department to develop expertise on railway vehicles and proof feasibility of designs and construction of railway vehicle bodies made of aluminum.	Aligning technology strategy by establishing business unit mass-transport systems to teach railway OEMS to employ and process aluminum instead of steel.
4	Company 4 (0:12, 0:20, 1:44)	**Potential substitution of core technology**	Anticipating that infrared-spectroscopy technology may be superior in online and lab measurement of alcohol content compared to density measurement.	Preempting infrared-spectroscopy technology by investing in a multi-functional infrared-spectroscopy equipment to understand basic functional and potential of technology.	Aligning of technology strategy by including infrared-spectroscopy (NIR module) as complementary and substitutive technology to existing technological core competences.
5	Company 6 (0:32, 0:39)	**Alternative engine and drive train technology scenarios**	Anticipating that mandatory reduction of fuel consumption and emissions will increase variety of engines and will limit the improvement possibilities of pure engine development.	While adopting a new core technology strategy which included all no-regret moves, all contingency technologies where bundled in one learning project (diesel-hybrid drive train project).	Various elements and modules which were explored and developed in working towards the worst case scenario were continuously adopted by regular customer projects.
6	Company 8 (0:19)	**Global warming scenario, climate change and snow free alps**	Anticipating published long-term predictions of global warming, climate change and decreasing amount of snowfall in the Alps an the consequences for winter tourism.	Preempting multiple possibilities to diversify existing technological competences from ropeway construction into new applications, markets and industries.	As preempted possibilities seem feasible and successful, continuous alignment of intended product and manufacturing strategy.
7	Company 8 (0:56)	**Scarcity of parking space as enabler for technology transfer**	Anticipating that in Japan ropeway-based parking towers create supply of car parking space in urban regions when available space is highly scarce.	Preempting technology by securing license and adaption of technology for European applications. Observing triggering indicator like land price in cities and scarcity of parking space.	If conditions in European cities justify feasible applications of rope-way based parking towers, technological competence is transferred into new markets.
8	Company 9 (0:12)	**Material substitution in core business**	Anticipating that breakthroughs in and industrialization of material and manufacturing technology of plastics could substitute the core business of metal piping systems.	Preempting plastic technology by establishing an internal but independent core-team on plastic with few constraints which gradually grew.	Continuous and gradual alignment of technology strategy as plastics increasingly substituted all metallic materials and manufacturing processes in piping systems.

#	Imaginable Scenario		Anticipate	Preempt	Align
9	Company 10 (0:47)	**Regulation and energy-efficiency enables technology substitution**	Anticipating that increasing regulations of safety issues, noise and acoustic emissions may allow market entry and technology transfer in certain mining applications.	Preempting unknown but adjacent mining industry by establishing an independent start-up within the corporations to develop industry and intelligence and technology adoptions.	After successfully introducing first substitution product for noisy and pneumatic mining hammer drills, internal mining industry start-up was converted into regular business.
10	Company 11 (0:03, 0:40)	**Multiple standards and no global technological dominant design**	Anticipating that further growth, US market entry and establishing of a global standard is only possible when current US standard and technology is adopted (DRSC 915).	Preempting by evaluating, exploring and pursing different opportunities in parallel like M&A, joint venture and funding and developing a local subsidiary.	After one local American with existing IPRs, knowledge base and supplier network was acquired, parallel efforts were abandoned and technology strategy was aligned (WAVE).
11	Company 12 (0:09, 0:12, 0:33)	**Combustion engine vs. electro engines and battery technology**	Anticipating that restrictive emission regulations and decreasing size, weight, costs and charging time and of sophisticated battery technology may enable electro-motorbikes.	Preempting by entering partnerships to develop and customize batteries and electrical engines for motorbike applications and engineering of a demonstrator prototype.	If electro-engines and sophisticated battery technology seem feasible and competitive, refinement of technology strategy by preparing for mass production of electro-motorbikes.
12	Company 13 (0:32)	**Rising importance of fiber-based composite materials**	Anticipating increasing demand for and rising industrialization of carbon-fiber composite materials, which need polyacrylnitrile fibers as quality and function-relevant precursor material.	Preempting the emerging industry for carbon-fiber composite materials by entering an joint-venture with a carbon fiber producer and supplier.	Alignment of technology strategy by reinforce commitment to synthetic fiber technology and increasing competence in hybrid fiber technology of cellulose and synthetic fibers.
13	Company 14 (0:54)	**Commoditization of water pumps as engine components**	Anticipation that in five years water pumps may not deliver any return because of commoditization and competitive price pressure.	Creating and preparing alternative scenarios for product and technology exit as transfer to low-cost countries, market exit and outsourcing.	Alignment of technology strategy by deciding for one alternative and abandonment of others.
14	Company 15 (0:23)	**Alternative engine and drive train technology scenarios**	Anticipating various possible alternatives for future car engine and drive train systems.	Identifying necessary technological competences for all and each alternative. While initiating no-regret moves, also parallel low-commitment preemption for each scenario.	As new dominate architecture for engine and drive train emerges alignment and re-focusing of technology strategy.
15	Company 18 (0:05, 0:36)	**Different technology scenarios for different global locations**	Anticipating that driving and enabling factors of technology development and resulting technology scenarios are diverse for different regions (e.g. water consumption, energy, quality).	Preempting different technology scenarios for each region by identifying and pursuing core and non-core topics and initiatives within technology strategy.	Continuously aligning and adaption of technology strategy on corporate and plant level.
16	Company 18 (0:12)	**Bio-plastics as substitution material for paper**	Anticipating that improvements in production an processing of sustainable organic plastic may enable substitution of conventional paper.	Preempting by screening of already available extrusion technologies to process conventional and organic plastic and observing prices for raw material and energy.	Aligning of intended technology strategy, if break-through in material and process technologies enable similar quality to conventional paper.

