Insights into the monitoring of disruptive technologies: evidence from a study of global industry leaders from Germany

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The theory of disruptive technologies, mainly influenced by Clayton M. Christensen combined with a rising technological complexity and diversity in almost all industry sectors, is challenging companies in their decision making on technological investments. Methods, structures and processes seem to be widely applied to support decisions on technologies and technological developments in general. But what are the practices from technology oriented industry leaders to respond to the special challenges of disruptive technologies?

To obtain insights into the monitoring of disruptive technologies in practice, a semi-structured, qualitative study among global industry leaders from Germany has been carried out. All companies selected for the sample are technology oriented global leaders in their business field. To focus the sample on companies with a high innovation potential, all selected companies have been rewarded with an innovation award at least once within the last five years. For being able to compare the monitoring of technologies in general with the practices applied for the monitoring of disruptive technologies, the study was classified into different topic areas including an extended technology monitoring process, the support through information technologies, the monitoring of disruptive technologies and good or best practices to be recommended for further application in other companies.

1. Introduction

The identification of disruptive technologies is a key challenge, especially for technology oriented companies. It is principally based on the fear of being the incumbent who misses out a development that disrupts and thereby destroys current businesses. The theory of disruptive technology and innovation has been significantly shaped by Clayton M. Christensen, first through his doctoral dissertation (Christensen, 1992) getting famous through an the article "Disruptive Technologies: Catching the Wave" (Bower & Christensen, 1995) and the following publication of the well-known book "The Innovators' Dilemma" (Christensen, 1997). Compared to radical innovations, that are primarily defined through their nature of exceeding a certain degree of innovation, e.g. through an entirely new set of performance features, a performance improvement of at least five times or a cost reduction of more than 30% (Leifer et al., 2000, p. 5), disruptive technologies are defined by their effect to the market. They render established technologies obsolete and thus destroy the value of previous investments from incumbents (Danneels, 2004, p. 248). The prominence of the theory of disruptive technologies, despite regular critical discussions (such as Lepore, 2014), is principally based on the high number of examples from different industries where disruptions occurred and lead to the failure of incumbents paired with the establishment of new players (see e.g. Christensen, 2013, Chapter 17.7). Despite the large amount of examples, the key challenge of how companies shall best respond to the danger of being disrupted in their business still remains to a large extend unanswered. Furthermore, the relevance of disruption is rising in today's global and digital economy: enabling technologies such as the internet or low cost sensors and connectivity solutions combined with extensive financing of start-up companies changed the pace at which disruptions can take place.

Thus, key challenge of how disruptive technologies can best be monitoring in a practical context was addressed in a study with German technology oriented companies. In the study, CEOs and technology or innovation managers from a sample of eight industry leading companies have been interviewed personally in semi-structured interviews on their practices, methodologies and tools for technology monitoring and especially for the identification, evaluation and implementation disruptive technologies.

2. Spotlight on the practical monitoring of disruptive technologies

A key question for the definition of the field of research is the differentiation between the monitoring of disruptive technologies compared to the monitoring of technologies and thereby how disruptive technologies are defined compared to other technologies. Following the definition of Clayton M. Christensen, a disruptive technology is principally based on the concept that one technology is substituted by an alternative technology in a defined field of application. From a technology development perspective, this therefore goes beyond further development of a technology or enhancing it through adding complementary technological elements (for the differentiation of technological developments, see e.g. Spath & Warschat, 2008). Furthermore, a disruptive technology is defined by its destructive capability (Danneels, 2004, p. 248). Based on these definitions, the key focus of a disruptive technology is not the technological development itself, but a combination of the technological development of one technology reaching a certain performance level and thus allowing a new application able to substitute technologies applied by incumbents on a specified market. This market perspective was highlighted through the evolution of the terminology from the initial term "*disruptive technologies*" towards "*disruptive innovation*" (see also Yu & Hang, 2010, p. 436f). It is considered mandatory for the monitoring of disruptive technologies to define a specific field of application based on which the performance of a technology can be analysed, evaluated or projected. Thus, technology driven disruptive innovations will be addressed under the terminology of disruptive technologies as a sub-group of disruptive innovations within this paper.

From the perspective of the system architecture, existing definitions do not include any mandatory effect of disruptive technologies. They can thus lead to the preservation or to the destruction of existing system architectures. An example is the principle of simplification creating a different package of value attributes for new markets based on the same system architecture (Christensen, 1997, p. 15).