#	Imaginable Scenario		Anticipate	Preempt	Align
17	Company 21 (0:17, 0:48)	**Electrification and digitalization of fire fighting equipment**	Anticipating that information and communications technologies increase the potential for additional service and product functionalities and concepts for fire fighters.	Experimenting with portable communications devices and software technology to provide mission content for fire fighters during operation (e.g. supported EU project, local clusters).	Aligning of intended technology strategy by including new product technology and integrating new services if enabled by third parties information and service providers.
18	Company 21 (1:22)	**Potential substitution of mobile by stationary fire fighting**	Anticipating that legal requirements may enable stationary fire fighting applications to substitute conventional mobile fire fighting facilities.	Identify and supply overlapping niche between mobile and stationary fire protection systems for local areas of increased fire risk (e.g. industry, tunnels, engine testing facilities).	Continuously aligning of intended technology strategy by incrementally entering stationary fire protection.
19	Company 21 (1:27)	**Frame construction vs. self-supporting body design**	Anticipating that self-supported body construction with aluminum and composite materials enable vehicles with higher modularity, more options, more space and lower weight.	Incrementally building competences in advanced engineering methods, laser cutting, adhesive bonding and canted aluminum sheets parallel to dominating frame construction.	Aligning technology strategy by outsourcing me-too technologies like grinding and welding of frames for low-cost vehicles, but fully adopting new technologies.
20	Company 22 (0:29)	**Alternative scenarios for exploiting unit injection technology**	Anticipation of various alternatives how to exploit a patent protected technology in an unknown market.	While preparing to supply unit injector components directly to automotive OEMs like Volvo (high risk), alternative ways of exploitation were explored (selling, licensing).	Because of limited market knowledge the hole business unit including the technology was spun off and eventually bought by BOSCH.
21	Company 23 (0:13)	**Enabled hot stamping process technology**	Anticipation that missing enabling technology (zinc coating process) will enable advantageous applications of hot stamping process technology.	Preemption of hot stamping technology and starting a project on enabling technology of zinc coating for corrosion protection.	Breakthrough in zinc coating triggered technology adoption of hot stamping process technology.
22	Company 23 (0:20)	**Low-emission and low-energy steel mill scenario**	Anticipation of various scenarios: Breakthrough in low-emission steel mill technology, off-shoring of steel production or technology exit.	Participation in technology research alliance of various European steel producers for low-emission steel mill and alternatives.	Influencing and observing national and European emission regulation and adoption of realizing scenario when feasible.
23	Company 25 (0:08, 0:18, 0:28)	**Switching drivers of technology development as innovation enabler**	Anticipating that technological progress in complementary areas and changed drivers of technological development may enable initially aborted technology projects today.	Identifying existing technological concepts and patents which, while maintaining speed and quality of process and product, decrease overall energy consumption of process.	Developing an integrated and more energy efficient module for drying and smoothing (BoostDryer) which is offered as upgrade for existing paper mills or as integrated module.

#	Weak Signals		Anticipate	Preempt	Align
1	Company 1 (0:10)	**Alternative cooling technologies which make compressors and engine obsolete**	.Anticipating that there are cooling technologies which are based on completely different scientific know-how which have a potential to substitute cooling compressors.	Although no breakthrough is expected, irregular and informal review and increased sensitivity to customers' activity on these topics (e.g. magnetic cooling, fuel cell).	If significant substitution process seems realistic, reformulation of technology strategy by high efforts to diversify existing technology to other industry markets.
2	Company 3 (0:40, 1:07)	**Emerging market of bio-fuel and renewable energy production**	Anticipating the emerging and fast-growing industry of bio-fuels and renewable energy (biomass boilers) and the technological overlaps to existing business fields.	Preempting by continuous screening of existing process technologies, entrepreneurial activity, and national and international legislation and identification of acquisition targets.	Minor acquisitions (bio mass gasification), internal technology transfer and customization for industry needs and establishing of bio-fuel business unit.
3	Company 6 (1:37 and 0:07)	**Possible material substitutions in drive train systems**	Although materials are not part of the intended technology strategy, it is anticipated that material substitution (e.g. magnesium) may be a triggering factor for technological innovations.	Use low-commitment initiatives to passively follow and observe trends in new material development which may affect drive train systems and related manufacturing technologies.	If significant substitution processes appear, a timely and proper realignment of the intended technology strategy is possible.
4	Company 7 (0:50)	**Increasing potential of electrical cars and alternative materials**	Anticipating potential threat of significant substitution of combustion engines by electrical cars and a parallel substitution of steel and light-metal by composite materials.	Preempting by technology monitoring of relevant industries, markets and individual companies by a designated automotive trend group and mutual R&D an with other steel companies.	If significant substitution process become predictable, increasing efforts to find new applications, markets and industries for existing competence.
5	Company 8 (0:09)	**New cable car technology which allows operation at high wind speed**	Anticipating that many remaining potential routes for cable cars in the Alps are heavily exposed to wind and current technology may not allow untroubled operations.	Preempting a potential solution by identifying and contacting an inventor and designing engineer who owns patent and wants to realize his idea.	Aligning of technology strategy by license agreement for the relevant patent and internal adoption of new product technology.
6	Company 8 (0:41)	**Cornering technology of cable cars as enabler for various applications**	Anticipating that a feasible cornering technology for cable cars would allow improvements for existing applications and enable completely new product technology applications.	Constant monitoring and review of current and past alternative efforts, projects and patents to realize cornering of cable cars and adjacent products.	Aligning of technology strategy and adoption and exploitation of cornering technology if feasible solution emerges and disabling factors are resolved.
7	Company 9 (0:14, 0:19, 1:03)	**Composite material as substitution for auto body and chassis parts**	Anticipating increasing amount of applications of composite material technology and beginning substitution of light metal in aerospace and automotive industry (body, chassis).	Analyzing current applications and monitoring further progress of composite materials technology and the emerging supplier and technology provider industry.	If significant substitution processes appear, a timely and proper realignment of the intended technology strategy is possible.
8	Company 11 (1:52)	**Increasing convergence of applications into mobile phones**	Anticipating that mobile phone and related products incorporate technologies, functionalities and applications which may threaten current or future core businesses.	Establishing an observation team which identifies and communicates threats and opportunities for the current business model by mobile communication technology.	Realigning of technology strategy if mobile information and communication technology creates relevant opportunities or threats.

#	Weak Signals		Anticipate	Preempt	Align
9	Company 14 (0:37)	**Increasing relevance of main transmission systems**	Anticipating that technological sophistication and increasing complexity of drive train systems enables additional technology and know how exploitation possibilities.	Developing first prototypes for complex double clutch transmission systems and identifying technology gaps for entry into main transmission systems.	Aligning and extend formulated technology strategy by including new necessary technologies and prepare market entry into main transmissions.
10	Company 14 (0:59)	**Magnesium as a material for drive train applications**	Anticipating that magnesium would be a feasible material for gear boxes if non-advantageous like creeping property could be remedied.	Monitoring progress in magnesium alloys with a special focus on identified disabling factor like creeping properties and processability (Thixo).	Aligning of intended technology strategy by resumption of existing but suspended projects on magnesium introduction as disabling factors were mastered.
11	Company 15 (0:46 and 1:15)	**Composite materials for auto body applications**	Anticipating by technology screening at corporate level that composite material show increasing potential.	Establishing informal contacts to composite material industry, analyze and asses technology potential and establish linkage to relevant business units in the corporation.	If triggered by identified potential or threat, include composite materials technology in reformulated intended technology strategy.
12	Company 15 (0:31)	**Enabled car to car and car to infrastructure communication**	Anticipating that increasing sensor technology within cars and within infrastructure will enable communication between cars and infrastructure.	Continuous screening of new technologies, entrepreneurial activity of start-up firms, and national and international legislation to trigger technology adoption.	Aligning intended technology strategy if legal prerequisites and emerging standards for technologies and interfaces decrease uncertainty.
13	Company 16 (0:16, 0:23, 1:08)	**Potential technological obsolescence in main markets**	Anticipating rising potential of electrical car to become the dominant vehicle in the future and to substitute internal combustion engines triggered by restrictive emission regulation.	Preempting by monitoring progress of battery, fuel cell and other alternative technologies which make many produced parts manufactured with sintering technology obsolete.	If significant substitution process are predictable, increasing efforts to find new applications, markets and industries for current sintering competence.
14	Company 17 (1:24)	**Possibilities for wire-less and decentralized energy supply**	By entering radio control systems it was anticipated that for some applications wire-less energy control should be complemented by wire-less and decentralized energy supply.	Preemption fuel-cell technology by partnering with university institute to monitor fuel-cell technology for household applications.	If technology shows possibilities for potential household applications, realigning technology strategy by including fuel cell as add-on technology for radio technology.
15	Company 18 (0:09)	**Complete virtualization and digitalization of information**	Anticipating that scenarios which forecast paper-less offices, e-books may significantly reduce the demand for or substitute business paper.	Permanent monitoring and screening of technological developments and innovations which may threaten paper as dominant media and searching diversification possibilities.	Reformulation of intended technology strategy, if technology and market break-through indicate substitution if business paper.
16	Company 20 (0:06, 0:12, 0:33)	**Technology convergence into existing diagnostic products**	A new medical, clinic study suggests the measurement of an additional blood parameter which could be implemented in existing products by a complementary technology.	Preempting by initiating an exploration project with external partners to identify technology gaps and to pre-develop missing technologies and integration into existing products.	If feasibility is proven, realigning intended technology strategy by including identified technologies in the current technology roadmap.

#	Weak Signals		Anticipate	Preempt	Align
17	Company 21 (0:58)	**Development of sophisticated sensor technology in adjacent industry**	Anticipating that sophisticated sensor technology for automotive applications in mass production may have applications in fire fighting industry.	Identifying and analyzing various sensor technologies for application in fire fighting vehicles (e.g. measuring precise localization of and distance to fire source, wind speed and direction)	Aligning of intended technology strategy, if application of functionality is feasible and dominant sensor technology is emerging.
18	Company 23 (0:21)	**Anticipated potential of sheet casting technology**	Anticipating alternative but currently inferior technology of thin sheet casting and disabling characteristics.	Irregular and informal review of thin sheet casting process technology (e.g. general cost structure of process and the quality of produced goods).	If triggered by substantial improvement, reformulation of initial technology strategy which does not include any commitment to thin sheet casting.
19	Company 25 (0:56, 0:59, 1:54)	**Increasing potential of carbon fiber and composite materials in all business units**	Anticipating that composite material components are increasingly applied and have further potential for applications in all business units and product groups.	Preempting carbon-fiber based composite material technology by screening emerging industry and identifying potential targets for M&A or minority equity investment.	If importance of composite materials in existing and adjacent businesses is increasing, realignments of intended technology strategy by specifically including composite materials.

#	Sudden Emergencies		Sense	Respond	Renew
1	Company 2 (0:43, 0:50, 1:26)	**Unexpected substitution of aluminum in the aerospace industry**	Recognizing that Boeing and Airbus announce rising content of composite materials in new generation large-capacity commercial aircrafts, which substitutes aluminum.	Responding by evaluate expansion of existing composite competence, developing new aluminum alloys and emphasize rising market of low-size, medium-range commercial aircrafts.	Renewal of intended strategy by focusing on new aluminum grades and alloys for the aircraft industry and higher priority of composite materials.
2	Company 3 (1:12)	**Unanticipated breakthrough of substitutive technology**	Sensing that provided galvanization facilities for high quality sheet steel (electrolytic zinc coating) in the automotive industry are substituted by cheaper hot-dip galvanization.	Fast response by establishing some internal technological competence and acquiring the complete hot-dip galvanization business of another international corporation.	By acquiring the substitutive technological competence, the initially intended technology strategy of the business unit, which did not include hot-dip galvanization was disrupted.
3	Company 4 (2:31)	**Unanticipated technological innovation of competitor**	Sensing that competitor has realized product with technological add-on functionalities and applications which were not scheduled for the current product generation.	Fast response by rescheduling and reprioritization of existing technology roadmap and R&D agenda and reverse engineering of competitors product.	By quick resource reallocation and rescheduling of R&D agenda, disruption of intended technology and product strategy of the relevant product group.
4	Company 6 (0:34)	**Unexpected standardization of add-on technology**	Unexpected enactment of international legislation which privileged particle filter as de-facto standard for exhaust after-treatment over internal engine optimization.	Responding by customizing existing diesel engine development programs for the adoption of add-on particle filter technology.	Renewal of intended technology strategy, which did not include particle filter but pursued means of internal optimization of diesel engine combustion.
5	Company 8 (0:14)	**Unexpected applications for ropeway technology**	Sensing that ropeway technology in combination with conventional conveyor technology enables continuous long-distance conveying in challenging territory.	Fast response by engineering and installing a demonstration facility for technology without doing any detailed market analysis (RopeCpn technology).	After reference project was realized diversifying into completely new markets (e.g. industrial plants, mines) by adapting technological competence.
6	Company 8 (1:02)	**Unexpected introduction of planetary gear set into ropeways**	Sensing by a main competitor's presentation of a model of planetary gear at an industry exhibition that this technology may have many potential and advantageous applications.	Fast response by rapid resource reallocation to engineer planetary gear system together with new supplier for planetary gear drives.	Ability to offer ropeway drive train system with planetary gear before main competitor had a market-ready solution.
7	Company 9 (0:03, 0:17, 0:21, 0:59, 1:06)	**Unexpected applications of technological competence**	Technology scanning identified life-science as emerging and fast growing industry where existing technological expertise of mature business unit may be applicable.	Hiring external industry experts and establishing a low-commitment spin-off which should adapt and transfer precise injection molding and sterile manufacturing to life-science industry.	Renewal of intended technology strategy by establishing a new organization which could promptly be reintegrated into regular corporate structure.
8	Company 11 (2:00)	**Unexpected breakthrough in complementary technology**	Sensing the potential of a breakthrough in video and software-based technology for traffic surveillance and incident detection.	Responding by acquiring a medium-sized engineering company with significant know-how and IPRs within weeks.	Renewal of intended technology strategy by acquiring a company which explores and employs adjacent technologies on adjacent markets.