From a practical perspective, a key challenge is the definition of methods and tools able to support companies in the identification, analysis and evaluation of disruptive technologies. These shall enable companies to early recognise disruptive technologies and integrate them into business, R&D or into their technology strategy. The reduced availability of predictive methods and tools is one of the key criticisms of the initial theory of disruptive technology and innovation (see Lepore, 2014). Within the core of the identification and evaluation of disruptive technologies stands the use of technological trajectories

allowing the analysis and evaluation of future technological performances (see e.g. Christensen & Bower, 1996). Examples for the specification of these performances, such as the hard disk capacity quantified in megabytes (Christensen, 1997, pt. 87/534), are provided in case studies based on past examples of disruptive technologies. In this example, the performance trajectory of smaller hard disks (from originally 14 inches to 2,5 inches), considered in this case as the potentially disrupting technology, is developed based on the timely development of the storage capacity. Once a certain limit is exceeded, smaller hard disks substitute larger hard disks sold by incumbents. In more recent versions of the visualisation of performance trajectories, it has been complemented by the market perspective that allows the combined analysis of different existing or new markets with different performance measures (Christensen, Anthony, & Roth, 2004, pt. 27/717). The identification and prediction of industry changes as a first step of the management of disruptive technologies shall thus be based on the analysis of existing and potential customers. These are grouped into non-consumers, undershot customers and overshot customers. Whereas non-consumers open up the potential of new-market disruptions and overshot customers to low-end disruptions, undershot customers appreciate evolving technological performance and thus represent the most important customer group for incumbents (Christensen et al., 2004, pt. 85/717). In this context, market research methods are stated as a key method to facilitate the identification of both, customer needs and non-consumers – but without stating any specific method to be recommended for the identification of potentials for disruption. From a market or customer perspective, user-research (especially the method of design thinking) has evolved as a key method for the identification of customer-needs and non-consumers (see e.g. Kelley & Kelley, 2013; Kelley & Littman, 2001; Kelley, 2006; Williams, 2010). Design thinking aims to create considerable added value for the user through idea generation and early prototype testing based on user empathy. Thus, low-end or new market disruptions can be considered as a potential outcome of design thinking or as a sub-category of design thinking results. However, the even most prominent practical examples do only partly reflect the interdependency between market and technology driven innovations, also referred to as market pull and technology push (see e.g. Brockhoff, 1969; Bullinger & Seidel, 1994; Specht, Beckmann, & Amelingmeyer, 2002). The explicit differentiation into market pull based on customer requirements and technology push based on specific technological performance trajectories in combination with forecasting methodologies would be able to considerably support companies in the identification of disruptive innovations and technologies (as conceptionally done by Narasimhalu, 2012). However, from a practical perspective there is only little guidance available on how to consider both, market and technology trajectories to identify disruptive technologies and innovation.

Based on the analysis of these methods for the management and monitoring of disruptive technologies, a key question is how industry leading companies are managing disruptive technologies and how these practices can be differentiated from general technology monitoring methods.

3. Framework and structure of the study

To answering the abovementioned question and to obtain insights from industry leaders, the format of a qualitative study based on personal, semi-structured interviews was chosen, carried out with a relatively small sample of industry leading and innovative companies. This methodology implies, that the results have to be carefully analysed for explorative research and that no empirical evidence can be derived. As the challenge of managing disruptive technologies is shared among industries, no special industry focus was set for the study (see Table 1 for details on the participating companies). To obtain results from companies that are successfully managing their technology portfolio, the restriction of only choosing industry leaders in technology centric fields of activities was set-up, including a leading position in key markets as well as the position of innovation leadership. Both restrictions were not measured quantitatively but validated on a qualitative basis within relevant industries and markets. Furthermore, to ensure a certain level of innovativeness of the sample – one of the hardest criteria to define – only companies were selected that won at least one price for a specific innovation or their approach to manage technologies or innovation within the last five years. Representatives involved in the interviews included R&D, technology and innovation managers as well as CEOs. The choice of representatives principally depended on the size and the internal structures of the participating company.

#	Industry	Turn-over (€)	R&D intensity (%)	Staff
1	Photovoltaic semi-conductors	2,5 mio	n.a.	20
2	Aeronautics	11 mio	n.a.	94
3	Machine engineering	197 mio	n.a	1.400
4	Machine & plant engineering	600 mio	n.a.	3.600
5	Cleaning technology	1,7 bn	n.a.	8.700
6	Automation technologies	2,1 bn	8,5	15.800
7	Transmission technologies	6,3 bn	3,4	37.000

#	Industry	Turn-over (€)	R&D intensity (%)	Staff
8	Machine & plant engineering	5,2 bn	5,1	39.754

Table 1. Industry, turnover, R&D intensity and number of employees of participating companies collected during the study[1].