#	Sudden Emergencies		Sense	Respond	Renew
9	Company 12 (0:25)	**Introduction of substitution technology by main competitor**	Main competitor unexpectedly and successfully introduces 4-stroke engines into off-road motorbike segment, which was completely dominated by 2-stroke engines.	Responding by initially acquiring and developing know-how and engineering competence for 4-stroke engines and rapidly reallocating resources and budgets.	Disruption of initially intended technology strategy and product portfolio which did not include 4-stroke engines, but was fully focused on 2-strike engine technology.
10	Company 15 (0:26 and 0:29)	**Success of hybrid engine technology of main customers' competitors**	Sensing that hybrid engine and drive train system technology of customers' competitors have unanticipated market success.	Entering battery technologies and complementary technologies to complex hybrid engines (e.g. transmission and control systems).	Renew initial technology strategy which did not include hybrid engine technology as significant business.
11	Company 21 (1:20)	**Unexpected application of produced nozzle systems**	Sensing by newly installed innovation management that produced nozzles may be applied for de-icing facilities and vehicles at airports.	Fast response by newly installed business development unit by evaluating market entry and identifying potential customers.	After successful market entry, formal renewal of intended product strategy as exploitation of technology became reasonable.
12	Company 24 (1:16)	**Significant and IP protected product technology of competitor**	Sensing the future potential of a competitor's patent-protected technology and recognizing its is superior to all existing alternative.	Acquiring the company and focusing on access to necessary IPRs and keeping of involved engineers their know-how.	Reformulate initially intended technology strategy and apply FAKOP technology to all products.

#	Converging Evolutions		Sense	Respond	Renew
1	Company 1 (1:09)	**Unexpected possibilities for material substitution**	During a creativity workshop within the design phase of a new electrical engine, one abolished idea was to replace the copper in electrical engines by aluminum.	When the copper price increased dramatically, involved engineers remembered the rejected idea and transferred the idea into the current product development.	While the initial intended technology strategy never included the aluminum engine, it was adopted after first application was promising and successful.
2	Company 3 (0:10, 0:43, 1:03)	**Further exploitation opportunities for dewatering and drying technologies**	.Decision to cover alternative dewatering technologies for pulp and paper mills allowed to recognize multiple industrial applications for solid/liquid separation and dewatering.	Responding by transferring module competence for dewatering and drying within paper and pulp business unit into a separate new business unit (environment & process).	Although never intended by the initial technology strategy, the know-how on dewatering and solid/liquid separation from paper business is now exploited on very different markets.
3	Company 4 (1:23, 1:30, 2:23)	**External exploitation of technological competence**	The necessary supply of core products with high-end components made it necessary to vertically integrate in various technological disciplines which can be exploited externally.	Responding by acquiring complementary metal processing manufacturing and engineering company as a flagship to externally exploit technology competences.	Renewal of initial technology strategy by exploiting cumulated technological competence for external industrial and engineering service for special low-batch production and prototyping.
4	Company 6 (0:25)	**Technology exploitation from niche product development**	After diversifying into engineering stationary and single-unit diesel engines, development of simulation and virtual engineering because prototyping was not feasible.	Transfer of simulation and virtual design know-how from single-unit and low-batch engineering projects to mainstream business of car engines.	The simulation and virtual engineering and design methodology became a new source of competitive advantage for all engineering projects and became a separate business unit.
5	Company 6 (0:39 and 0:11)	**Unexpected application opportunity for technology**	Because fuel cell is regarded as a long-term substitution technology to conventional combustion engines of cars, a fuel-cell based drive-train of limited success was engineered.	While the engineered fuel cell was never realized, the project created the ability to recognize the application of fuel cells in the automotive industry as stationary energy supply of HDV.	Although initially engineered as substitution for a conventional car engine, the developed fuel cell serves as ancillary energy supply unit for HDV.
6	Company 8 (0:06)	**Technological insights from unsuccessful new market venture**	During the efforts to diversify ropeway technology into leisure park market it was recognized that “giant wheel” principle may be applicable for conventional cable car projects.	Involved engineers transferred “giant wheel” technology into a conventional cable car project as an add-on technology with a unique selling proposition.	Successful first application significantly changed existing product strategy by adding a new source of technology-based competitive advantage .
7	Company 9 (0:07, 0:10, 0:36)	**Application for laser technology in existing business unit**	Sensing at an occasionally trend workshop on laser technology with external technology experts that there are numerous potential applications for laser technology.	Existing business development function at corporate level supported business unit to initiate project on most promising application from generated idea pool.	Renewal of intended technology strategy by adopting laser technology which was not included in any technology roadmap before.
8	Company 10 (0:39)	**Increasing maturity and commoditization of laser technology**	Sensing in on-construction site field studies that technological improvement of traditional products made manual measuring procedures a dominating bottle-neck on construction sites.	Responding by introducing increasingly mature, robust, miniaturized and commoditized laser technology from analytical lab applications into on-site measurement procedures.	Renewal of initial technology strategy by entering an new technology field and establishing of a business unit based on this new technology and its application in the existing market.

#	Converging Evolutions		Sense	Respond	Renew
9	Company 12 (0:25, 0:31 0:50)	**Opportunity for exploitation of unsuccessful technology project**	Sensing that restrictive regulation of urban traffic and emissions may allow to exploit technology competences (street bikes, battery, electrical engine, lightweight, X-Bow, ATV).	Initiating development and of an electronic car for urban traffic which exploits existing competences in lightweight construction of electrical street vehicles with 4 wheels.	Complete erosion of initial product and technology strategy which did not include becoming an automotive OEM for electrical vehicles.
10	Company 13 (0:28)	**External exploitation of Integrated process optimization competence**	Established cross-sectional business unit "Technology" which absorbed all maintenance and technology process competence recognized increasing service demand by third parties.	Offering internal expertise to third parties to enable involvement in new plant projects which is regarded as the real driver of technological innovation in mature, asset intensive industries.	Although never intended, the new business unit became a profit and learning center, which absorbs and transfers innovation and ideas from green-field projects of third parties.
11	Company 14 (1:08 and 0:10)	**Rotary swaging technology for automotive applications**	Sensing possible application of a mature technology from an unrelated industry (barrel manufacturing in fire arms industry) in the automotive industry.	Developing process technology for requirements of the automotive industry (scale, quality) by cooperating with new equipment supplier.	Reformulating initially intended technology strategy by introducing rotary swaging technology to technology program.
12	Company 15 (1:01 and 0:27)	**Unexpected application of cryogenic technology**	Establishing a spin-off organization as sensor platform for potential technology transfers from aerospace industry applications into automotive industry.	Hydrogen and natural gas cars demand liquid hydrogen fuel lines and tanks which are standard application in aerospace industry.	Transfer relevant cryogenic fuel tank and line technology from space systems unit into vehicle engineering for hydrogen and natural gas cars.
13	Company 21 (0:32)	**Unexpected possibilities of modular product architecture**	Engineering and manufacturing recognized that the modularization of products which was intended to enable local content assembling has unanticipated advantages.	Responding of engineering and manufacturing by incrementally expanding modularization of products on all product groups to allow variety optionally configurations.	Stepwise erosion of initial product and manufacturing strategy which did not include modularization of products.
14	Company 24 (1:24)	**Friction stir welding technology for railway application**	Sensing on a internal corporate technology conference that window frames of aluminum are welded by friction welding technology, a formerly unknown technology.	Screening friction welding for application how to combine aluminum and steel and initiating feasibility studies for manganese steel for turnouts and conventional rail steel.	Substituting successful butt welding technology by friction welding and reducing necessary welding by 50 % (cost and smoothness).

APPENDIX E – PARAPHRASED & CODED INTERVIEW DATA ON ENABLING EFFORTS

1	• Establish dialog-based technology strategy development process with regular formal and informal meetings.	I30, 0:29; I13, 0:27; I17, 0:17, 0:50; I20, 0:22, 0:38; I18, 0:10; I12, 0:09; I21, 0:06; I10, 1:24;
	• Identify and know current substitutive and complementary technologies.	I17, 0:56; I12, 1:00; I21, 0:16, 0:55; I11, 0:57; I19, 1:05; I9, 0:08;
	• Identify and know the underlying drivers of technological development and innovation.	I28, 0:04; I21, 0:13, 0:55; I10, 0:12, 1:38; I9, 0:33;
	• Identify, categorize and classify your technological competences and their future potential and limitations.	I14, 0:38, 0:55; I17, 0:29; I21, 0:55; I11, 0:59; I11, 0:57; I19, 1:05; I9, 0:04; I5, 0:08; I6, 0:09
	• Holistic and integrated technology appropriation and exploitation routines.	I14, 0:19; I25, 1:27; I9, 0:30; I24, 0:03; I23, 0:41;
	• Organizing your products and technologies in systems, modules and platforms as adequate unit of analysis.	I30, 0:44; I14, 0:26; I16, 0:08, 0:19; I28, 0:43; I22, 0:19, 1:19; I21, 0:54; I10, 1:11; I11, 0:27; I19, 0:08; I9, 0:04, 0:20; I23, 1:42; I2, 0:37;
	• Using and linking technology portfolios and skill, resource, project, product and technology and trend roadmaps.	I30, 0:36; I13, 0:23; I14, 0:30; I16, 0:23, 0:50; I17, 1:12; I28, 0:44; I25, 1:14; I20, 0:27; I18, 0:10, 1:09; I22, 0:24; I12, 0:08;I21, 0:39; I11, 0:19, 0:31; I19, 0:57; I27, 0:44; I9, 0:04, 0:33;
2	• Score-card systems to track successful adoption of new technology strategy	I25, 1:18;
	• Adjustable continuous improvement processes and change management routines.	I30, 0:52; I14, 0:50; I25, 1:46; I9, 0:30;
	• Strong R&D&E program and project management routines to implement new technology strategy.	I30, 1:07; I15, 1:15; I13, 1:32; I25; 0:07, 1:31; I20, 0:27; I18, 1:08; I21, 0:45; I19, 0:04; I9, 0:30; I23, 0:44;
3	• Chief technology officer as an corporate executive board member for technology-related research, development, engineering and manufacturing.	I13, 0:29; I16, 0:28; I25, 1:19; I26, 0:14; I20, 0:25; I18, 1:05; I29, 0:03, 0:20; I21, 0:34; I19, 0:56; I24, 0:02; I23, 0:39; I6, 0:03;
4	• Participative technology strategy formation increases acceptance and probability of successful adoption of strategy.	I29, 1:04; I9, 0:23;
	• Clear internal communication of developed technology strategy.	I29, 1:04; I10, 0:14, 2:09; I4, 1:07;
	• Right balance of bottom-up and top-down technology strategy formation.	I13, 0:24; I14, 0:28; I17, 0:46; I25, 1:33; I26, 0:12; I20, 0:26; I18, 0:27, 1:04; I12, 0:06; I21, 0:31, 0:44; I11, 0:33; I19, 0:09; I7, 0:56;
	• Separate yearly planning and budgeting routines and quarterly reviews from real strategy formation processes.	I13, 0:31; I19, 0:59; I9, 0:06; I23, 2:28;
	• Introduce strategic initiatives to face predicted change in form of a yearly strategic headline with primary focus and commitment of top management.	I20, 0:22, 0:49; I29, 0:13; I10, 2:10;

Absorptive and Adaptive Capabilities	
Strategic (P)Reprogramm-ability	**Strategic Adoptability**
Strategic Hedging Ability	**Strategic Corrigibility**
Strategic Versatility	**Strategic Adaptability**
Receptivity	**Strategic Reformulation**
Agility	**Strategic Responsiveness**
Learning Ability	**Strategic Incrementalism**