For the exploration of structures, processes, methods and tools applied within the participating companies, the study has been structured according to the following topic areas:

1. *Identification of technologies:* the objective of this topic area is to gather insights on how the search field is structured, what information sources are used and how the transfer of identified information on technologies is handled within the company.
2. *Evaluation of technologies:* this topic area is focused on processes, classifications and criteria for the evaluation of technologies as well as the documentation of evaluation results for further usage.
3. *Implementation:* within this topic area, it is investigated, how technologies are translated into practical applications following the technology monitoring process.
4. *Support through information technologies:* within supporting methods and tools, especially the support through specific information technologies and the usage intensity is analysed in this topic area.
5. *Methods, processes and structures for the monitoring of disruptive technologies:* this topic area emphasises special methods, processes and structures required for the monitoring of disruptive technologies compared to the monitoring of technologies in general.
6. *Good and best practices:* this topic area aims to identify good and best practices in the monitoring of disruptive technologies applied and recommended by participating companies.

Throughout all topic areas, questions included the distribution of responsibilities for tasks identified as well as the application of methods and tools supporting the process. Furthermore, all topic areas were implicitly investigated to identify hints for the monitoring of disruptive technologies in addition to the general management of technologies.

[1] Interviews were carried out between Mai and September 2012

4. Insights into the monitoring of disruptive technologies from German industry leaders

The presentation of insights gathered during the study into the management of disruptive technologies from German industry leaders is structured according to the abovementioned topic areas. Based on the results of an introductory question, the discipline of technology management and monitoring was rated as very important throughout the participating companies confirming the dependence on the management of technologies and the position of industry leadership in technology-oriented companies.

4.1 Identification of technologies

The first step for the identification of technologies is the technology strategy, defining the mid- and long-term objectives for the development and application of technologies. All participating companies confirmed the existence of a technology strategy – whereas explicit formulations, communication structures as well as responsibilities and processes for the update were only established in larger companies.

A key element for the identification of technologies is the selection of information sources that are used in a company. Without prioritisation, the information sources shown in Table 2 were mentioned by the participating companies. The internet, that was highlighted as an important information source in previous studies (see e.g. Schimpf, 2010) was not mentioned as an important information source – whereas it might be that it was considered as a channel towards information and not as an information source itself. Despite a relatively clear differentiation between technology and market perspective in theory, information sources from later, market oriented phases of the value chain such as customers, market studies, user research and competitors were mentioned alongside with information sources from earlier phases such as suppliers, research organisations or patents.

Information sources for technology identification		
Fairs	Seminars	Microtrends
Journals	Competitor	Serendipity
Supplier	Experts	User research
Inventors	Customers	New employees
Patents	Market studies	Clusters
Expert networks	Trend database	Personal contacts
Research organisations	Technology studies	Companies in the same sector

Table 2. Information sources used by the participating companies for the identification of technologies and technological developments.

For the methodological support in the identification of technologies, a relatively wide bandwidth of different methods was used throughout participating

companies. From a very general perspective, this included idea competitions, collaborative research projects, student theses and technology studies. From a more specific perspective for technology identification, user-research methods such as quality function deployment, conjoint analysis and the kano model of customer satisfaction were stated. Furthermore, technology monitoring instruments such as the technology atlas, technology roadmapping and technology or future radar were mentioned as key methods supporting the identification of technologies as well as their evaluation.

4.2 Evaluation of technologies

A key insight was the differentiation between different kinds of technological developments that is considered for the evaluation. Substitution technologies were mentioned as the least complex technologies for evaluation, as they can be compared to reference technologies by means of their performance and cost. Table 3 provides an overview on the evaluation criteria mentioned during the interviews by the participating companies.

Criteria for technology evaluation		
Relevance	Investment	Sales
Effort	Demand	Qualification
Sustainability	Market success	Strategic fit
Maturity	Differentiation	Price
Cost	Market share	

Table 3. Criteria used by participating companies for the evaluation of technologies.

Responsibilities and evaluation methods were described as evolving alongside with the concreteness of the application. For a first step evaluation, the qualitative basis by experienced employees coming e.g. from the functional areas of engineering, R&D, patents, mergers and acquisitions or technology development was mentioned as most important. This evaluation was then said to be complemented by more detailed market and technology studies in a next step. Especially within the small participating companies, customers were involved from very early phases of the evaluation process.

4.3 Implementation of technologies

In the topic area of implementing technologies or technological developments, participating companies were very focused on internal processes for the development activity. Development is done in internal R&D, pre-development, technology development, process or product development and only to a minor part with external support from companies or research organisations. Decisions on which technologies to integrate into a company were said to be either taken by the general management, which was the case especially within the smaller participating companies, or in committees where current and future market demand was matched with today's and tomorrow's technological capability. The market perspective were partly driven by a customer-supplier relationship between development departments and market oriented departments where technologies are only developed or integrated on special demand from a market oriented department. In some cases, creativity techniques were mentioned as a method for the identification of potential application areas for new technologies or technological developments.