1	• Hedge important technology developments by pursuing alternative technological realizations in parallel projects.	I13, 0:47; I21, 1:42; I19, 0:11; I5, 0:27;
	• Hedge by limit first application of new technology to a single plant, market, platform or production line for a pilot phase.	I14, 0:40; I11, 0:50; I6, 0:18; I5, 1:08; I4, 0:18;
	• Hedge new process technology by old product technology and vice versa.	I14, 0:40; I18, 0:25; I22, 0:15; I29, 0:43; I21, 1:42; I19, 0:22; I5, 1:07; I4, 0:59;
	• Hedge new technology by existing market know-how and new market by existing technological know-how.	I20, 0:02; I18, 0:25; I22, 0:15; I21, 1:54; I9, 0:38;
	• Hedge technological innovation in one product or process module or component by mature overall system.	I22, 0:15; I19, 0:22; I9, 0:38;
2	• Hedge for opportunistic behavior of quasi-monopolistic supplier of new technologies.	I14, 0:48; I10, 1:50, 1:59; I9, 0:20; I6, 1:14;
	• Keep basic technology know-how of sourced or outsourced technology in-house.	I30, 1:27; I15, 0:21; I22, 0:18;
	• Involve lead-customers into your technology strategy	I9, 0:22; I23, 0:09, 0:24;
3	• Substitute an “avoid risk”-culture by a “manage risk”-culture.	I17, 2:07; I18, 0:54; I10, 1:27, 2:26;
	• Avoid to punish risk-takers and to reward risk-avoiders systematically.	I18, 0:54; I10, 1:27, 2:26;
4	• Use contingency planning and fallback positions techniques for verifying assumptions and strategies.	I22, 0:13, 1:23; I21, 2:28; I9, 0:20, 0:38; I23, 2:32;
	• Avoid unintended parallel technology projects to allow for intended parallel efforts	I30, 0:52; I13, 0:04, 0:46; I26, 0:19; I21, 2:26; I19, 0:24, 0:55; I4, 0:44; I8, 0:03
	• Integrate risk management approaches into technology strategy formulation procedures.	I13, 0:49; I17, 1:15; I20, 0:16; I22, 0:13; I21, 1:13, 2:29; I10, 2:32; I9, 0:18, 0:38; I4, 0:10;

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Agility	**Strategic Responsiveness**
Learning Ability	**Strategic Incrementalism**

1	• Limit fraction of R&D&E expenses for one business unit, product group or core technology.	I29, 0:15; I21, 0:40; I23, 0:40;
	• Identification of a robust core technology strategy and no-regret moves.	I12, 0:31; I10, 2:11; I19, 0:33;
	• Emancipate your technology strategy from your most dominating customers.	I26, 0:32; I20, 0:03; I21, 2:02; I10, 0:43; I11, 0:20; I19, 0:39; I5, 0:34; I6, 0:31;
	• Central R&D budget and project supervision but decentralized R&D&E units to increase incentives for business units to collude in long-term R&D projects.	I25, 1:22; I27, 0:31;
2	• Inverse risk analysis fosters technological versatility	I13, 0:16; I25, 1:48; I21, 2:26; I23, 2:12; I2, 0:51;
	• Explicit or implicit development of alternative or supplementary technology scenarios.	I13, 0:25; I22, 0:25; I21, 0:05; I19, 0:33; I27, 0:54; I9, 0:38; I2, 0:22;
	• Real option valuation of strategic technology projects.	I13, 1:22;
	• Separate general technology assessment and technology valuation as a business case.	I17, 0:29; I25, 1:39; I20, 0:16; I21, 1:52; I19, 0:37; I4, 0:09, 0:31;
3	• Responsible idea broker function which oversees all external technology relationships and public funds and subsidies.	I13, 0:45; I25, 1:09; I10, 1:48; I19, 0:01; I27, 0:01; I4, 0:23; I8, 0:12; I7, 1:04;
	• Central business or corporate development function.	I30, 0:06, 0:54; I20, 0:02;
	• Pre-competitive, horizontal partnerships with competitors to explore mutual technological threats.	I9, 0:36;
	• Redundant and overlapping funding possibilities for emerging technology innovations.	I30, 1:15; I17, 0:16; I18, 0:21, 1:07; I18, 1:06, I21, 1:51; I10, 2:02, 2:06;
	• Employ various alternative forms of external technology partnering for exploring and exploiting technologies.	I13, 0:15, 0:40; I17, 1:07; I12, 0:22; I21, 0:48,1:19; I21, 2:26; I10, 2:12; I19, 0:35; I9, 0:12, 0:35; I3, 1:23; I7, 0:18;
	• Enable sponsored spin offs or internal star-up routines of potentially disruptive or emerging technologies.	I18, 0:58; I19, 0:47;
	• Internal venture capital organization	I10, 2:02;
4	• Review goal conformance and underlying assumptions for goal relevance in review meetings of strategic projects.	I22, 0:17; I10, 1:25;
	• Continuous ability to rescale, suspend or kill technology development projects	I30, 0:52; I16, 1:46; I17, 0:29; I22, 0:18; I21, 1:49; I10, 2:11; I19, 0:20; I9, 0:17; I23, 1:57; I2, 0:33; I4, 0:19;
	• Failed technology innovation project as a valuable result which decreases uncertainty.	I15, 0:09; I17, 2:07; I26, 0:08; I20, 0:59; I22, 0:40; I12, 0:29; I21, 1:38; I10, 1:29, 2:17; I19, 0:04; I4, 1:00;
	• "Fail early – fail cheap" approach in new technology development.	I15, 0:15; I26, 0:08; I18, 0:54; I12, 0:28; I21, 1:38; I10, 1:29, 2:28; I2, 0:02;
	• Stage-gate process for new technology developments which reviews, controls and adjusts initial assumptions, project and process performance.	I16, 0:22; I26, 0:23; I29, 0:35; I21, 0:02, 0:41; I10, 1:22, 1:34; I11, 0:18; I19, 0:20; I9, 0:06, 0:20; I23, 0:13;