4.4 Support through information technologies

Throughout all participating companies, no specialised software was applied for the identification, evaluation and implementation of technologies and technological developments. Different search engines for analysing the internet or patent databases were applied to support the identification of technologies. For the documentation and communication, general office solutions, email, databases, fileserver and collaboration platforms were used. In case, special formats had to be stored or shared, product data management (PDM) systems were used. Enterprise resource planning systems were said to be used for process support and project management rather than the storage of technological information (see Table 4).

Supporting information technologies		
Fileserver	Email	Databases
Collaboration platforms	Enterprise resource planning	Office applications
Patent search engines	Internet search engines	Product data management

Table 4. Information technologies supporting the identification, evaluation and implementation of technologies.

Supporting information technologies were considered by participating companies as a complementing part to the key success factor for the identification, evaluation and implementation of technologies and technological developments that was the involvement of highly competent employees.

4.5 Methods, processes and structures for the monitoring of disruptive technologies

Throughout participating companies disruptive technologies were management based on the same

general principals as other technologies and technological developments. However, within the management of technologies, some methods, processes and structures, were stated as being especially important to support the management of disruptive technologies:

- Broad definition of the search field to allow the identification of technologies that go beyond technologies that are currently applied.
- Maintenance of R&D and market networks including actors able to provide new input from other industries or markets.
- Definition of disruptive topics in the product roadmap as an input to R&D, technology development and predevelopment.
- Continuous exchange of the company's point of view with experts from other companies, other sectors and research organisations.
- Tracking of technological developments and performances in a technology radar or technology roadmap.

In addition to the abovementioned methods, processes and structures, the intuition of employees and management was mentioned as a key success factor for the identification, evaluation and implementation of disruptive technologies.

4.6 Good and best practices

Practices, methods and tools are able to support the monitoring of disruptive technologies. The following practices, methods and tools were applied within participating companies and defined as good or best practices from the participant's point of view:

- *Employee's involvement:* highly qualified employees were defined as the most important source for the identification and evaluation of technologies. Beyond the structures for supporting them in the identification, evaluation and implementation of disruptive technologies in their core business, additional support such as idea management systems were mentioned by participating companies as a good or best practice to take benefit from their know-how in unexpected areas.
- *Central R&D planning*: decentralised engineering departments were said to concentrate on internal technological know-how for the fulfilment of customer or user requirements. A central R&D planning can respond to upcoming requirements on a more abstract level and open a wider horizon of potential solutions.
- *Open and experimental company culture:* the company culture was mentioned to have major influence on the appreciation of change and thus the handling of disruptive technologies. An open and experimental company culture was seen as a key enabler for the identification and implementation of disruptive technologies.
- *Regular discussion of technology trends:* the creation of structures, platforms and environments for the regular internal and external discussion of technological trends was said to enable better projections of future developments and improved evaluation of technological performances related to specific application. It was therefore seen as an important practice to increase the awareness on disruptive technologies as well as a better understanding of potential options.
- *Technology monitoring methods:* structured methods for the monitoring of technologies such as technology atlases, technology radars and technology roadmaps were mentioned as an enabling factor for the integrated management of technologies and their matching to relevant applications. Based on the continuous monitoring of technology performance parameters as well as their projection, they are able to support the early recognition of potentially disruptive technologies.
- *Common pictures of the future:* the creation of common pictures of the future especially considering potential future technological developments were said to be an enabler for improved planning of different options able to respond to the challenges of these pictures. Furthermore, their potential for facilitating discussions on relevant trends, their impacts and enablers in an industrial context was highlighted.

The application of methods for the monitoring of disruptive technologies was stated as a good and best practice principally by larger companies whereas smaller companies did not require specific supporting methods or tools.

5. Conclusions

Within the sample involved in the study, potentially disruptive technologies were principally identified, evaluated and implemented based on the same principles that were used for the monitoring of other technologies. Performance trajectories were monitored and projected either without any methodological support by technology experts or with the support of technology atlases, technology radars or technology roadmaps. A key element for the identification of disruptive technologies was the appropriate and broad definition of the search field to enable a perspective beyond technologies currently applied in the organisation. Consequently, external information sources have to be defined for technologies that are not

part of a company's core competencies, including a continuous discussion of technologies and their potential applications with experts from other companies or sectors. Furthermore, technology monitoring methods have to be specifically adapted for the management of disruptive technologies, e.g. through defining disruptions in the technology roadmap. This was said to allow the tracking of relevant developments and thereby the early development of appropriate strategic options. Consistently to these principles, good and best practices identified included highly qualified employees, an open and experimental company culture and the regular discussion of technological developments for the implicit monitoring of disruptive technologies. Furthermore, the importance of central R&D planning, the application of technology monitoring methods and the creation of common pictures of the future were highlighted for the explicit identification and evaluation of disruptive technologies.