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1	• Being involved in your customers market research to identify new drivers for technology development.	I30, 1:37; I18, 1:13; I22, 0:05, 0:51; I29, 0:53; I12, 0:40; I21, 0:11; I10, 0:43; I11, 0:23; I19, 0:06;
	• Use trend scouts to identify non-obvious trends in consumer and end-user behavior.	I13, 1:01; I28, 0:51; I20, 0:03; I18, 1:13; I29, 0:53; I12, 0:42; I11, O:22; I19, 0:06, 0:41;
	• Observe and analyze technological trends within the complete value chain of the industry.	I13, 1:14; I22, 0:06; I12, 0:42; I21, 0:11; I11, O:22; I19, 0:06;
	• Send scientific and technical employees with intelligence assignment to industry conventions, trade fares, conferences to explore new or emerging technologies.	I14, 0:59; I16, 0:40, 1:43; I17, 1:10; I28, 0:46; I25, 1:08; I18, 0:56; I12, 0:44; I21, 1:07, I11, 0:48; I24, 1:06; I23, 0:55; 2:30; I4, 0:27; I3, 1:09; I4, 0:27;
2	• Systematic search for internal and external exploitation possibilities of existing technological competences.	I14, 0:36; I17, 0:58; I18, 1:16; I9, 0:31;
	• Corporate technology and innovation management function.	I30, 0:11, 0:51; I14, 0:02; I16, 0:43; I17, 1:22; I18, 0:03; I29, 0:34; I12, 0:23; I21, 0:01; I19, 0:01; I23, 0:41; I2, 0:02; I5, 0:44;
	• Organizational separation of technology scouting and scanning from technology monitoring.	I30, 0:57, 1:09; I13, 1:06; I16, 1:03; I17, 1:22; I26, 0:03; I20, 0:42; I18, 0:50, 1:12; I12, 0:24, 0:44; I21, 1:04; I10, 1:40; I19, 0:05, 0:39; I7, 0:45;
	• External technology experts as counseling members of the technology board.	I9, 0:30;
3	• Designated academic partners and research institutions for low-commitment monitoring and exploration of promising new technologies and applications.	I14, 0:45; I25, 1:08; I18, 0:46; I10, 0:32; I23, 0:55;
	• Heavy involvement in industry associations and standardization organizations.	I30, 1:38; I14, 1:01; I17, 1:46; I28, 0:07; I25, 1:08; I20, 0:47; I29, 1:01; I19, 0:18; I27, 1:05; I2, 0:43;
	• Sophisticated patent analysis techniques to identify emerging and fast-growing technological disciplines and trends.	I13, 0:56;
	• Technology, topic and competitor specific technology intelligence and patent analysis.	I14, 0:59; I16, 1:02; I17, 1:00, 1:25; I28, 0:46; I25, 1:27; I20, 0:40; I18, 1:17; I22, 0:34; I12, 0:24, 0:44; I21, 0:26, 1:07, 2:17; I10, 1:10; I11, 0:55; I24, 1:10; I23, 0:41; I2, 0:44; I3, 1:09; I4, 1:22;
	• Install gatekeeper functions for technology monitoring of currently valid elements of technological dominant design.	I22, 0:26; I10, 1:12, 1:40; I23, 0:59;
	• Technology monitoring responsibility of product champions on system and module level.	I15, 1:23; I28, 0:47; I29, 0:41; I23, 0:59;
	• Identify, remember and continuously review enabling or disabling factors for applications of existing technologies in adjacent industries.	I14, 0:52; I20, 0:02; I18, 0:23, 0:26; I10, 2:17; I19, 1:10; I4, 0:12; I2, 0:13; I5, 0:37;
4	• Organize topic-centered technology trend and scenario workshops with external technology experts from various and also exotic disciplines.	I13, E14, 0:57, 1:03; I20, 0:06; I12, 0:36; I21, 1:27; I10, 0:34; I19, 0:40; I27, 0:29; I23, 0:56, 2:20; I3, 0:14; I2, 0:41;
	• Organize technology colloquia with equipment and material suppliers and complementors of your products.	I23, 1:59;
	• Listen to current and potential, soliciting technology suppliers.	I15, 1:06; I13, 0:42; I22, 1:23; I21, 1:22; I23, 1:59; I4, 0:28;
	• Internal and external idea management portals & procedures.	I13, 0:50; I14, 0:51; I17, 1:11; I25, 1:05; I26, 0:26; I18, 0:21, 0:52; I12, 1:17; I10, 1:21; I27, 0:42; I24, 1:04; I8, 0:11;
	• Transform "Strategic Filter"-Gates of innovation processes into "Strategic Interfaces".	I25, 1:48; I26, 0:27; I20, 0:28; I21, 0:06; I10, 1:36, 1:54; I11, 1:05;
	• Use customized incentive systems to transform "Not invented here"-syndrome into "Invented anywhere – innovated here"-approach.	I15, 0:12; I13, 0:52; I12, 1:16; I21, 1:25, 1:31; I10, 0:30, 2:22; I24, 1:32;
	• Involve all technical employees in technology intelligence.	I15, 0:25; I25, 1:08, 1:48; I10, 2:07;

Absorptive and Adaptive Capabilities	
Strategic (P)Reprogramm-ability	**Strategic Adoptability**
Strategic Hedging Ability	**Strategic Corrigibility**
Strategic Versatility	**Strategic Adaptability**
Receptivity	**Strategic Reformulation**
Agility	**Strategic Responsiveness**
Learning Ability	**Strategic Incrementalism**

1	• Use analysis, planning and communication tools for technology strategy with explicit time dimensions to create a sense of urgency.	I13, 0:58; I16, 0:50; I21, 0:40; I11, 1:16; I9, 0:05;
	• Continuous review of market and technology adjacencies for easy and rapid exploitation opportunities.	I20, 0:02; I18, 0:23, 0:26; I9, 0:28, 0:31; I5, 0:55;
	• High frequency of periodically technology strategy meetings and workshops.	I17, 0:52; I25, 1:20; I9, 0:24, 0:31; I2, 0:39;
	• Care for scalability and replication of valuable technology expertise (mentoring and buddy-system).	I25, 0.57; I21, 0:57;
	• Simultaneous and concurrent engineering, rapid prototyping and reverse engineering routines for fast benchmarking, innovation and imitation.	I15, 0:15; I14, 1:02; I10, 0:02, 0:25; I11, 0:48; I19, 0:21; I9, 0:28; I24, 1:13; I23, 2:35;
	• Procedures and capabilities for fast industrialization and scalability of successful technology exploration.	I13, 0:17; I21, 1:39; I5, 0:28;
2	• Avoid that technological core competencies become core rigidities.	I29, 0:50; I21, 2:25; I19, 0:10, 1:09; I5, 0:51; I6, 0:13;
	• Be proactively disruptive for other technologies on their own home grounds.	I18, 0:38, 1:18;
	• Embrace substitution technologies and turn them into complements.	I20, 0:20; I18, 1:26; I23, 0:22;
	• Cannibalizing your own technologies before others do it	I20, 0:20; I21, 2:25; I10, 1:13;
3	• Emphasize temporary forms of organization over static organizational structure	I30, 1:54; I13, 1:30; I28, 0:48; I26, 0:15; I21, 2:40; I9, 028;
	• Intentionally undesignated funding possibilities for unexpected technological ventures.	I30, 1:15; I17, 0:16; I18, 1:06; I12, 0:25;
	• Establish and maintain the ability for fast technology access by M&A	I14, 1:02; I17, 0:46; I18, 0:50, 1:11; I12, 0:48; I5, 0:13;
	• Intentional slack and inefficiencies in research & development	I17, 0:16; I12, 0:25;
4	• Direct communication between technology experts and executives.	I30, 1:20; I16, 0:31, 1:45; I17, 0:18; I28, 0:49; I25, 1:05; I22, 1:00; I10, 1:30;
	• Fast decision making and resource reallocation decisions and avoidance of paralysis by analysis.	I30, 1:20; I16, 0:32, 1:45; I17, 0:18; I28, 0:49, 1:02; I25, 1:04; I22, 1:18; I10, 1:30; I19, 0:45; I9, 0:17;
	• Open door policy and accessibility of executives.	I30, 1:14; I15, 1:23; I17, 0:18; I28, 1:00; I25, 1:02; I22, 0:54, 1:18; I10, 1:30;
	• Reduce barriers for spontaneous and easy technology contacts and communication within the company.	I22, 1:00; I12, 0:27; I10, 1:23; I4, 0:29;
5	• Establish broadly qualified and flexible employees to allow rapid resource fluidity.	I30, 1:52, I15, 1:15; I28, 1:02; I20, 0:56; I22, 1:26; I19, 0:51; I23, 1:16;
	• Hire a diverse and heterogeneous technology personnel.	I25, 0:41; I19, 0:34; I23, 1:16;

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1	• Reserve a fraction of your R&D&E resources for long-term learning projects which are not related to a specific and currently existing business unit, product group, key account or core competence.	I25, I26; I12, 0:26; I21, 0:40; I19, 0:26, 0:37; I27, 0:30; I24, 1:34;
	• Avoid to use current technological dominant design of processes and products as the only and permanent unit of strategic analysis (e.g. TRIZ).	I16, 0:15; I14, 0:52; I21, 1:32;
	• Participate in consortia-sponsored technology competence centers at universities for long-term technology exploration and transfer projects.	I13, 0:18; I14, 0:47; I26, 0:16; I18, 0:45; I23, 1:56;
	• Regarding new technological developments, emphasize “Do it yourself”, “Be involved and curious” over “sourcing and outsourcing” approaches (e.g. under-utilized process technologies).	I28, 1:03; I22, 0:07; I23, 2:23;
2	• Pool product and manufacturing technology engineering, research, development expertise and know how into one innovation group (e.g. competence centers, centers of excellence).	I13, 0:32; I14, 0:35; I29, 0:10; I21, 0:03, 0:51; I10, 0:03; I19, 0:26; I25, 1:41; I10, 0:01; I4, 0:43;
	• Join technology experts from different sites and units in technology specific networks.	I13, 0:37; I25, 0:53, 1:30; I18, 1:00; I29, 0:20; I12, 0:55; I21, 0:52, 2:41; I10, 1:24; I19, 0:53; I27, 0:36, 1:25; I23, 0:49; I3, 1:05; I7, 0:45;
	• Organize regular internal technology and product trade shows, fairs and conferences.	I25, 0:50, 0:53; I12, 0:54; I21, 2:44; I10, 1:15; I27, 0:35, 1:28; I23, 0:48; I3, 1:05; I7, 0:45;
	• Install cross-sectional, corporate wide technology committees and boards.	I25, 1:30; I20, 0:26; I29, 0:22; I12, 0:02; I21, 0:34, 0:52; I10, 1:15; I19, 0:02, 0:58; I27, 0:28, 1:28; I9, 0:30; I24, 0:03; I23, 0:35, 0:49; I3, 0:10;
	• Expose your researchers and scientists to product and manufacturing engineering.	I26, 0:19, 0:44; I22, 1:26; I19, 0:51; I4, 1:09;
	• Support personal contacts within company to establish inter-corporate networks.	I10, 2:24; I19, 0:28, 0:51; I27, 1:27;
3	• Use IT-supported knowledge management tools for code-able, explicit and relatively stable knowledge.	I13, 0:39; I25, 0:49, 1:11; I26, 0:24; I18, 1:01; I10, 2:24; I23, 1:02; I2, 0:45;
	• Corporate directory of technical and scientific employees and their competencies, experiences and current occupations and projects.	I20, 0:36; I18, 1:10; I10, 2:15; I19, 0:53; I2, 0:45; I7, 0:40;
	• Internal corporate social software network to link tacit technological knowledge.	I10, 2:15; I19, 0:54; I27, 0:32;
4	• Internal management development programs and corporate education programs (e.g. corporate academies and universities).	I30, 1:58; I12, 0:30; I17, 2:04; I29, 0:34;
	• Let technologists follow “their” technology over its life-cycle within the company.	I26, 020; I19, 0:24; I4, 1:14;
	• Encourage and develop horizontal mobility between engineering, manufacturing and R&D by technical and scientific employees and offer horizontal careers.	I30, 1:56; I15, 0:50; I25, 0:43; I22, 1:26; I19, 0:51; I27, 0:47;
	• Aspiring long term employment of technical and scientific employees and executives to avoid brain drain.	I30, 1:56; I15, 0:47; I25, 0:43; I18, 0:18; I22, 1:23; I12, 0:52; I19, 0:28, 0:51; I23, 2:31, 2:40;
	• Continuing training and education of employees in new and related technologies	I13, 1:35; I17, 2:04; I20, 1:01; I21, 2:41; I23, 2:39
5	• Set general and individual learning goals additionally to regular project objectives for your technology projects (e.g. lessons-learned routines, identified disabling and enabling factors)..	I26, 0:08; I16, 1:48; I3, 1:05; I4, 0:19;
	• Stimulate and endure engagement of technical employees in scientific communities which are non-core to the company.	I13, 1:26; I14, 1:08; I17, 1:10; I25, 1:08; I26, 0:29; I20, 0:46; I18, 0:56; I21, 1:07, I23, 1:29;
	• Avoid exclusively individual and financial incentive system for new technology development.	I15, 1:30; I25, 0:44; I26, 0:27;
	• Allow and support technological experts to pursue initiative projects.	I18, 0:56; I29, 0:10; I12, 0:07; I7, 0:56;
	• Multiple incentive system that facilitates technological learning, teaching and knowledge sharing.	I26, 0:28; I18, 1:00; I21, 1:30;

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