The focus area of the study, mainly due to the functional areas involved, was the identification and evaluation of disruptive technologies. Beyond these two phases, the implementation is another key factor for the successful management of disruptive technologies. Based on the insights achieved, it might be valuable to further explore this area in more detail in an additional study and with the functional areas of business development, corporate venturing and corporate incubation involved.

9. References

Bower, J. L., & Christensen, C. M. (1995). Disruptive Technologies: Catching the Wave. *Harvard Business Review*, *73*(1), 43–53.

Brockhoff, K. (1969). Probleme und Methoden technologischer Vorhersagen. *Zeitschrift Für Betriebswirtschaft*, *39*(2), 1–24.

Bullinger, H.-J., & Seidel, U. A. (1994). *Einführung in das Technologiemanagement. Modelle, Methoden, Praxisbeispiele*. Stuttgart: Teubner.

Christensen, C. M. (1992). *The Innovator's Challenge: Understanding the Influence of Market Environment on Processes of Technology Development in the Rigid Disk Drive Industry*. Harvard University, Graduate School of Business Administration.

Christensen, C. M. (1997). *The Innovator's Dilemma*. Boston, Massachusetts: Harvard Business School Press. First eBook Edition: January 1997.

Christensen, C. M. (2013). Disruptive Innovation. In M. Soegaard & R. F. Dam (Eds.), *The encyclopedia of Human-Computer Interaction* (2nd ed.). Aarhus, Denmark: The Interaction Design Foundation.

Christensen, C. M., Anthony, S. D., & Roth, E. A. (2004). *Seeing What's Next: Using the Theories of Innovation to Predict Industry Change*. Boston: Harvard Business School Publishing Corperation. First eBook Edition: September 2004.

Christensen, C. M., & Bower, J. (1996). Customer Power, Strategic Investment, and the Failure of Leading Firms. *Strategic Management Journal*, *17*.

Danneels, E. (2004). Disruptive Technology Reconsidered: A Critique and Research Agenda. *Journal of Product Innovation Management*, *21*(4), 246–258.

Kelley, T. (2006). *The Ten Faces of Innovation*. London: Profile Books.

Kelley, T., & Kelley, D. (2013). *Creative Confidence - Unleashing the creative potential within us all*. New York: Crown Business.

Kelley, T., & Littman, J. (2001). *The Art of Innovation*. London: Profile Books.

Leifer, R., McDermott, C. M., O'Connor, C., Peters, L. S., Rice, M., & Veryzer, R. W. (2000). *Radical Innovation: how mature companies can outsmart upstarts*. Boston, Massachusetts: Harvard Business School Press.

Lepore, J. (2014). The disruption machine - what the gospel of innovation gets wrong. *The New Yorker*. New York. Retrieved from http://www.newyorker.com/magazine/2014/06/23/the-disruption-machine

Narasimhalu, A. D. (2012). *Innovation rules: a method for identifying disruptive innovation opportunities?*. Singapore. Retrieved from http://ink.library.smu.edu.sg/sis_research/1667

Porter, M. E. (1980). *Competitive Strategy. Techniques for analyzing industries and competitors* (Vol. 1, p. 396). New York: Free Press. Retrieved from http://www.amazon.com/Competitive-Strategy-Michael-E-Porter/dp/0743260880

Schimpf, S. (2010). *Social Software-Supported Technology Monitoring for Custom-Built Products*. University of Stuttgart.

Spath, D., & Warschat, J. (2008). Innovation durch neue Technologien. In H.-J. Bullinger (Ed.), *Fokus Technologie. Chancen erkennen, Leistungen entwickeln* (pp. 1–12). München: Hanser.

Specht, G., Beckmann, C., & Amelingmeyer, J. (2002). *FuE-Management* (2. Auflage.). Stuttgart: Schäffer-Poeschel Verlag.

Williams, L. (2010). *Disrupt: Think the Unthinkable to Spark Transformation in Your Business*. New Jersey: FT Press.

Yu, D., & Hang, C. C. (2010). A Reflective Review of Disruptive Innovation Theory. *International Journal of Management Reviews*, *12*(4), 435–452.